Idaho between 1972 and 1979 (Ansell and Smith 1980). Some studies have documented higher percentages of great horned owls in electrocution records. For example, of the species identified, great horned owls accounted for 15% of avian electrocutions (*n*=555) in the western United States from 1986 to 1996 (Harness and Wilson 2001), 20% of electrocutions (*n*=61) in Montana from 1980 to 1985 (O'Neil 1988), and 33% of electrocutions (*n*=210) in Nebraska from 1988 to 2003 (USFWS/Nebraska unpubl. data). Of APLIC-member utilities surveyed (*n*=13), 69% noted electrocutions of owls, with 54% specifically listing great horned owls as one of the species most frequently electrocuted in their areas (APLIC 2005). Electrocution was the cause of death in <1% of great horned owl mortalities (*n*=207) in Saskatchewan (Gillard 1977). Likewise, 2% of great horned owls admitted to wildlife rehabilitation centers in Florida from 1988 to 1995 (*n*=174) were electrocuted (Forrester and Spaulding 2003). Electrocution accounted for 6% to 7% of great horned owl mortalities evaluated in Colorado from 1995 to 1998 (*n*=85) (Wendell et al. 2002) and by the National Wildlife Health Center from 1975 to 1993 (*n*=132) (Franson and Little 1996).

FIGURE 4.5: Great horned owl nest on transformer bank.

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In North America, the barn owl (*Tyto alba*) is the second most frequently electrocuted owl. Barn owls accounted for 10% of owl electrocutions (*n*=20) in Utah and Wyoming from 2001 to 2002 (Liguori and Burruss 2003). Barn owl electrocutions have also been documented by Williams and Colson (1989), Harness and Wilson (2001), and USFWS/Nebraska (unpubl. data). In an assessment of barn owls in the northeastern United States, electrocution was noted as a cause of mortality, yet was not considered a population limiting factor (Blodget 1989). In Hawaii, 1% of barn owls evaluated for cause of death from 1992 to 1994 (*n*=81) was killed by electrocution (Work and Hale 1996). Of barn owls admitted to wildlife rehabilitation centers in Florida from 1988 to 1995, 5% (*n*=63) were electrocuted (Forrester and Spaulding 2003).

Barn owl electrocutions are not limited to North America. Of marked and recovered barn owls (*n*=171) in England, 5.8% died of electrocution (Meek et al. 2003). In a study of barn owl carcasses (*n*=627) in Britain from 1963 to 1989, electrocution was documented as the cause of death in <1% of birds (Newton et al. 1991). Barn owls comprised <5% of raptor electrocutions in Germany (*n*=567) and between 5% and 10% of mortalities in France (*n*=686) (Bayle 1999). In Spain, barn owls comprised 3% of electrocutions (*n*=233) documented by Ferrer et al. (1991) and <5% of raptor electrocutions (*n*=1,282) documented by Bayle (1999). In South Africa, barn owls accounted for 6% of electrocutions (*n*=147) documented from 1996 to 1998 (Kruger 2001a).

Electrocution records of other North American owls are rare. Much like accipiters, many owl species inhabit forested areas and infrequently perch on power poles. No records were found for spotted owl *(Strix occidentalis)*. Barred owl *(S. varia)* electrocutions have been documented on transformer poles in Washington (M. Walters, pers. comm.). In Florida, 1.2% of barred owls admitted to wildlife rehabilitation centers from 1988 to 1995 (n=330) were electrocuted (Forrester and Spaulding 2003). Bull and Duncan (1993) cite electrocution as a cause of mortality for a great gray owl *(S. nebulosa)*. Electrocutions of this species are probably uncommon, as <1% of electrocution records (n=301) reported for four western states were great gray owls (Harness 1996). Records of other forest owls are also rare, although electrocution has been documented in the eastern screech-owl *(Otus asio)* (APLIC 1996, 2005), western screech-owl *(O. kennicottii)* (Harness 1996; Harness and Wilson 2001; APLIC 2005), and long-eared owl *(Asio otus)* (APLIC 1996). Harness and Wilson (2001) documented 3 western screech-owls among avian species electrocuted (n=555) in the western United States from 1986 to 1996. Of eastern screech-owls admitted to wildlife rehabilitation centers in Florida from 1988 to 1995 (n=1,319), <1% was electrocuted (Forrester and Spaulding 2003). In Germany (n=567) and France (n=686), <5% of raptor electrocutions were long-eared owls (Bayle 1999). Electrocution records for snowy owls *(Nyctea scandiaca)* are also uncommon (Parmalee 1972; Gillard 1977; Williams and Colson 1989; Parmalee 1992). Smith and Ellis (1989) list electrocution as a cause of death for snowy owls, yet do not quantify electrocution rates for this species. Snowy owls are found primarily in arctic regions lacking utility structures, yet birds that winter in less remote areas of the northern United States and southern Canada may encounter power lines. Electrocution was the cause of death in 5.6% of snowy owls (n=71) wintering in Alberta, Canada (Kerlinger and Lein 1988).

Like the snowy owl, the burrowing owl *(Athene cunicularia)* and short-eared owl *(Asio flammeus)* nest and perch on the ground and, consequently, are unlikely to be electrocuted. There are no known electrocution records for the burrowing owl. Electrocution records of short-eared owls are uncommon (Williams and Colson 1989; APLIC 1996; Harness 1997; Harness and Wilson 2001; Cartron et al. 2005). In France, <5% of raptor electrocutions (n=686) were short-eared owls (Bayle 1999).

VULTURES/CONDOR

Despite their large size, electrocution records for North American vultures and California condors *(Gymnogyps californianus)* are not as common as buteo and eagle electrocutions. As of 2005, 6% of California condors (n=144) that have been released into the wild since 1992 were killed by electrocution (Energy and Environmental Economics, Inc. 2005). Power line collisions have been a greater threat to California condors than electrocutions. Prior to the release of hacked condors, the birds undergo power pole aversion training where they are offered natural snags and simulated power poles (Snyder and Schmitt 2002). If they perch on a simulated power pole, they receive a mild shock.

Electrocutions of vultures are also uncommon, with turkey vultures *(Cathartes aura)* accounting for only 2% of electrocutions (n=210) in Nebraska from 1988 to 2003 (USFWS/Nebraska, unpubl. data), 2% of electrocutions (n=113) in Arizona from 2003 to 2004 (Dwyer 2004), and 2% of electrocutions (n=51) in northern California from 2001 to 2004 (PacifiCorp, unpubl. data). In the western United States, vultures accounted for 1% of electrocutions (n=1,428) from 1986 to 1996 (Harness and Wilson

2001). Hallinan (1922) described turkey vulture electrocutions on three-phase, 13-kV lines with metal crossarms in Florida. In southern Florida, 14 confirmed electrocutions of both turkey and black *(Coragyps atratus)* vultures were documented over a six-year period (J. Lindsay, pers. comm.). Electrocutions of turkey vultures have also been reported in Chihuahua, Mexico (Cartron et al. 2005). Turkey vulture/power line interactions, including electrocutions, were noted by Williams and Colson (1989). Both black and turkey vulture electrocutions were documented in Texas (Harness 1997).

Electrocutions of Old World vultures are much more common. In South Africa, 42% of avian electrocution records from April 1996 to November 2005 (*n*=1,018) were vultures (C.S. van Rooyen, unpubl. data). The large wingspans (up to 2.7 m [8.9 ft]) of these species, coupled with their behavior of perching together on a pole, accounts for this elevated electrocution risk (C.S. van Rooyen, pers. comm.).

WATERBIRDS

Electrocutions of waterbirds, such as storks, egrets, herons, ibises, pelicans, and gulls, may occur in areas where such birds perch on poles that do not provide sufficient spacing to accommodate their relatively large wingspans and/or heights (see Figures 4.12, 4.13 and Table 4.1). Although avian-safe construction and retrofitting can protect most waterbird species, increased vertical separation may be needed to accommodate their taller heights. Like other birds, waterbirds may be electrocuted as they fly into lines mid-span and touch two conductors (Lano 1927; Pomeroy 1978; PacifiCorp, unpubl. data).

Storks have large wingspans (approx. 1.5 m [5 ft]) and measure approximately 102 cm (40 in) from head to foot. The wood stork *(Mycteria americana)* occurs in the southeastern United States and is currently (2006) listed as endangered under the Endangered Species Act. Wood stork electrocutions may result from power line collisions or from contacts on power poles (Forrester and Spaulding 2003; J. Newman, pers. comm.). Electrocutions of other storks have been documented outside of North America (Pomeroy 1978; Haas 1980; Bevanger 1998; Janss 2000). In Spain, the white stork *(Ciconia ciconia)* was the second most commonly electrocuted species, accounting for 13.3% of mortalities (*n*=279) (Janss and Ferrer 1999). White storks also accounted for 6% of avian electrocutions (*n*=100) in southeastern France (Bayle 1999).

The great blue heron *(Ardea herodias)*, which is commonly found throughout much of sub-arctic North America, has been documented in electrocution records from numerous states (Lano 1927; O'Neil 1988; Harness 1997; Forrester and Spaulding 2003; PacifiCorp, unpubl. data). Great blue herons accounted for 3% of electrocutions (*n*=61) in Montana from 1980 to 1985 (O'Neil 1988). Roseate spoonbill *(Ajaia ajaja)* electrocutions, likely associated with power line collisions, have been identified (Forrester and Spaulding 2003; J. Roberts, pers. comm.). Electrocutions of egrets and herons have been documented outside of North America (Pomeroy 1978). Ciconiiformes, including white stork and cattle egret *(Bubulcus ibis)* accounted for nearly 10% of avian electrocutions (*n*=600) in southwestern Spain from 1990 to 1994 (Janss and Ferrer 2001).

Line investigations and avian surveys near Port Arthur, Texas, revealed that a variety of wading and shoreline birds were killed by electrocution and/or line strikes (J. Roberts, pers. comm.). Roseate spoonbills were impacted more severely than other waterbirds, with over 40 individuals killed in two years. Other birds killed or injured by lines in this area include cattle egrets, snowy egrets *(Egretta thula)*, and neotropic cormorants *(Phalacrocorax brasilianus)*. Preliminary results from an ongoing study suggest that many of the apparent collision deaths or injuries were juvenile birds with poor flight ability. However, carcass examination has indicated that some of the birds were electrocuted.

Gull electrocutions are uncommon but have been documented (Bevanger 1998). Harness (1997) reported electrocutions of 4 Franklin's gulls *(Larus pipixcan)* in a survey of electrocutions in the western United States from 1986 to 1996. In Alaska, gulls represented 3.4% of mortality records (*n*=264) from 2000 to 2004 (USFWS/Alaska, unpubl. data). PacifiCorp (unpubl. data) has documented gull electrocutions on poles with transformers in the western United States. Dickinson (1957) noted electrocutions of gulls at a landfill in North Carolina. In southeast France, 3% of avian electrocutions (*n*=100) were gulls and terns (Bayle 1999). In addition, of both electrocutions and collisions in this same region, 16% were gulls and terns, 43% were herons, and 4% were greater flamingos *(Phoenicoptens ruber)*.

Electrocutions have been reported for both sandhill cranes *(Grus canadensis)* (Harness 1997; Forrester and Spaulding 2003) and whooping cranes *(G. americana)* (Forrester and Spaulding 2003), although these are likely to have occurred as a result of mid-span collisions. Of 115 radio-tagged whooping cranes that died or disappeared between 1993 and 1999, 4.3% were electrocuted as a result of power line collisions (Forrester and Spaulding 2003). Although the North American cranes are not likely to perch on utility structures, grey crowned cranes *(Balearica regulorum)* in South Africa do perch on poles and have been electrocuted (C.S. van Rooyen, pers. comm.).

Electrocutions of brown pelicans *(Pelecanus occidentalis)* have been documented in the United States (Harness 1997; Forrester and Spaulding 2003; APLIC 2005; J. Roberts, pers. comm.). Along the Gulf Coast where large concentrations of brown pelicans occur, numerous electrocutions have been documented (J. Roberts, pers. comm.). These electrocutions occurred when young birds congregated on power lines near fish camps and caused the line to sag, allowing the birds to contact the neutral wire. The neutral wire was removed and there have not been any electrocutions since. In Georgia, an American coot *(Fulica americana)* was found inside a substation, where it was suspected to have been electrocuted as a result of contact with equipment (B. Estep, pers. comm.).

CORVIDS

Not long ago, crows, ravens, and magpies were considered pests for which some states offered bounties. The Migratory Bird Treaty Act (MBTA) of 1918 did not offer protection to corvids and birds of prey until amended in 1972. In recent years, there has been an increasing awareness that corvids are protected under the MBTA, and that they can have considerable impacts on power reliability, particularly in agricultural or suburban areas where their populations are increasing. Corvid electrocutions have received less attention than raptor electrocutions, therefore, less is known about corvid electrocution rates. Because of their large size and frequent use of power poles, ravens are likely electrocuted more often than currently documented. Although corvid mortality is unlikely to have population impacts, their electrocutions and nests can affect power reliability (Figure 4.6).

Corvid electrocutions were reported in 1921, when electrocutions of crows were documented in Florida (Hallinan 1922). Dickinson (1957) noted that crows nested on poles in North Dakota, causing faults on the line, particularly during wet weather.[15] In Montana, common ravens *(Corvus corax)*

[15] Carvings of kingbirds were mounted on the power line to deter the crows from nesting. The discouragers were considered effective, as the crows stopped building nests on the poles.

accounted for 2% of electrocution records (*n*=61) (O'Neil 1988).

Recent studies show an increased number of corvids in electrocution records, possibly due to enhanced reporting, increasing numbers of utility structures and/or increasing populations of some corvid species. Bridges and Lopez (1995), Harness (1997), and Boarman and Heinrich (1999) cite electrocution as a cause of death for the common raven. Common ravens were the most frequently electrocuted species in Utah and Wyoming, occurring in greater numbers than eagles and buteos and accounting for 32% of mortality (*n*=547) (Liguori and Burruss 2003). American (black-billed) magpies *(Pica hudsonia)* also accounted for 2% of electrocutions documented in this study. Likewise, 2% of mortalities in northern California and southern Oregon from 2004 to 2005 (*n*=103) were magpies (PacifiCorp, unpubl. data). In a survey of 3,120 poles in Colorado, corvids accounted for 7% of mortality (Harness 2001). Of 156 electrocutions in Arizona, 4% were common ravens (Dwyer 2004). Ravens accounted for approximately 40% of electrocution records for one Arizona utility (P. Jelen, pers. comm.). In Chihuahua, Mexico, the Chihuahuan raven was the most frequently electrocuted species, accounting for 69% of mortalities (*n*=178) (Cartron et al. 2005). In Arkansas and Louisiana, reports of American crow *(C. brachyrhynchos)* electrocutions have been rare, although dead crows have been observed in substations on four occasions (J. Roberts, pers. comm.). The deceased crows were found in groups of two to five and the circumstances of the electrocutions have not been determined. Although uncommon, electrocutions of jays have also been documented (PacifiCorp, unpubl. data). Of APLIC-member utilities surveyed that report mortalities of all protected species (*n*=10), 50% listed corvids as birds of issue in their area, and 30% cited crows and ravens as the birds most frequently electrocuted in their area (APLIC 2005).

FIGURE 4.6: Common raven nest on wishbone configuration.

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Corvid electrocutions are not limited to North America (Bevanger 1998). In Spain, common ravens comprised 10% to 25% of electrocutions (*n*=279, Janss and Ferrer 1999; *n*=467, Janss 2000). Common raven and jackdaw *(C. monedula)* together accounted for approximately one-quarter (16% and 10.2%, respectively) of avian mortalities (*n*=600) found in southwestern Spain from 1990 to 1994 (Janss and Ferrer 2001). In southeast France, corvids accounted for 45% of avian electrocutions (*n*=100) (Bayle 1999). Corvid electrocutions are considered fairly common in South Africa (C.S. van Rooyen, pers. comm.).

SONGBIRDS AND OTHER SMALL BIRDS

Although often overlooked, electrocutions of passerines (songbirds) have been documented throughout the 1900s. Electrocution of purple martins *(Progne subis)* flocking on power lines was noted during the early twentieth century (Anderson 1933). Loggerhead shrikes *(Lanius ludovicianus)* were electrocuted in Florida when they attempted to impale prey on tie wires (Hallinan 1922). An electrocuted Baltimore oriole (*Icterus galbula*) was reported in Ohio during the 1950s (Dexter 1953). In India, rose-ringed parakeets (*Psittacula krameri*) were electrocuted when they bridged two closely spaced conductors (Dilger 1954). Their habit of climbing poles by clinging to different wires with their feet and bills made them more vulnerable to electrocution than are other small birds. Interestingly, Dilger also noted that large fruit bats, *Pteropus*, were killed on these poles as well.

Reports of songbird electrocutions are becoming more common as utilities, agencies, and the public become increasingly aware of the interactions of small birds with power lines. Records of such electrocutions, often associated with power outages, involve species such as starlings, woodpeckers, jays (mentioned with Corvids), robins, pigeons, doves, kingbirds, thrushes, shrikes, sparrows, swallows, orioles, and blackbirds (Bevanger 1998; Michigan Dept. Natural Resources 2004; APLIC 2005; PacifiCorp, unpubl. data) (Figure 4.7). Although infrequent, some outages result from domestic species or pets not protected by the MBTA (PacifiCorp, unpubl. data).

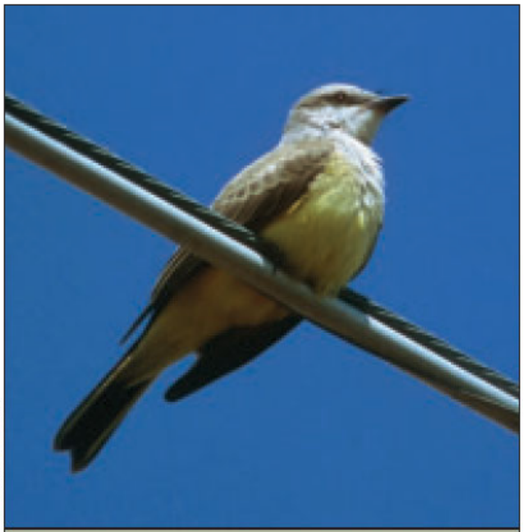

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FIGURE 4.7: Western kingbird perched on power line.

In some circumstances, songbirds can cause outages when large flocks take off at once, causing lines to gallop or slap together. In Mexico, roosts of purple martins can be so large that they break electrical wires (Brown 1997). Perched flocks of small birds may span from phase to phase or ground, causing an electrical current to pass through multiple individuals. This can result in outages and electrocutions. Individual small birds may not be at risk of conductor-to-conductor contact, yet can be vulnerable to electrocution on transformers or other exposed equipment where separations between energized and grounded hardware are considerably less. On poles where protective coverings have been installed on transformer bushings, arresters, or insulators, insectivorous birds may attempt to glean insects from inside the covers.

MONK PARAKEET

Monk parakeets (*Myiopsitta monachus*) were brought to the United States from South America beginning in the late 1960s to be sold as pets. Escaped birds have since established populations throughout much of the United States and their numbers continue to grow (Pruett-Jones et al. 2005). Monk parakeets build nests in urban and suburban areas in trees and on electric utility structures (Figure 4.8; also see Chapter 6). Fires and outages can occur when monk parakeet

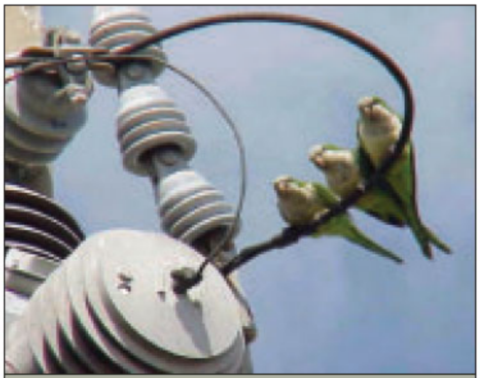

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FIGURE 4.8: Monk parakeets.

nesting material comes in contact with energized parts, or from the nesting activity of the birds themselves. Monk parakeets continually maintain their nests and, consequently, individuals have been electrocuted when attempting to weave nesting material (i.e. twigs) into the nest (J. Lindsay, pers. comm.). In addition to posing outage and fire risks, monk parakeet nests on utility structures attract predators and trespassing pet-trade trappers, potentially resulting in electrocutions of both birds and humans (Newman et al. 2004).

FACTORS INFLUENCING ELECTROCUTION RISK

AVIAN USE OF POLES

Raptors, waterbirds and small birds use power poles for hunting, resting, roosting and nesting—particularly in habitats where trees, cliffs, or other natural substrates are scarce (Figure 4.9). For waterbirds, power poles and lines can provide sites to perch while drying their feathers. Eagles and other raptors tend to use "preferred poles" that facilitate hunting success. Still-hunting conserves energy, provided suitable habitat for prey is within view. Preferred poles typically provide elevation above the surrounding terrain, a wide field of view, and easy take-off (Boeker 1972; Boeker and Nickerson 1975; Nelson and Nelson 1976, 1977; Benson 1981). When the design of a preferred pole is not avian-safe, multiple electrocutions can occur. Researchers have found up to a dozen eagle carcasses or skeletons under a single pole (Dickinson 1957; Benton and Dickinson 1966; Edwards 1969; Olendorff 1972a; Nelson and Nelson 1976, 1977; Manosa 2001).

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FIGURE 4.9: In open habitats with few natural alternatives, power poles can provide perching, nesting, hunting, or roosting sites for raptors and other birds.

Benson (1981) confirmed that the height of a perch above the surrounding terrain was important to the frequency of eagle electrocutions. Since pole height generally varies only 1.2 to 3 m (4 to 10 ft), there was no significant difference in the heights of poles with or without electrocuted eagles. However, poles that provided the greatest height above the surrounding terrain, e.g., those on bluffs and knolls, had a higher probability of causing electrocutions.

Habitat diversity plays an important part in pole preference. In one study (Pearson 1979), raptors used poles in heterogeneous environments more often than those in homogeneous environments. In fact, increased habitat diversity is only an indirect cause of increased use. A more direct cause is the increase in prey types and density of prey typical of greater habitat diversity. Eagles and other raptors spend more time hunting in areas that offer a greater chance of a successful capture. It is reasonable to expect that one pole will receive no more use than the next in uniform habitats, other factors notwithstanding (Ansell and Smith 1980). The "preferred pole" concept, therefore, may not apply when addressing an electrocution problem in homogeneous habitats or "preferred areas."

Choice of prey can also influence electrocution risk. Benson (1981) found highly significant differences both in eagle use and eagle mortalities along electric distribution lines in agricultural versus non-agricultural areas in six western states. More use and mortality occurred in native shrublands, primarily because of variations in rabbit distribution and availability. In particular, more golden eagles were electrocuted where cottontails (*Sylvilagus* spp.) occurred than where only jackrabbits (*Lepus* spp.) occurred. In jackrabbit habitat, about 14% of poles had raptor carcasses under them, compared to nearly 37% in cottontail habitat. Where both cottontails and jackrabbits were present, about 22% of poles had raptor carcasses under them. The most lethal 25% of lines studied were in sagebrush-dominated areas where both types of rabbits occurred in large numbers. No correlation was found in this study between rodent population densities and the incidence of raptor electrocutions.

Other studies have also documented a correlation between prey populations and raptor electrocution risk. The attraction of eagles to areas with high rabbit populations and increased electrocution risk was noted by Olendorff (1972a) near the Pawnee National Grassland in Colorado. Kochert (1980) concluded that the incidence of eagle electrocutions in the Snake River Birds of Prey Area in southwestern Idaho was a function of mid-winter eagle density that was, in turn, strongly related to the density of jackrabbits. The highest densities of jackrabbits in southwestern Idaho occur in native shrublands (Smith and Nydegger 1985); accordingly, more eagles were electrocuted in such habitats.

In the Butte Valley of northern California, irrigated agricultural fields support ground squirrels and other small mammals that, in turn, attract large numbers of raptors. In these habitats, particularly on dead-end poles with transformers lacking avian protection, raptors are at risk of electrocution. Prior to extensive retrofitting efforts in this region, numerous eagles, hawks, and owls had been electrocuted (PacifiCorp, unpubl. data).

Concentrations of wintering raptors, including ferruginous hawks and golden eagles, are attracted to the continent's largest prairie dog complex in Chihuahua, Mexico, where numerous birds had been electrocuted prior to retrofitting efforts (Manzano-Fischer 2004; Cartron et al. 2005).

In Alaska, an abundance of food sources from municipal waste facilities, canneries, and fish cleaning stations attract bald eagles that have been electrocuted on nearby power poles (Harness 2004).

Research on the proximity of nesting bald eagles to human activity in Florida suggest that fledging eagles from "suburban" nest sites have a higher risk of mortality from human activities, including electrocution, than do their "rural" counterparts (Millsap et al. 2004).

Agricultural areas attract pigeons, blackbirds, and starlings. Large flocks of these birds perching on wires can weigh down conductors, causing lines to gallop when they flush. As with raptors, these smaller species are vulnerable to electrocution on transformer poles, and related outages can disrupt farming activities.

SIZE

Birds with large wingspans, such as eagles, may bridge the distance between conductors on horizontal crossarms, while tall birds, such as herons or storks, may simultaneously contact different conductors on poles with vertical construction. Golden eagles have large wingspans, ranging from 1.8 to 2.3 m (6 to 7.5 ft) (Figure 4.10, Table 4.1). The height of a golden eagle ranges from 46 to 66 cm (18 to 26 in) from head to foot. Bald eagles are similar in size to golden eagles, with wingspans ranging from 1.7 to 2.4 m (5.5 to 8 ft) and heights ranging from 46 to 71 cm (18 to 28 in). As with most other raptors, female eagles are larger than males.

Because dry feathers provide insulation, birds must typically contact electrical equipment with conductive fleshy parts for electrocution to occur. Fleshy parts include the feet, mouth, bill, and the wrists from which the primary feathers originate. For a large golden eagle with a 2.3-m (7.5-ft) wingspan, the distance from the fleshy tip of one wrist to the tip of the other can measure 107 cm (42 in). These distances are important when considering phase-to-phase or phase-to-ground separations of power lines and the susceptibility of eagles to electrocution (see Chapter 5).

The 150-cm (60-in) standard of separation between energized and/or grounded parts is intended to allow sufficient clearance for an eagle's wrist-to-wrist span (APLIC 1996; see Chapter 5). Applying this standard will also protect birds with wingspans smaller than eagles, (see Table 4.1 and Figures 4.10, 4.11, 4.12). In areas where eagles do not occur, a standard of 102 cm (40 in) may provide adequate separation for raptors other than eagles. In areas with condors, a 150-cm (60-in) separation may not be adequate. The wingspans of California condors range from 2.5 to 3 m (8.2 to 9.8 ft)[16] and condors measure 120 to 130 cm (46 to 53 in) in height (Snyder and Schmitt 2002; Wheeler 2003). Utilities in areas with condors should consider the large size of this endangered species when designing or retrofitting power lines.

"60 inches"...Where Did It Come From?

The 1981 edition of *Suggested Practices* recommended 150 cm (60 in) of separation to provide adequate space for a large eagle with a wrist-to-wrist distance of 140 cm (54 in). This measurement was calculated by subtracting the lengths of the outer primary feathers (estimated at 46 cm [18 in] each) from the total wingspan of a large, female golden eagle measuring 230 cm (90 in).

In the preparation of the 2006 edition of *Suggested Practices*, the dimensions of numerous bird species were obtained from the literature and from measurements of live birds. This research has raised some interesting questions and has identified the need for further investigation. Measurements of live birds have shown that subtracting primary feather length from total wingspan is not an accurate measure of wrist-to-wrist distance (APLIC, unpubl. data). Although sample sizes are small, the wrist-to-wrist measurements of golden eagles obtained from live birds were much shorter than the 140-cm (54-in) distance identified in previous editions of *Suggested Practices*. Even on birds with wingspans of 200 cm (80 in) or more, wrist-to-wrist measurements were less than 110 cm (43 in). Wrist-to-wrist measurements were much smaller on bald eagles; although bald eagles may have larger wingspans than golden eagles, their primary feathers are longer and account for a greater proportion of the wingspan.

APLIC continues to recommend 150 cm (60 in) horizontal separation for eagle protection in this edition of *Suggested Practices*. This edition also recommends 100 cm (40 in) vertical separation for eagles. However, utilities may choose to implement design standards using different separations based on the species or conditions at issue. To improve avian protection on power lines, APLIC encourages researchers to collect vertical and horizontal flesh-to-flesh separation measurements of large birds. This information will help utilities tailor their avian protection efforts. For example, in areas without eagles or in urban locations, a utility could design power lines to protect large birds such as red-tailed hawks and great horned owls; in areas with California condors, utilities could design structures to accommodate these large birds; and in coastal areas, utilities could consider the tall heights of wading birds when designing lines.

[16] Wrist-to-wrist measurements could not be documented for California condor.

For tall species, vertical distance can play a role as important as horizontal distance. Because the height (head to foot) can reach up to 66 cm (26 in) for a golden eagle and 71 cm (28 in) for a bald eagle, vertical separation sufficient to accommodate perching eagles is recommended in areas with these species. Long-legged wading birds, such as herons, egrets, ibises, and storks, may also be electrocuted on poles where there is insufficient vertical separation between conductors or conductor and ground. In areas where such species are at risk, vertical separation of 120 cm (48 in) or more may be needed to accommodate the heights of some species.[17] The heights of selected species are provided in Table 4.1 and Figure 4.13.

TABLE 4.1: Wrist-to-wrist, wingspan, and height measurements for selected birds.*

Species	Wrist-to-wrist cm (in) [sample size]†	Wingspan cm (in)	Height cm (in) [sample size]§
Turkey Vulture	58–61 (23–24) [*n*=2]	165–178 (65–70)	36–53 (14–21) [*n*=3]
Black Vulture		137–160 (54–63)	
California Condor		249–300 (98–118)	120–130 (46–53)
Osprey		150–180 (59–71)	
Bald Eagle	79–86 (31–34) [*n*=4]	168–244 (66–96)	46–71 (18–28) [*n*=5]
Harris' Hawk	43 (17) [*n*=1]	103–119 (41–47)	28–43 (11–17) [*n*=2]
Swainson's Hawk	41–58 (16–23) [*n*=2]	112–137 (44–54)	33–41 (13–16) [*n*=2]
Red-tailed Hawk	36–58 (14–23) [*n*=10]	107–142 (42–56)	34–56 (13.5–22) [*n*=9]
Ferruginous Hawk	56 (22) [*n*=1]	135–152 (53–60)	48 (19) [*n*=1]
Rough-legged Hawk		122–142 (48–56)	
Golden Eagle	79–107 (31–42) [*n*=10]	183–229 (72–90)	46–66 (18–26) [*n*=11]
American Kestrel	20–25 (8–10) [*n*=4]	51–61 (20–24)	15–20 (6–8) [*n*=4]
Merlin		53–69 (21–27)	
Peregrine Falcon	33–51 (13–20) [*n*=2]	94–117 (37–46)	28–38 (11–15) [*n*=3]
Prairie Falcon	41 (16) [*n*=1]	91–112 (36–44)	33 (13) [*n*=1]
Barn Owl	38–51 (15–20) [*n*=4]	104–117 (41–46)	25–38 (10–15) [*n*=4]
Great Horned Owl	43–64 (17–25) [*n*=8]	114–130 (45–51)	31–41 (12–16) [*n*=8]

Continued

[17] This distance is based on the height of a great blue heron, approximately 1.2 m (46 in).

TABLE 4.1: Wrist-to-wrist, wingspan, and height measurements for selected birds.* (cont.)			
Species	**Wrist-to-wrist cm (in) [sample size]†**	**Wingspan cm (in)**	**Height cm (in) [sample size]§**
Roseate Spoonbill		127 (50)	81 (32)
Wood Stork		155 (61)	102 (40)
White Pelican		244–290 (96–114)	157 (62)
Brown Pelican		203 (80)	130 (51)
Egrets		91–130 (36–51)	51–100 (20–39)
Great Blue Heron		183 (72)	117 (46)
Other Herons		66–112 (26–44)	46–66 (18–26)
Ibis		91–97 (36–38)	58–64 (23–25)
Cormorants		132–160 (52–63)	
Common Raven		135 (53)	41 (16) [$n=1$]
Chihuahuan Raven		112 (44)	
American Crow		99 (39)	
Magpies		64 (25)	
Jays		48 (19)	
Woodpeckers		31–53 (12–21)	
Blackbirds		28–58 (11–23)	

* Sources: Johnsgard 1988, 1990; Sibley 2000; Wheeler 2003; *Birds of North America* species accounts; City of Lawrence (KS) Prairie Park Nature Center (unpubl. data); HawkWatch International (unpubl. data); Kansas Department of Wildlife and Parks Milford Nature Center (unpubl. data); Operation WildLife, Inc. (unpubl. data); Oregon Zoo (unpubl. data); PacifiCorp (unpubl. data); Rocky Mountain Raptor Program (unpubl. data); Stone Nature Center (unpubl. data); and Utah Wildlife Rehabilitation (unpubl. data).

† Because wrist-to-wrist and head-to-foot measurements of most species are not typically available in the literature, measurements were obtained from wildlife rehabilitators and handlers as well as from deceased birds. Sample sizes are given for birds that were measured and blanks in this field indicate that these data are currently unavailable. Avian researchers are encouraged to record these measurements when collecting other morphometric data.

§ Height given is from the top of the head to the feet. See also footnote †, above.

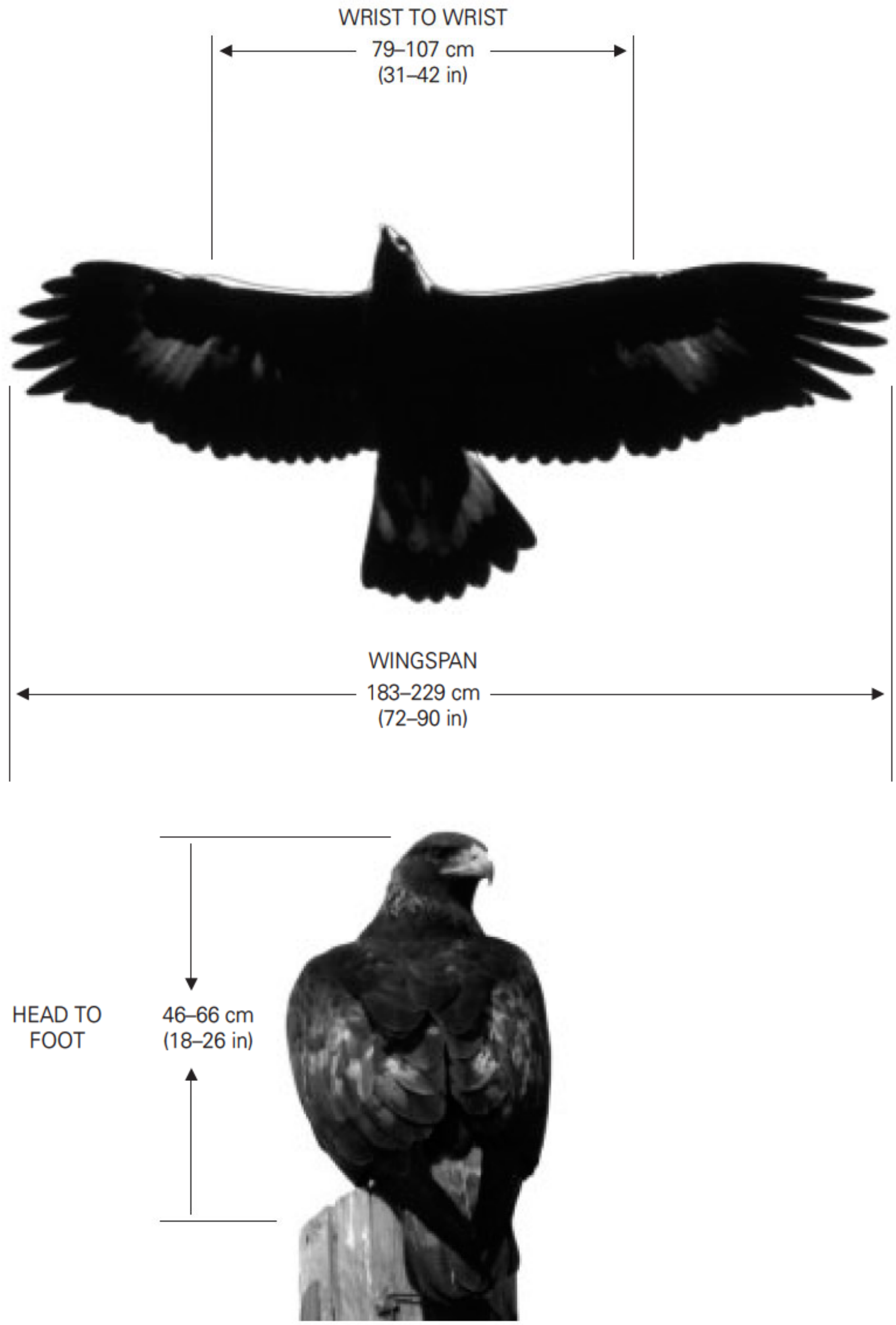

FIGURE 4.10: Critical dimensions of a golden eagle.

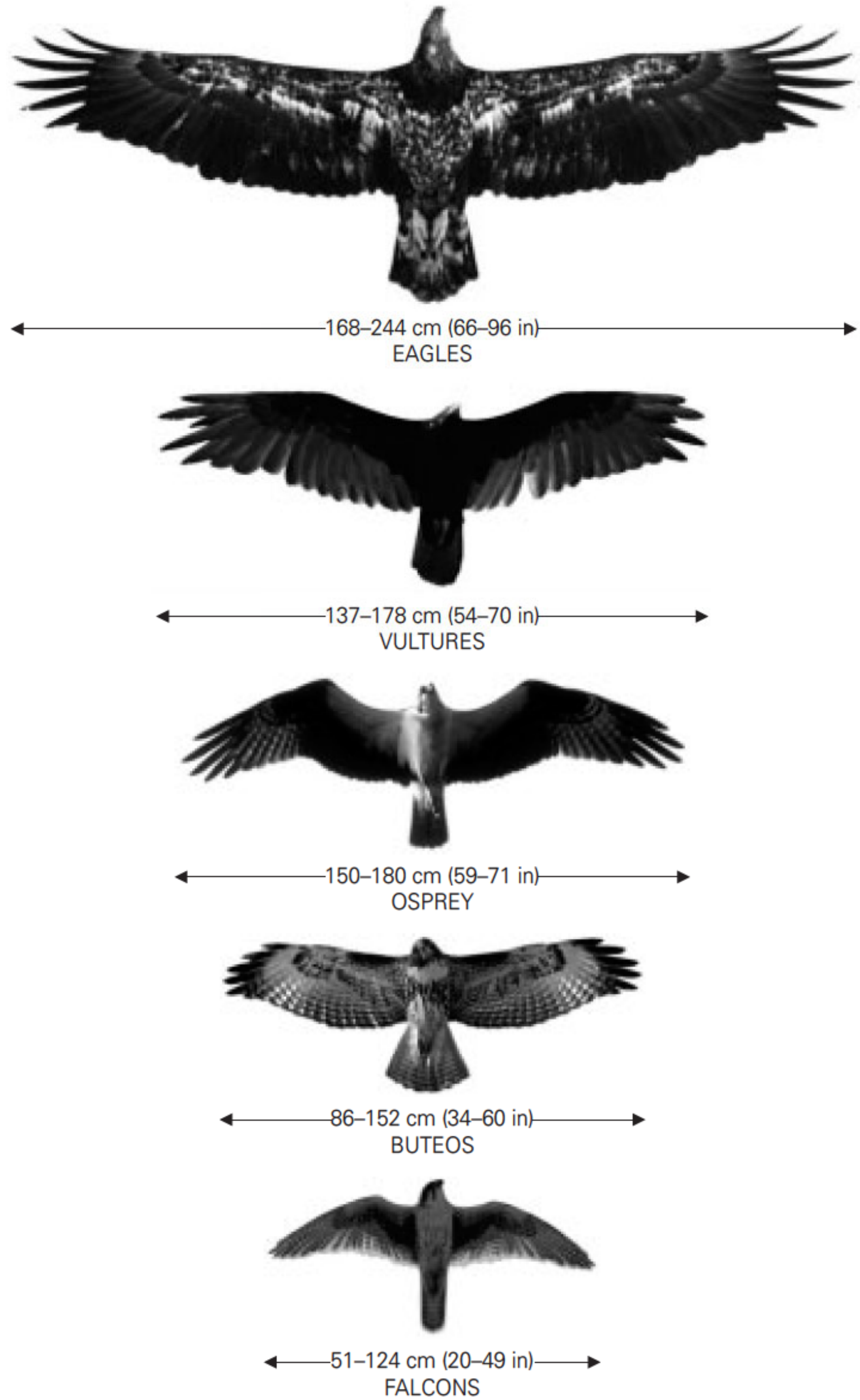

FIGURE 4.11: Wingspan comparisons of selected raptors.

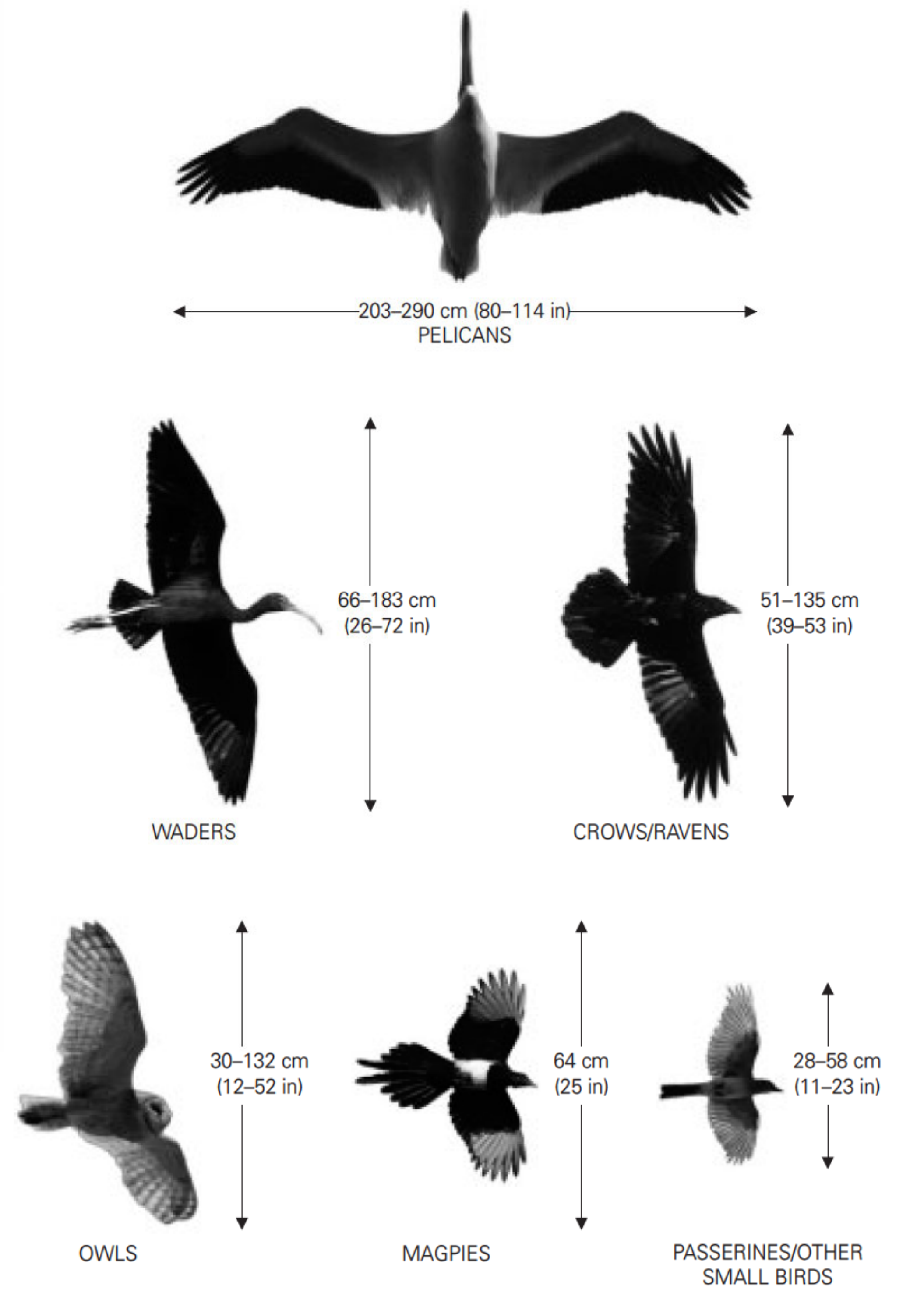

FIGURE 4.12: Wingspan comparisons of selected birds.

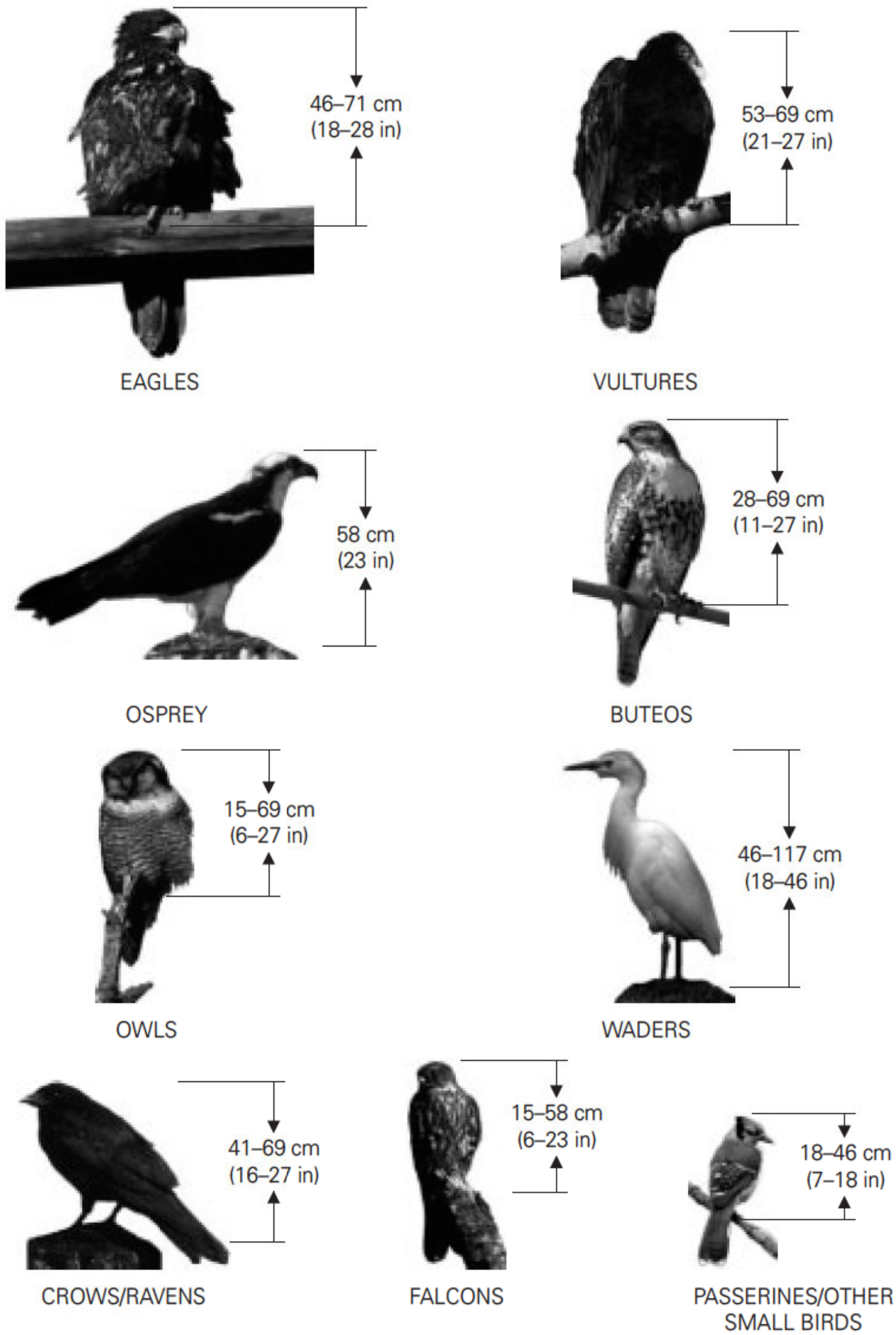

FIGURE 4.13: Height comparisons of perched birds.[18]

[18] Height ranges shown are from various sources and may include both head-to-foot and head-to-tail measurements. See Table 4.1 for additional information on height measurements.

TABLE 4.2: Percent of juvenile golden eagles in electrocution studies.

Study	Percent juvenile	Sample size
Benson (1981)	94.2%	52
Boeker and Nickerson (1975)	90.0%	419
Schomburg (2003)	87.9%	132
Harness and Wilson (2001)	66%	90
USFWS/Nebraska (unpubl. data)	63%	27

AGE

Research on golden eagles suggests that juvenile birds may be more susceptible to electrocution than adults (Table 4.2). Birds that nest on power poles may be electrocuted, particularly if the combined wingspans and simultaneous flapping behavior of several young birds cause them to bridge energized phase conductors and/or bridge between a conductor and grounded equipment. Post-fledging, juvenile birds may continue to experience increased risk compared to adults because they are less agile at landing on and taking off from poles. Regardless of an electrocuted bird's age, corrective actions to prevent electrocutions remain the same.

Susceptibility of juvenile golden eagles to electrocution involves several factors, but none seems more important than experience. Inexperienced birds may be less adept at landing and taking off, which increases their risk. Inexperience may also affect how juvenile birds hunt. Juvenile birds may learn to fly and hunt from a perch, particularly in flat country, where updrafts are less common. Learning to fly involves frequent short flights from perch to perch. The first attempts to hunt involve frequent changes of perches following unsuccessful chases. One juvenile golden eagle was observed making over 20 unsuccessful hunting sorties after cottontails from a distribution pole (Benson 1981). Had the line been unsafe for eagles and weather conditions been poor, the likelihood of electrocution would have been high.

Hundreds of hours of actual observations and analyses of slow-motion, 16-mm movies made by Nelson in the early 1970s demonstrated that juvenile eagles are less adept at maneuvering than adults, especially when landing and taking off (Nelson 1979b, 1980b; Nelson and Nelson 1976, 1977). Trained golden eagles were filmed landing on un-energized, mockup power poles of various configurations in both calm and inclement weather. The eagles did not perch on wires (conductors) and seldom perched on pole-top porcelain insulators that tended to be too small, smooth, or slick for comfortable gripping. Instead, they used pole tops and crossarms that offered firmer footing. When an adult eagle approached a three-wire power pole crossarm, for instance, the bird typically swooped in under the outside wire, swung up between wires with wings folded, and stalled onto the perch. The landing, when made into a headwind, was skilled and graceful, with very little flapping.

Juvenile birds, by contrast, often tried to settle onto a crossarm from above, using outstretched wings to slow their descent. They sometimes approached diagonally, flew to the highest point—perhaps an insulator—and tried to land. The birds often slipped off the insulator or tried in mid-flight to change to the crossarm—maneuvers accomplished by much wing flapping that increased their electrocution risk. Sometimes, juvenile birds began corrective action at a distance from the poles, particularly when the approach was too swift or at an improper angle. If they approached parallel to the lines, they often settled down across two conductors or tried to fly up between the conductors, increasing their electrocution risk (Figure 4.14). During landings, juvenile birds contacted the wires of the dummy poles making skin-to-skin contact near the wrists. Occasionally, contact also occurred on downward wing beats during

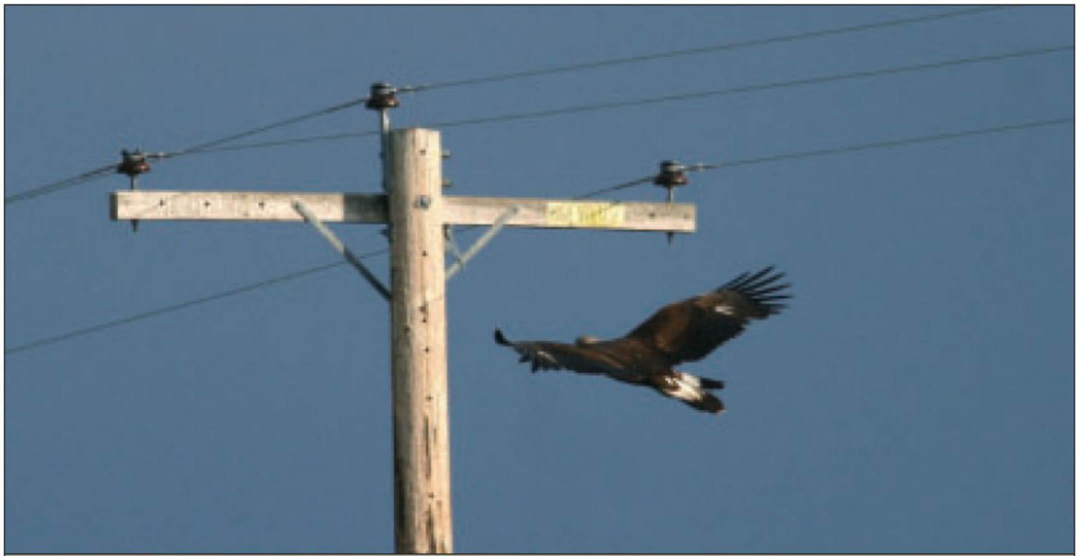

FIGURE 4.14: Juvenile golden eagle about to land on a distribution pole that is not avian-safe.

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take-offs. On energized lines, simultaneously touching differing phase wires or a phase and a ground with fleshy parts of the body or with wet feathers can result in electrocution.

Juvenile eagles may rely on poles as hunting perches more than adults. Benson (1981) attributed differences in electrocution risk of adult and juvenile birds to the fact that aerial hunting (as opposed to still-hunting from a perch) was the principal tactic used by adult golden eagles to capture jackrabbits. Catching jackrabbits with any consistency requires experience and tenacity in long, in-flight chases. Young birds find more success in pouncing on cottontails or other prey from stationary perches such as power poles. This increases their exposure to electrocution risk.

Florida has the largest breeding bald eagle population in the lower 48 states, with over 1,000 known nesting pairs (Nesbitt 2003). From 1963 to 1994, 16% of known bald eagle deaths in Florida (n=309) were due to electrocution. Contrary to previously mentioned data for golden eagles, these electrocutions were nearly evenly distributed between adult (55%) and juvenile (45%) birds. Likewise, 45% of known age bald eagle electrocutions in Nebraska (n=22) were juvenile birds (USFWS/Nebraska, unpubl. data).

Overall mortality rates (considering all causes of death) are greater for juvenile birds than for adults. Recoveries of banded golden eagles showed mortality in 50% of the population by an age of 31 months (Harmata 2002). Although age-related differences in electrocution risk are typically poorly understood for species other than eagles, it is likely that juvenile individuals of other species may be at greater risk than adults due to inexperience and overall higher mortality rates. For example, juveniles accounted for 61% of Harris' hawk electrocutions (n=75) in Tucson, Arizona (Dwyer 2004).

SEASONAL PATTERNS

Electrocution risk can vary with season. Many golden eagle mortalities along power lines (nearly 80% in the Benson 1981 study) occur during the winter. Of eagle electrocutions in the western United States with known mortality dates (n=96), 39% occurred from January to March; of eagle

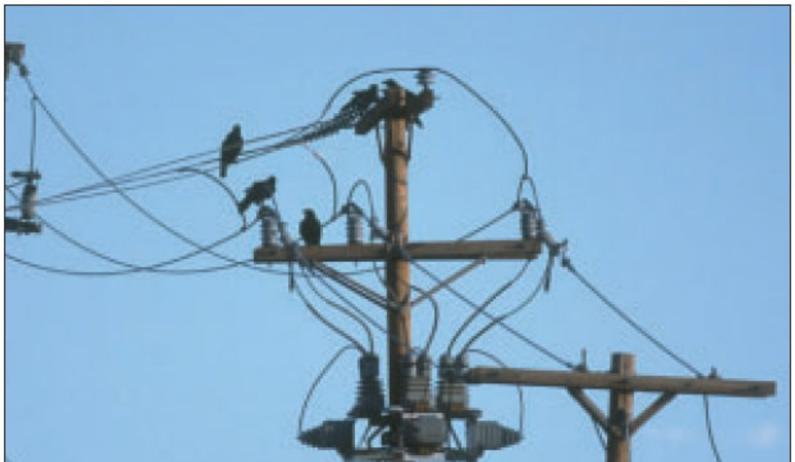

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FIGURE 4.15: Numerous birds perched on a pole can increase electrocution risk. Pictured: common ravens during breeding season.

carcasses discovered for which the date of mortality was unknown (*n*=516), 55% were found from January to April (Harness and Wilson 2001). Likewise, the majority (65%) of eagle mortalities reported during routine utility activities from 2001 to 2004 in the western United States by PacifiCorp (unpubl. data) occurred from December to April. The increased frequency of eagle electrocutions during the winter may be attributed to greater concentrations of these birds in open areas with power lines during the winter months. Likewise, eagles may be attracted to high seasonal prey concentrations that may, coincidentally, occur near non-avian-safe lines. In addition, eagles probably hunt from perches more during the winter than at other times of the year. In Florida, where bald eagles occur year-round, electrocutions occurred during every month of the year (Forrester and Spaulding 2003). However, most occurred from October through April, the period that encompasses the breeding season when eagle abundance is greatest in Florida and when dispersal and migration occur.

Electrocution rates of other species may also increase seasonally due to breeding behavior and the presence of young. Increased raptor electrocutions, particularly of Harris' hawks, corresponded with nesting activity in Tucson, Arizona (Dwyer 2004). Of known electrocution dates for hawks (*n*=119) in the western United States from 1986 to 1996, 57% occurred from July to September (Harness and Wilson 2001). In Chihuahua, Mexico, red-tailed hawk mortality peaked from September to November (Cartron et al. 2005). Similarly, electrocutions of hawks in the western United States from 2001 to 2004 were greatest from July to November, with 16% of annual mortalities occurring in both July and August, 14% in September, 11% in October, and 7% in November (PacifiCorp, unpubl. data). These seasonal peaks likely correspond with increases in hawk populations due to dispersal of fledglings during the breeding season and influxes of birds during fall migration. This dataset also showed a slight increase in hawk electrocution mortality during March and April (each with 8% of annual mortality), probably correlated with spring staging.

As with hawks, mortalities of owls in the western United States were greatest in late summer, particularly August and September (Harness and Wilson 2001). Likewise, electrocutions of eagle owls *(Bubo bubo)* in the Italian Alps were greatest during the period of juvenile dispersal in September (Rubolini et al. 2001). In the western United States, owl electrocutions from 2001 to 2004 were greatest during summer and early fall, with June, July, August, and September accounting for 26%, 24%, 7%, and 12%, respectively, of annual mortality (PacifiCorp, unpubl. data).

Electrocutions of other species also exhibit seasonal patterns. Records of corvid electrocutions in the western United States from 2001 to 2004 were greatest from April to August, with highest numbers in June (16%), July (22%), and August (15%) (PacifiCorp, unpubl. data). These months correlated with the local breeding season of these species, particularly the times when nestlings and/or fledglings are present (Figure 4.15). Raven electrocutions also peaked in August and September in Chihuahua, Mexico (Cartron et al. 2005). Electrocutions of songbirds in the western United States were correlated with the summer months, as 69% of electrocutions occurred from June to August (PacifiCorp, unpubl. data). The APLIC-member utilities surveyed documented seasonal differences in electrocution rates and noted overall increases during nesting and fall migration (APLIC 2005). In addition, species-specific seasonality was noted for eagles (winter) and passerines (spring).

BEHAVIOR

Nesting, courtship, and territorial behavior can make raptors and other birds susceptible to electrocution (Figure 4.16; also see Chapter 6). The gregarious social behavior of some birds, such as Harris' hawks or vultures, can also increase electrocution risk as multiple birds perch together on a pole.

Benson (1981) found that nearly 46% of red-tailed hawk electrocutions occurred during courtship and nesting. Most of these birds were adults. Benson also noted that nearly 30% of the hawks electrocuted during the late spring and early summer were fledglings. Dawson and Mannon (1994) reported that 37% of 112 electrocuted Harris' hawks in southern Arizona were birds that had recently fledged. Likewise, Dwyer (2004) found that 63% of electrocuted juvenile Harris' hawks (n=46) were killed within three weeks of fledging. Of raptor and raven electrocutions in Tucson, 79% were within 300 m (1,000 ft) of a nest (n=56) (Dwyer 2004). A young Swainson's hawk was found electrocuted in south-central Washington soon after it fledged (Fitzner 1978), and 2 fledgling great horned owls were found electrocuted near nests in Saskatchewan (Gillard 1977). Groups of 2 to 3 common ravens have been electrocuted in Utah and Wyoming, likely due to multiple birds simultaneously spanning conductors (PacifiCorp, unpubl. data).

Several instances of electrocution of birds carrying prey or nest material have been reported. A dangling prey item or stick can help span the gap between phase conductors or between an energized conductor and a grounded conductor, electrocuting a bird returning to the nest (Switzer 1977; Fitzner 1978). A young great horned owl was found electrocuted with a freshly killed snowshoe hare *(Lepus americanus)* lying nearby (Gillard 1977). Similar incidents were noted by Brady (1969) and Hardy (1970). In Utah, an electrocuted great horned owl was discovered with four nestling western kingbirds *(Tyrannus verticalis)* in its talons, likely retrieved from a kingbird nest behind the transformer that killed the owl (S. Liguori, pers. obs.). Golden eagles carrying large prey have been electrocuted on otherwise avian-safe poles in Wyoming (PacifiCorp, unpubl. data). Two adult red-tailed hawks were electrocuted at separate nests in Wyoming, possibly while carrying nesting material (Benson 1981). A pair of electrocuted red-tails was found below a pole in Utah, both birds with nesting material in their talons (S. Liguori, pers. obs.). Ospreys have been electrocuted when carrying seaweed (*New York Times* 1951) and barbed wire

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FIGURE 4.16: Swainson's hawk pair perched on distribution pole.

(Electric Meter 1953) to their nests. Nests and nestlings can also be destroyed if nesting material lies across conductors, resulting in a flashover and fire (Vanderburgh 1993).

During the nesting period, birds often engage in courtship and territorial defense. In such displays, raptors often lock talons, greatly increasing their effective wingspans. If these activities take place near a power line, the birds can be electrocuted. For example, in Montana, the electrocution of a subadult golden eagle was witnessed during an aggressive encounter with an adult eagle (Schomburg 2003). Benson (1981) documented a pair of electrocuted eagles below a pole, the talons of each bird imbedded in the breast of the other. In Oregon, two electrocuted red-tailed hawks were found below a pole, with the foot of the adult imbedded in the chest of the juvenile (S. Liguori, pers. obs.). Aggression between species may also have similar results, e.g., in Wyoming the foot of a great horned owl was found grasping the body of a red-tailed hawk (S. Liguori, pers. obs.). Likewise, in Arizona, a Harris' hawk and red-tailed hawk were electrocuted together during an aggressive encounter (Dawson and Mannan 1994). In areas of Montana where large concentrations of eagles winter, aggressive interactions between birds have led to the electrocution of two birds at once (S. Milodragovich, pers. comm.). In the Northern Cape Province of South Africa, vultures were electrocuted on vertically configured poles when aggressive interactions caused birds to slip off the insulators and fall onto conductors (Kruger et al. 2003).

Raptors and other birds may use power poles to provide protection from the elements. During hot weather in open, arid environments, birds seeking shade may perch on lower crossarms or perch close to the pole (Figure 4.17). Birds may also use the lower portions of power poles during rain or snow. Although power poles do not appear to offer much protection from the elements, they can provide some cover, particularly in habitats lacking natural shelter.

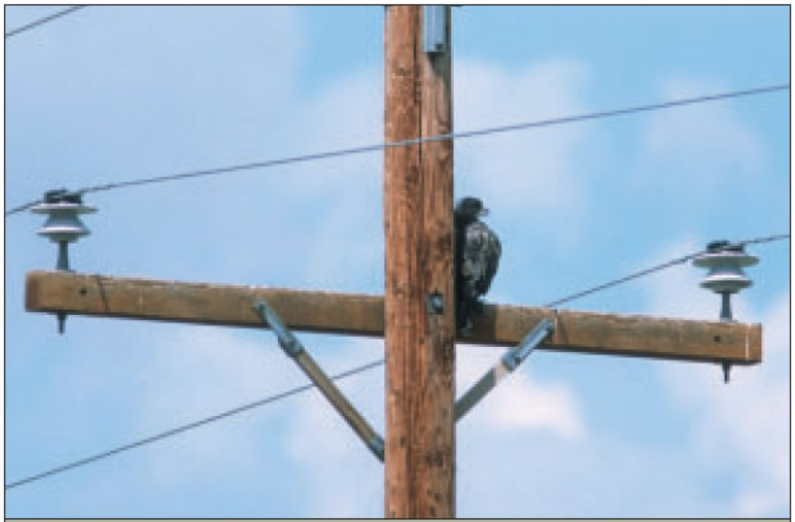

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FIGURE 4.17: Swainson's hawk using power pole for shade.

WEATHER AND THE INFLUENCE OF WET FEATHERS

Inclement weather (particularly rain, snow, and wind) increases the susceptibility of birds to electrocution. Wet feathers increase conductivity, and birds have greater difficulty landing on power poles in high winds. Because dry feathers provide insulation, most electrocutions are caused by simultaneous skin-to-skin, foot-to-skin, or bill-to-skin contact with two energized conductors or a conductor and a ground.

Nelson (1979b, 1980b) conducted experiments to determine the conductivity of a live eagle by attaching electrodes to the skin of the wings and to the toes. Although lethal voltages and currents were not determined, these experiments demonstrated that, at 280 volts (V) and a current of 6.3 milliamperes (mA), the eagle's respiration increased. At 400 to 500 V and a current range of 9 to 12 mA, the eagle convulsed. Wet feathers burned at 5,000 to 7,000 V, but there was no measurable current through a dry feather at 70,000 V. Skin-to-skin contacts were on the order of ten times more dangerous than contacts