LETTER

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CONSERVATION LETTER: RAPTORS AND OVERHEAD ELECTRICAL SYSTEMS

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Raptor interactions with overhead electrical systems have the potential to negatively affect individual birds, species, and populations, primarily in the form of electrocutions and collisions. This Conservation Letter provides a scientific review of these interactions and concludes by highlighting lessons learned and potential solutions. This letter is not intended as an exhaustive literature review. Rather, the intent of the Raptor Research Foundation (RRF) is to provide readers with enough evidence-based examples that readers can appreciate the scope and prevalence of raptor interactions with overhead electrical systems, and understand the potential effects on raptor species and populations as well as the challenges associated with addressing these effects across regions.

Raptors can be electrocuted (killed by electric current) or incur electric shock injuries (Dwyer 2006) when simultaneously contacting two uninsulated energized components of differing electric potential (phase-to-phase electrocution), or when contacting an uninsulated energized component and a path to ground (phase-to-ground electrocution; Avian Power Line Interaction Committee [APLIC] 2006, Dwyer et al. 2017). Energized components of overhead power systems usually are not insulated, but are elevated to place them safely out of people's reach. This strategy elevates energized wires into places that can be attractive perches for raptors. Most electrocutions occur at relatively low voltages associated with distribution systems where phase-to-phase and phase-to-ground separations are minimal, rather than with transmission systems where the separations created by longer insulators and wider air-gaps around wires are larger (APLIC 2006). Because electrocutions result from birds bridging the air-gaps around energized conductors, larger birds such as eagles are disproportionately affected (Lehman et al. 2007, Guil et al. 2015, Mojica et al. 2018).

Raptor electrocutions were recognized as early as the 1920s when electric utility systems were first constructed (Hallinan 1922, Lano 1927). Sporadic reports continued until the 1970s when electrocutions, particularly of Golden Eagles (*Aquila chrysaetos*) in the United States, were recognized as a conservation concern (Olendorff 1972, Miller et al. 1975). Now almost 50 yr later, electrocutions persist for Golden Eagles (US Fish and Wildlife Service [USFWS] 2016, Mojica et al. 2018), and for numerous raptor species worldwide (Harness et al. 2013, Dixon et al. 2017, Demeter et al. 2018). Electrocutions may be increasing, given the pylon construction practices in many developing countries where thousands of newly constructed grounded steel or grounded concrete configurations place even small raptors at risk (Pérez-García et al. 2016, Demeter et al. 2018).

Power line collisions appear to be a less frequent source of mortality for raptors compared to electrocutions (Loss et al. 2014). For example, 16–24% of power-line-related mortalities of Cape Vultures (*Gyps coprotheres*) are related to collisions, while the majority are caused by electrocution (Boshoff et al. 2011, Howes 2016). The apparently low susceptibility and exposure of raptors to power line collisions is likely due to a combination of their high aspect-ratio wings (Bevanger 1998), good visual acuity (Martin and Shaw 2010), and high flight altitude, particularly while engaged in thermal soaring (Janss 2000).

Nevertheless, some raptor species or power line locations are involved in a disproportionate number of

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collisions, the additive effects of which are of conservation concern (Rollan et al. 2010). Raptor power line collisions are more common when lines intersect home ranges, particularly if they are in areas of core use by raptors with relatively small home ranges, such as some species of eagles (Mañosa and Real 2001, Rollan et al. 2010, Watts et al. 2015), or if lines span regularly used flight paths between nesting and foraging grounds (Mojica et al. 2009, Rollan et al. 2010). Migrating raptors do not appear to be highly susceptible to colliding with power lines (Luzenski et al. 2016).

Raptors safely nesting or perching on overhead electrical systems may also be subject to human disturbance or persecution. For example, raptor attraction to power pole perches in relatively open landscapes may make them conspicuous targets for shooting persecution (Ellis et al. 1969, APLIC 2006). Raptor nests on power poles, transmission towers, and associated structures may be removed or exposed to human disturbance during maintenance activities (APLIC 2006).

Fewer than 10% of electrocutions cause outages (Dwyer and Mannan 2007, Kemper et al. 2013). Collisions cause even fewer outages. Although exact numbers have not been reported, collisions only cause outages when a colliding raptor is large enough and collides at just the right angle to bridge the space between conductors, resulting in a secondary electrocution and an outage. Though relatively rare, outages can result in costly damage to electric equipment and in rare cases, cause wildfires (Lehman and Barrett 2002, Guil et al. 2018, Dwyer et al. 2019a).

Effects of Electrocutions on Raptor Populations. Raptor electrocution has been most studied in Europe, South Africa, and North America (Lehman et al. 2007), though studies in Asia and elsewhere are increasing (see below). In Europe, electrocution is a main cause of death for large eagles and owls, and has negatively affected population structure or has been the direct cause for population declines for some species (Bayle 1999, Bassi et al. 2002, Sergio et al. 2004). Populations of large eagles in Spain have been particularly negatively affected by electrocutions (Ferrer and de la Riva 1991, Guil et al. 2015, Martínez et al. 2016). For example, most (97%) of the world's population of Spanish Imperial Eagles (*Aquila adalberti*) live in Spain, where electrocution is the leading cause of death (48–60% of recorded mortalities; González et al. 2007, Guil et al. 2015). The cumulative loss of individuals and a skewed sex ratio due to the higher mortality rate of female than male Spanish Imperial Eagles (females are larger, so more likely to bridge conductors) could drive rapid population decline (Ferrer and Hiraldo 1992, but see González et al. 2007). Spain also supports 70% of the global population of Bonelli's Eagles (*Aquila fasciata*), for which electrocution accounts for approximately 55% of mortalities (Real et al. 2001, Guil et al. 2015) and threatens the viability of local populations (Hernández-Matías et al. 2015). Electrocutions have also been implicated in declining numbers of Eurasian Eagle-Owls (*Bubo bubo*) in Italy (Sergio et al. 2004) and Spain (Fabrizio et al. 2004), Tasmanian Wedge-tailed Eagles (*Aquila audax fleayi*) in Australia (Bekessy et al. 2009), and New Zealand Falcons (*Falco novaeseelandiae*; Fox and Wynn 2010).

Studies investigating raptor electrocutions in most of Africa (except South Africa) and Asia (Lehman et al. 2007, Bernardino et al. 2018) are rare. After poisoning and use in traditional medicine, power lines pose the third-greatest threat to vultures in Africa (Ogada et al. 2016). Electrocutions affect at least six of the seven high conservation priority (International Union for Conservation of Nature status of Critically Endangered [CE] or Endangered [EN]) vulture species in Africa, namely; Egyptian Vulture (*Neophron percnopterus*, EN), White-headed Vulture (*Trigonoceps occipitalis*, CE), White-backed Vulture (*Gyps africanus*, EN), Lappet-faced Vulture (*Torgos tracheliotos*, EN), Rüppell's Vulture (*Gyps rueppelli*, CE), and Cape Vulture (EN, Smallie and Virani 2010, Boshoff et al. 2011, Angelov et al. 2013). The number of electrocutions of Cape Vultures in the Eastern Cape of South Africa (estimated at 67 birds per yr; 4% of the local population) is enough to drive the regional extinction of the species within a 20–35-yr period in areas with high risk of electrocution (Boshoff et al. 2011). Population effects may act remotely in migratory populations. Large numbers of Egyptian Vultures (hundreds to thousands in the past 50 yr) have been electrocuted during the nonbreeding season on a single 31-km power line in Sudan, likely driving observed population declines on the species' breeding ground in Israel (Angelov et al. 2013).

In North America, Golden Eagle electrocution has been a long-term issue resulting in localized high mortality (e.g., Olendorff 1972, Lehman et al. 2007) and widespread and pervasive mortality (Lehman et al. 2007, Mojica et al. 2018). Electrocutions account for an estimated 504 Golden Eagle mortalities per year in North America (USFWS 2016), with juveniles electrocuted at nearly twice the rate of subadults or adults (Mojica et al. 2018). Bald Eagle (*Haliaeetus leucocephalus*) electrocutions are less well studied, but also occur in substantial numbers (Mojica et al. 2009). Over half of the 31 diurnal raptors and 19 owl species breeding in North America have been reported in electrocutions (Lehman et al. 2007). Mortality rates can be high for non-eagle raptors also. For example, an estimated minimum 249 raptors, comprising Red-tailed Hawks (*Buteo jamaicensis*), Great Horned Owls (*Bubo virginianus*), and unidentified raptors, were electrocuted in a 13,400-km^2 study area in Alberta, Canada during a 6-wk period (Kemper et al. 2013). Electrocutions also accounted for 7 of 76 (9.2%) definitive causes of death within the reintroduced California Condor (*Gymnogyps californianus*) population (Rideout et al. 2012). The Ridgway's Hawk (*Buteo ridgwayi*) reintroduction program in the Dominican Republic has also been impacted by electrocution mortalities (Dwyer et al. 2019b). Electrocutions also involve multiple South American raptor species, including Black-chested Buzzard-Eagles (*Geranoaetus melanoleucus*; Orellana and Cornejo 2010, Ibarra and De Lucca 2015) and Chaco Eagles (*Buteogallus coronatus*; Galmes et al. 2017).

In Asia, where the electricity distribution network is growing rapidly, raptor electrocutions are also problematic. Power lines often traverse open and largely tree-less landscapes in Mongolia and China, attracting raptors. Despite the relatively recent installation of many of the power lines (2004–2006), unsafe configurations have resulted in large numbers of electrocuted raptors (Dixon et al. 2013). Electrocutions are responsible for up to 54% of the adult mortalities of globally endangered Saker Falcons (*Falco cherrug*) in Mongolia (Gombobaatar et al. 2004). Although the population effects of these mortalities is unknown, impacts are expected to increase with economic and industrial development in the region (Dixon et al. 2013).

Effects of Collisions on Raptor Populations. Generally, collisions are believed to be a lesser concern for raptors than electrocutions, but past studies have not always thoroughly investigated mortalities found under power lines (Lehman et al. 2007). However, for some species, collision mortality may be a major conservation concern. Power line collisions are a main cause of mortality for the endangered Bonelli's Eagle in Spain (Rollan et al. 2010). At least 21 Bald Eagle mortalities were attributed to line collisions over a 23-yr period in a dense nesting study area in the eastern USA totaling 160 km^2 (compared to 24 electrocutions; Mojica et al. 2009). Four post-reintroduction California Condor mortalities have been attributed to collisions vs. seven electrocutions (Rideout et al. 2012). In contrast, migrating raptors in Pennsylvania avoid newly constructed transmission lines (Luzenski et al. 2016).

Disturbance and Persecution on Power Lines. Very little data exist on disturbance or persecution related to raptor nesting and perching on power poles, with a few exceptions. In Wyoming, raptor electrocutions on power lines were first identified during investigations of Golden Eagles being shot (Olendorff et al. 1981). These discoveries led to the initiation of electrocution mitigation programs which continue today (APLIC 2006). In Utah, the majority of 48 dead raptors, including 26 Golden Eagles and 17 *Buteo* spp., found during repeated surveys of a single 19.5-km roadway were attributed to illegal shooting along a power line (Ellis et al. 1969).

Methods to Reduce Negative Effects. Raptor electrocutions can be prevented (Dwyer and Mannan 2007, Tintó et al. 2010, Chevallier et al. 2015, Dwyer et al. 2019b). Raptor-friendly pole designs that minimize electrocution risk can be used in new installations, and mitigation techniques and materials can be applied to existing installations. To mitigate electrocution risk in the USA, many electric utilities conduct a field risk assessment of existing structures and prepare an Avian Protection Plan (APP) to direct mitigation activities (APLIC and USFWS 2005). Electrocution risks are mitigated by creating separation between conductors of differing electric potentials, by placing insulation over conductors, or by redirecting birds to perch or nest away from conductors (APLIC 2006, Dwyer et al. 2017). Separation is usually unattainable on poles or pylons supporting energized equipment, the most dangerous pole configurations (Harness and Wilson 2001, Dwyer and Mannan 2007, Lehman et al. 2007), so insulation is the most widely used mitigation strategy. Redirection via perch deterrent devices is less frequently used today, though it was widely used with questionable effectiveness in the 1980s and 1990s. Redirection is now usually recommended only when separation and insulation are precluded by pole design or limited budgets, though redirection strategies have improved (Dwyer and Doloughan 2014, Dwyer et al. 2016a, 2016b). Aversion training has been successful in reducing electrocutions of reintroduced California Condors (Kelly et al. 2015).

In areas with few natural nest substrates but abundant prey, raptors are highly motivated to nest on human-made structures. In general, redirection devices installed on structures are not successful in preventing raptor nesting, and may actually aid nest building (APLIC 2006). Alternatively, nest platforms installed on or near power lines or towers may reduce hazards to both birds and the electrical system (APLIC 2006, Jenkins et al. 2013). To reduce collisions with existing wires, habitat management and wire markers are suggested, whereas proper siting and configuration are key to reducing impacts of new construction (APLIC 2012, Bernardino et al. 2018).

Regulatory mechanisms are a key tool in motivating electric utilities to reduce or avoid negative effects on raptors (APLIC and USFWS 2005). Various national and international regulations or agreements prohibit avian or raptor mortality, but enforcement and punitive incentives are highly variable worldwide. It is beyond the scope of this paper to summarize the complex geopolitical regulatory landscape, but we suspect protections are lagging in less-developed portions of the world.

Future Research Directions. Raptor electrocutions can cause wildfires when electric current passing through a bird ignites the plumage, and the burning bird then falls into dry vegetation at the base of a power pole (Lehman and Barrett 2002, Guil et al. 2018, Dwyer et al. 2019a). In one case, a bird-caused fire killed 15 people (Vargas 2016), and the risks of such catastrophic fires may be increasing as climate change affects understory vegetation structure and density. Importantly, Guil et al. (2018) found that the proportion of species electrocuted correlated with the proportion of species implicated in wildfire ignitions. This being so, retrofitting to reduce raptor electrocution risks may simultaneously reduce wildfire risks, perhaps offering electric utilities added incentive. Future research should include new focus on the occurrences, costs, and consequences of wildfires ignited by the electrocutions of raptors and other wildlife.

Relationships between raptor nests and electrocution risk are very poorly understood. To our knowledge, only Dwyer and Mannan (2007) studying Harris's Hawks (*Parabuteo unicinctus*), and Jenkins et al. (2013) studying three species of eagles, have quantitatively considered nests as part of an electrocution risk assessment. APPs, which are typically developed by evaluating pole configurations in detail, often consider habitat in only general terms (e.g., Dwyer et al. 2014). Future research should quantify electrocution risk across pole configurations as a function of distance from nests, and should do so for a broader array of species.

Despite the lack of evidence for its widespread efficacy, redirection continues to be used by the electric industry. Additionally, past studies demonstrating successful redirection have been observational rather than experimental (e.g., Slater and Smith 2010). Current research on redirection is being conducted primarily by one research group (e.g., Dwyer and Doloughan 2014, Dwyer et al. 2016a, 2016b). Experimental research by others would lessen the possibility that unintended bias within a single research group might overly influence an entire retrofitting strategy.

Very little research has been directed at the effectiveness of wire markers, wire height/configuration, or vegetation management on reducing bird collisions (Jenkins et al. 2010, Luzenski et al. 2016, Bernardino et al. 2018). Finally, we echo previous recommendations for researchers studying power line mortality to take pains to distinguish between electrocutions, collisions, shooting, etc. with lab necropsies when possible, or detailed field investigations at a minimum (e.g., Lehman et al. 2007, Kagan 2016).

As a leading professional society for raptor researchers and raptor conservationists, the RRF is dedicated to the accumulation and dissemination of scientific information about raptors, and to resolving raptor conservation concerns (RRF 2018). Raptor interactions with overhead electrical systems remain an ongoing conservation concern, presenting a global threat to raptor populations. Based on the science summarized here, resolving the factors associated with raptor electrocutions and collisions associated with electrical systems will allow long-term co-occurrence of raptor populations with human populations.

LITERATURE CITED

Angelov, I., I. Hashim, and S. Oppel (2013). Persistent electrocution mortality of Egyptian Vultures *Neophron percnopterus* over 28 years in East Africa. Bird Conservation International 23:1–6.

Avian Power Line Interaction Committee (APLIC) (2006). Suggested Practices for Avian Protection on Power Lines: The State of the Art in 2006. Project report prepared by Edison Electric Institute, APLIC, and the California Energy Commission, Washington, DC, and Sacramento, CA, USA.

Avian Power Line Interaction Committee (APLIC) (2012). Reducing Avian Collisions with Power Lines: The State of the Art in 2012. Edison Electric Institute and APLIC. Washington, DC, USA.

APLIC (Avian Power Line Interaction Committee) and USFWS (US Fish and Wildlife Service) (2005). Avian Protection Plan (APP) guidelines. Edison Electric Institute, Washington, DC, USA.

Bassi, E., D. Rubolini, P. Galeotti, G. Bogliani, and R. Garavaglia (2002). Eagle Owl *Bubo bubo* and power line interactions in the Italian Alps. Bird Conservation International 11:319–324.

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

Bekessy, S. A., B. A. Wintle, A. Gordon, J. C. Fox, R. Chisholm, B. Brown, T. Regan, N. Mooney, S. M. Read, and M. A. Burgman (2009). Modelling human impacts on the Tasmanian Wedge-tailed Eagle (*Aquila audax fleayi*). Biological Conservation 142:2438–2448.

Bernardino, J., K. Bevanger, R. Barrientos, J. F. Dwyer, A. T. Marques, R. C. Martins, J. M. Shaw, J. P. Silva, and F. Moreira (2018). Bird collisions with power lines: state of the art and priority areas for research. Biological Conservation 222:1–13.

Bevanger, K. (1998). Biological and conservation aspects of bird mortality caused by electricity power lines: a review. Biological Conservation 86:67–76.

Boshoff, A. F., J. C. Minnie, C. J. Tambling, and M. D. Michael (2011). The impact of power line-related mortality on the Cape Vulture *Gyps coprotheres* in a part of its range, with an emphasis on electrocution. Bird Conservation International 21:311–327.

Chevallier, C., A. Hernández-Matías, J. Real, N. Vincent-Martin, A. Ravayrol, and A. Besnard (2015). Retrofitting of power lines effectively reduces mortality by electrocution in large birds: An example with the endangered Bonelli's Eagle. Journal of Applied Ecology 52:1465–1473.

Demeter, I., M. Horváth, K. Nagy, Z. Görögh, P. Tóth, J. Bagyura, S. Solt, A. Kovács, J. F. Dwyer, and R. E. Harness (2018). Documenting and reducing avian electrocutions in Hungary: a conservation contribution from citizen scientists. Wilson Journal of Ornithology 130:600–614.

Dixon, A., R. Maming, A. Gunga, G. Purev-Ochir, and N. Batbayar (2013). The problem of raptor electrocution in Asia: case studies from Mongolia and China. Bird Conservation International 23:520–529.

Dixon, A., M. L. Rahman, B. Galtbalt, A. Gunga, B. Sugarsaikhan, and N. Batbayar (2017). Avian electrocution rates associated with density of active small mammal holes and power-pole mitigation: implications for the conservation of threatened raptors in Mongolia. Journal for Nature Conservation 36:14–19.

Dwyer, J. F. (2006). Electric shock injuries in a Harris's Hawk population. Journal of Raptor Research 40:193–199.

Dwyer, J. F., and K. Doloughan (2014). Testing systems of avian perch deterrents on electric power distribution poles. Human-Wildlife Interactions 8:39–55.

Dwyer, J. F., R. E. Harness, and K. Donohue (2014). Predictive model of avian electrocution risk on overhead power lines. Conservation Biology 28:159–168.

Dwyer, J. F., R. E. Harness, and D. Eccleston (2017). Avian electrocutions on incorrectly retrofitted power poles. Journal of Raptor Research 51:293–304.

Dwyer, J. F., R. E. Harness, T. Gallentine, and A. H. Stewart (2019a). Documenting and preventing wildlife-caused fires in power line rights of way. Environmental Concerns in Rights-of-Way Management. 12th International Symposium. Utility Arborist Association 12:23–31.

Dwyer, J. F., T. I. Hayes, R. Thorstrom, and R. E. Harness (2019b). Retrofitting power poles to prevent electrocution of translocated Ridgway's Hawks (*Buteo ridgwayi*). Journal of Caribbean Ornithology 33:4–10.

Dwyer, J. F., and R. W. Mannan (2007). Preventing raptor electrocutions in an urban environment. Journal of Raptor Research 41:259–267.

Dwyer, J. F., M. C. Tincher, R. E. Harness, and G. E. Kratz (2016a). Successful use of a perch deterrent to manipulate raptor perching on model power poles. Colorado Birds 50:166–174.

Dwyer, J. F., M. C. Tincher, R. E. Harness, and G. E. Kratz (2016b). Testing a supplemental perch to prevent raptor electrocution. Northwestern Naturalist 97:1–6.

Ellis, D. H., D. G. Smith, and J. R. Murphy (1969). Studies on raptor mortality in western Utah. Great Basin Naturalist 29:165–167.

Fabrizio, S., L. Marchesi, P. Pedrini, M. Ferrer, and V. Penteriani (2004). Electrocution alters the distribution and density of a top predator, the eagle owl *Bubo bubo*. Journal of Applied Ecology 41:836–845.

Ferrer, M., and M. J. de la Riva (1991). Electrocution of raptors on power lines in Southern Spain. Journal of Field Ornithology 62:181–190.

Ferrer, M., and F. Hiraldo (1992). Man-induced sex-biased mortality in the Spanish Imperial Eagle. Biologial Conservation 60:57–60.

Fox, N., and C. Wynn (2010). The impact of electrocution on the New Zealand Falcon (*Falco novaeseelandiae*). Notornis 57:71–74.

Galmes, M. A., J. H. Sarasola, J.M. Grande, and F. H. Vargas (2017). Electrocution risk for the endangered Crowned Solitary Eagle and other birds in semiarid landscapes of central Argentina. Bird Conservation International 28:403–415.

Gombobaatar, S., D. Sumiya, O. Shagdarsuren, E. Potapov, and N. Fox (2004). Saker Falcon (*Falco cherrug milvipes* Jerdon) mortality in central Mongolia and population threats. Mongolian Journal of Biological Sciences 2:13–21.

González, L. M., A. Margalida, S. Mañosa, R. Sánchez, J. Oria, J. I. Molina, J. Caldera, A. Aranda, and L. Prada (2007). Causes and spatio-temporal variations of non-natural mortality in the Vulnerable Spanish Imperial Eagle *Aquila adalberti* during a recovery period. Oryx 41:495–502.

Guil, F., M. Ángeles Soria, A. Margalida, and J. M. Pérez-García (2018). Wildfires as collateral effects of wildlife electrocution: an economic approach to the situation in Spain in recent years. Science of the Total Environment 625:460–469.

Guil, F., M. Àngels Colomer, R. Moreno-Opo, and A. Margalida (2015). Space-time trends in Spanish bird electrocution rates from alternative information sources. Global Ecology and Conservation 3:379–388.

Hallinan, T. (1922). Bird interference on high tension electric transmission lines. The Auk 39:573.

Harness, R. E., P. R. Juvvadi, and J. F. Dwyer (2013). Avian electrocutions in western Rajasthan, India. Journal of Raptor Research 47:352–364.

Harness, R. E., and K. R. Wilson (2001). Electric-utility structures associated with raptor electrocutions in rural areas. Wildlife Society Bulletin 29:612–623.

Hernández-Matías, A., J. Real, F. Parés, and R. Pradel (2015). Electrocution threatens the viability of populations of the endangered Bonelli's Eagle (*Aquila fasciata*) in Southern Europe. Biological Conservation 191:110–116.

Howes, C. G. (2016). Power line risk to Cape (*Gyps coprotheres*) and White-backed (*G. africanus*) Vultures in Southern Africa. M. S. thesis, University of Witwatersrand, Johannesburg, South Africa.

Ibarra, J. and E. De Lucca (2015). Águilas Moras (*Geranoaetus melanoleucus*) Víctimas de electrocución en Luján de Cuyo, Mendoza, Argentina. Nótulas Faunísticas 176:1–7.

Janss, G. F. E. (2000). Avian mortality from power lines: a morphologic approach of a species-specic mortality. Biological Conservation 95:353–359.

Jenkins, A. R., K. de Goede, L. Sebele, and M. Diamond (2013). Brokering a settlement between eagles and industry: sustainable management of large raptors nesting on power infrastructure. Bird Conservation International 23:232–246.

Jenkins, A. R., J. Smallie, and M. Diamond (2010). Avian collisions with power lines: a global review of causes and mitigation with a South African perspective. Bird Conservation International 20:263–278.

Kagan, R. A. (2016). Electrocution of raptors on power lines: a review of necropsy methods and findings. Veterinary Pathology 53:1030–1036.

Kelly, T. R., B. A. Rideout., J. Granthamc, J. Brandt, L. J. Burnett, K. J. Sorensond, D. George, A. Welche, D. Moend, J. Rasico, M. Johnson, C. Battistone, and C. K. Johnson (2015). Two decades of cumulative impacts to survivorship of endangered California Condors in California. Biological Conservation 191:391–399.

Kemper C. M., G. S. Court, and J. A. Black (2013). Estimating raptor electrocution mortality on distribution power lines in Alberta, Canada. Journal of Wildlife Management 77:1342–1352.

Lano, A. (1927). Great Blue Heron (*Ardea herodias*) electrocuted. The Auk 44:246.

Lehman, R. N., and J. S. Barrett (2002). Raptor Electrocutions and Associated Fire Hazards in the Snake River Birds of Prey National Conservation Area. Technical Bulletin No. 02-7. Idaho Bureau of Land Management, Boise, ID, USA.

Lehman, R. N., P. L. Kennedy, and J. A. Savidge (2007). The state of the art in raptor electrocution research: a global review. Biological Conservation 136:159–174.

Loss, S. R., T. Will, and P. P. Marra (2014). Refining estimates of bird collision and electrocution mortality at power lines in the United States. PLoS One 9:e101565. https://doi.org/10.1371/journal.pone.0101565.

Luzenski, J., C. E. Rocca, R. E. Harness, J. L. Cummings, D. D. Austin, M. A. Landon, and J. F. Dwyer (2016). Collision avoidance by migrating raptors encountering a new electric power transmission line. The Condor 118:402–410.

Mañosa, S., and J. Real (2001). Potential negative effects of collisions with transmission lines on a Bonelli's Eagle population. Journal of Raptor Research 35:247–252.

Martin, G. R., and J. M. Shaw (2010). Bird collisions with power lines: failing to see the way ahead? Biological Conservation 143:2695–2702.

Martínez, J. E., I. Zuberogoitia, M. V. Jiménez -Franco, S. Mañosa, and J. F. Calvo (2016). Spatio-temporal variations in mortality causes of two migratory forest raptors in Spain. European Journal of Wildlife Research 62:109–118.

Miller, A. D., E. L. Boeker, R. S. Thorsell, and R. R. Olendorff (1975). Suggested practices for raptor protection on power lines. Edison Electric Institute, Washington, DC, and Raptor Research Foundation, Provo, UT, USA.

Mojica, E. K., J. F. Dwyer, R. E. Harness, G. E. Williams, and B. Woodbridge (2018). Review and synthesis of research investigating and mitigating Golden Eagle electrocutions. Journal of Wildlife Management 82:495–506.

Mojica, E. K., B. D. Watts, J. T. Paul, S. T. Voss, and J. Pottie (2009). Factors contributing to Bald Eagle electrocutions and line collisions on Aberdeen Proving Ground, Maryland. Journal of Raptor Research 43:57–61.

Ogada, D., P. Shaw, R. L. Beyers, R. Buij, C. Murn, J. M. Thiollay, A. Botha, C. M. Beale, R. M. Holdo, D. Pomeroy, N. Baker, et al. (2016). Another continental vulture crisis: Africa's vultures collapsing toward extinction. Conservation Letters 9:89–97.

Olendorff, R. R. (1972). Eagles, sheep and power lines. Colorado Outdoors 2:3–11.

Olendorff, R. R., A. D. Miller, and R. N. Lehman (1981). Suggested Practices for Raptor Protection on Power Lines: The State of the Art in 1981. Raptor Research Report No. 4. Raptor Research Foundation, Saint Paul, MN, USA.

Orellana, S. A., and M. R. Cornejo (2010). Electrocution of Black-chested Buzzard Eagles *Geranoaetus melanoleucus* on power lines in Calera de Tango, Chile. Neotropical Raptors 9:11–14.

Pérez-García, J. M, E. Sebastián-González, F. Botella, and J. A. Sánchez-Zapata (2016). Selecting indicator species of infrastructure impacts using network analysis and biological traits: bird electrocution and power lines. Ecological Indicators 60:428–433.

Raptor Research Foundation (RRF) (2018). About us. https://raptorresearchfoundation.org/about/history/.

Real, J., J. M. Grande, S. Mañosa, J. Real, J. M. Grande, S. Mañosa, and J. Antonio (2001). Causes of death in different areas for Bonelli's Eagle *Hieraaetus fasciatus* in Spain. Bird Study 48:221–228.

Rideout, B. A., I. Stalis, R. Papendick, A. Pessier, B. Puschner, M. E. Finkelstein, D. R. Smith, M. Johnson, M. Mace, R. Stroud, J. Brandt, et al. (2012). Patterns of mortality in free-ranging California Condors (*Gymnogyps Californianus*). Journal of Wildlife Diseases 48:95–112.

Rollan, L. E. X., J. Real, R. Bosch, and A. Tinto (2010). Modelling the risk of collision with power lines in Bonelli's Eagle *Hieraaetus fasciatus* and its conservation implications. Bird Conservation International 20:279–294.

Sergio, F., L. Marchesi, P. Pedrini, M. Ferrer, and V. Penteriani (2004). Electrocution alters the distribution and density of a top predator, the Eagle Owl *Bubo bubo*. Journal of Applied Ecology 41:836–845.

Slater, S. J., and J. P. Smith (2010). Effectiveness of raptor perch deterrents on an electrical transmission line in southwestern Wyoming. Journal of Wildlife Management 74:1080–1088.

Smallie, J., and M. Z. Virani (2010). A preliminary assessment of the potential risks from electrical infrastructure to large birds in Kenya. Scopus 30:32–39.

Tintó, A., J. Real, and S. Mañosa (2010). Predicting and correcting electrocution of birds in Mediterranean areas. Journal of Wildlife Management 74:1852–1862.

US Fish and Wildlife Service (USFWS) (2016). Bald and Golden Eagles: Population Demographics and Estimation of Sustainable Take in the United States, 2016 Update. US Fish and Wildlife Service, Division of Migratory Bird Management, Washington DC, USA.

Vargas, S. (2016). Risk communication in Chile: a study of 2014 Valparaiso wildfire. M.S. thesis, Simon Fraser University, Burnaby, BC, Canada. http://summit.sfu.ca/system/files/iritems1/16691/etd9621_SVargas.pdf.

Watts, B. D., E. K. Mojica, and B. J. Paxton (2015). Using Brownian bridges to assess potential interactions between Bald Eagles and electrical hazards within the upper Chesapeake Bay. Journal of Wildlife Management 79:435–445.

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