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COLLISION AVOIDANCE BY WINTERING BALD EAGLES CROSSING A TRANSMISSION LINE

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ABSTRACT.—Collision with electric lines is a global conservation concern for many birds but raptor species are generally thought to have a low risk of line collision. Collision risk at electric lines is not well understood for Bald Eagles (*Haliaeetus leucocephalus*), with only incidental reports of collisions in the literature. Line collisions reported for Bald Eagles predominantly occur where lines intersect movement corridors around foraging, roosting, or nesting areas. During five winters from 2014 to 2018, we monitored 602 Bald Eagle crossings of a 230/500-kV transmission line at the Delaware River to determine collision risk. Eagles successfully crossed the line by flying predominantly below the wire zone. There was no difference in flight heights for immature or adult eagles crossing the line. Wire-marking protocols within the electric industry are primarily focused on marking the top plane of wires to alert birds flying above the wires. Additional development of wire-marking options for energized conductors could further reduce collision risk for eagles and other bird species flying below wires. Overall, collision risk appears low for Bald Eagles making localized movements across transmission lines.

KEY WORDS: *Bald Eagle*; Haliaeetus leucocephalus; *collision risk*; *Delaware River*; *line marking*; *mortality*; *transmission line.*

EVITACIÓN DE COLISIONES POR INDIVIDUOS INVERNANTES DE *HALIAEETUS LEUCOCEPHALUS* QUE CRUZAN UNA LÍNEA ELÉCTRICA DE TRANSMISIÓN

RESUMEN.—La colisión con líneas eléctricas es una preocupación global para la conservación de muchas especies de aves. Sin embargo, se considera que las aves rapaces tienen por lo general un bajo riesgo de colisión. Esta amenaza no es muy bien comprendida para *Haliaeetus leucocephalus*, para la que existen casos puntuales de colisiones descritos en la bibliografía. Las colisiones con líneas eléctricas reportadas para *H. leucocephalus* suceden predominantemente donde las líneas intersectan corredores de vuelo alrededor de dormideros y áreas de alimentación y nidificación. Durante cinco inviernos, desde 2014 hasta 2018, seguimos 602 individuos de *H. leucocephalus* atravesando líneas de transmisión de 230/500 kV en la zona del Río Delaware con el fin de determinar el riesgo de colisión. Las águilas cruzaron con éxito la línea volando predominantemente por debajo de la zona de cables. No hubo diferencias en las alturas de vuelo entre individuos inmaduros o adultos que cruzaron la línea. Los protocolos de señalización de los cables utilizados por las compañías eléctricas se enfocan principalmente en marcar el plano superior de los cables para alertar a las aves que vuelan por arriba de los mismos. El desarrollo adicional de sistemas de señalización de los cables para conductores energizados podría reducir aún más el riesgo de colisión de águilas y de otras especies de aves que vuelan por debajo de las líneas eléctricas. En general, el riesgo de

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colisión parece ser bajo para los individuos de *H. leucocephalus* que se desplazan a través de las líneas de transmisión.

[Traducción del equipo editorial]

Avian collision with electric lines is an ongoing conservation concern for many species worldwide (Bernardino et al. 2018). Raptor species are generally thought to have a lower risk of line collisions compared to other bird families because of their sharp eyesight and flight agility (Bernardino et al. 2018, Eccleston and Harness 2018). Raptor behavior during foraging flights, however, can increase collision risk if their gaze is focused downward searching for prey and they fail to recognize electric lines in their flight path (Martin 2012). Olendorff and Lehman (1986) report that raptors are more vulnerable to collision when distracted, such as when pursuing prey. Collisions with power lines during foraging have been documented in Alaska where Bald Eagles (*Haliaeetus leucocephalus*) often congregate near power lines located at artificial food sources such as canneries, fish cleaning stations, and municipal waste facilities (Harness 2008).

Eagle species are thought to be susceptible to line collisions during hunting bouts or conspecific interactions (Schomburg 2003), especially where lines intersect flight paths to foraging areas, nests, or roosts (Avian Power Line Interaction Committee [APLIC] 2012, Watts et al. 2015). Although line collisions are relatively rare in eagle species, documented collisions exist for the Bonelli's Eagle (*Aquila fasciata*; Manosa and Real 2001), Golden Eagle (*Aquila chrysaetos*; Olendorff and Lehman 1986, Harness et al. 2003, Amartuvshin and Gombobaatar 2012), Spanish Imperial Eagle (*Aquila adalberti*; González et al. 2007), Steppe Eagle (*Aquila nipalensis*; Amartuvshin and Gombobaatar 2012), and Bald Eagle (Olendorff and Lehman 1986, Harness et al. 2003, Mojica et al. 2009).

In the United States, incidental take of Bald Eagles (hereafter "eagle") from line collisions is a regulatory focus for the US Fish and Wildlife Service. The agency sets population thresholds for permitted take of the species (US Fish and Wildlife Service 2016) and can require monitoring of transmission lines (typically >60 kilovolts [kV]) in eagle habitat as part of conditions for incidental take permits (Church et al. 2014, Luzenski et al. 2016). Accurately estimating incidental take for transmission lines is difficult because eagle collision risk is not well understood for electric lines, as there are only incidental reports documented in the literature. Collisions have been reported with both distribution (<60 kV) and transmission lines (Olendorff and Lehman 1986, Harness et al. 2003, Mojica et al. 2009). In one retrospective study of distribution lines in Maryland, Bald Eagles were more likely to collide with wires located close to shorelines where eagles foraged and also in locations where wires were not shielded by vegetation (Mojica et al. 2009). Collision rates were also higher where distribution lines intersected eagle movement corridors between shorelines and inland communal roosts (Watts et al. 2015). A similar collision pattern was documented in Alaska, where foraging eagles collided with distribution lines near a fish-canning operation (Harness et al. 2003). Olendorff and Lehman (1986) provide the only published account of eagles, both Bald Eagle and Golden Eagle, colliding with transmission lines. Factors contributing to collisions with higher voltage transmission lines are unknown but are likely similar where lines intersect eagle movement corridors.

Here, we describe a collision monitoring study for a transmission line rebuild crossing the Delaware River where Bald Eagles annually winter to forage, roost, and nest. In comparison to the original line, the rebuilt line doubled the number of wires intersecting the eagle movement corridor over the river but also raised the wire elevation by doubling the transmission tower height. The primary objective of the study was to document collision risk to eagles crossing the new transmission line after installation of mitigation and minimization measures.

METHODS

The study was conducted at the Delaware Water Gap National Recreation Area on the Delaware River approximately 2 km south of Bushkill, Pennsylvania, on the border of Pennsylvania and New Jersey. The Delaware River is a historic wintering site for eagles; however, recent Midwinter Bald Eagle Surveys show eagle presence is declining along the river (Eakle et al. 2015). A small communal roost, with up to five eagles per night (Katzmire 1989, EDM International 2014), is located 675 m northwest of the transmission line on the west bank of the Delaware River at Hogback Ridge.

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The Susquehanna–Roseland transmission line was rebuilt across the Delaware River in 2013–2014 to upgrade the voltage and replace aging infrastructure. The original transmission line was a single circuit 230-kV line with two planes of wires and towers 20–25 m tall. The new transmission line is a double circuit with 230-kV and 500-kV wires strung on opposite sides of 55–60-m monopole towers. The wires are vertically configured with four planes of wires including three energized conductor wires and an optical ground wire (OPGW) on the top plane. During construction and permitting of the project, line markers were included as mitigation and minimization measures to increase the visibility of the wires to flying eagles and reduce the risk of incidental take. The entire span of each OPGW was marked with yellow spiral Swan Flight Diverters (1 m long; Preformed Line Products, Cleveland, OH, USA). Markers were staggered on each OPGW above the 230-kV and 500-kV lines during installation at 15.2-m spacing intervals, effectively producing the recommended 7.6-m spacing thought to increase visibility to flying birds (Jenkins et al. 2010, APLIC 2012). Additionally, the bundled conductor design on the 500-kV circuit acted as surrogate collision markers, presumably increasing visual recognition of the wire to eagles. The conductors were bundled with 45.7-cm wire spacers that separated the conductors by 60.9 cm in a triangular configuration. The spacers were located every 60–74 m on the conductor wires. Photographs of markers and line configuration are available in Luzenski et al. (2016).

We hypothesized that (1) eagles would avoid collision by either flying below or above the wire zone, (2) immature eagles would fly within the wire zone more frequently than adults, and (3) eagles would cross the line more often over water.

We conducted observations of the transmission line at the river crossing on weekdays in the morning from civil dawn to 1000 H and in the evening from 2 hr before sunset until civil dusk. These observation periods were selected to coincide with established daily eagle movement patterns along the river (Katzmire 1989, EDM International 2014) and during periods of low light when the potential for collision was assumed to be highest (APLIC 2012). Observations totaled 5.5–6.5 hr/d depending on day length. Eagles were observed for five consecutive winters from 13 December to 31 March during 2014–2018, with the exception of the first year when observations began in mid-February 2014 immediately after completion of line construction. We monitored the entire observation area consisting of a 660-m span of transmission line crossing over a 162-m-wide river corridor and adjacent forested shorelines (Fig. 1A). The observer was located in the right-of-way on the west riverbank with views of the line in both directions. Eagles were aged as either adult or immature (<4 yr old) based on plumage characteristics (Wheeler 2003). Eagles were recorded crossing the line when an individual traversed the line in any direction. Circling flight by the same eagle was recorded as one crossing event based on the first height and direction of crossing.

An observer used binoculars and a laser range finder (RX-1000i TBR W/DNA, Leupold & Stevens, Beaverton, OR, USA) equipped with a clinometer to record the flight distance and angle of eagle crossings from the observation site. Flight direction of each eagle crossing was recorded either as heading north or south across the line. We also categorized eagle crossings as above or below tree line. The absolute elevation above sea level was calculated for each observation by adding the observer's elevation to the relative height of the crossing using a 10-m digital elevation model in ArcGIS 10.4 (Esri, Redlands, CA, USA). The three-dimensional location of each wire was imported into ArcGIS from PLS-CADD (Power Line Systems, Madison, WI, USA) and used to set the boundaries for the wire zones during analyses. The wire zones accounted for line sag between poles where the spacing between the OPGW and bottom conductor increased at farther distances from the towers (Fig 1B).

Eagle crossing observations were categorized by flight height in proximity to categories of wire zone as eagles crossed the transmission line (Fig. 1B). Categories in the observation area included flying above wires (1 m above the top of tallest transmission tower to OPGW, 50% of available airspace), within the wires (between the OPGW and the lowest conductor wire, 31% of available airspace), or below wires (lowest conductor wire to surface of river or ground, 19% of available airspace). Eagles were also categorized as crossing the line over water or over land. Airspace proportions over the river, hereafter "river observation area" (Fig 1B), consisted of 60% above the wires, 26% within the wires, and 14% below the wires. The distance from the river to the top of the observation area was 150 m. Eagles flying higher than 1 m above the tallest transmission tower

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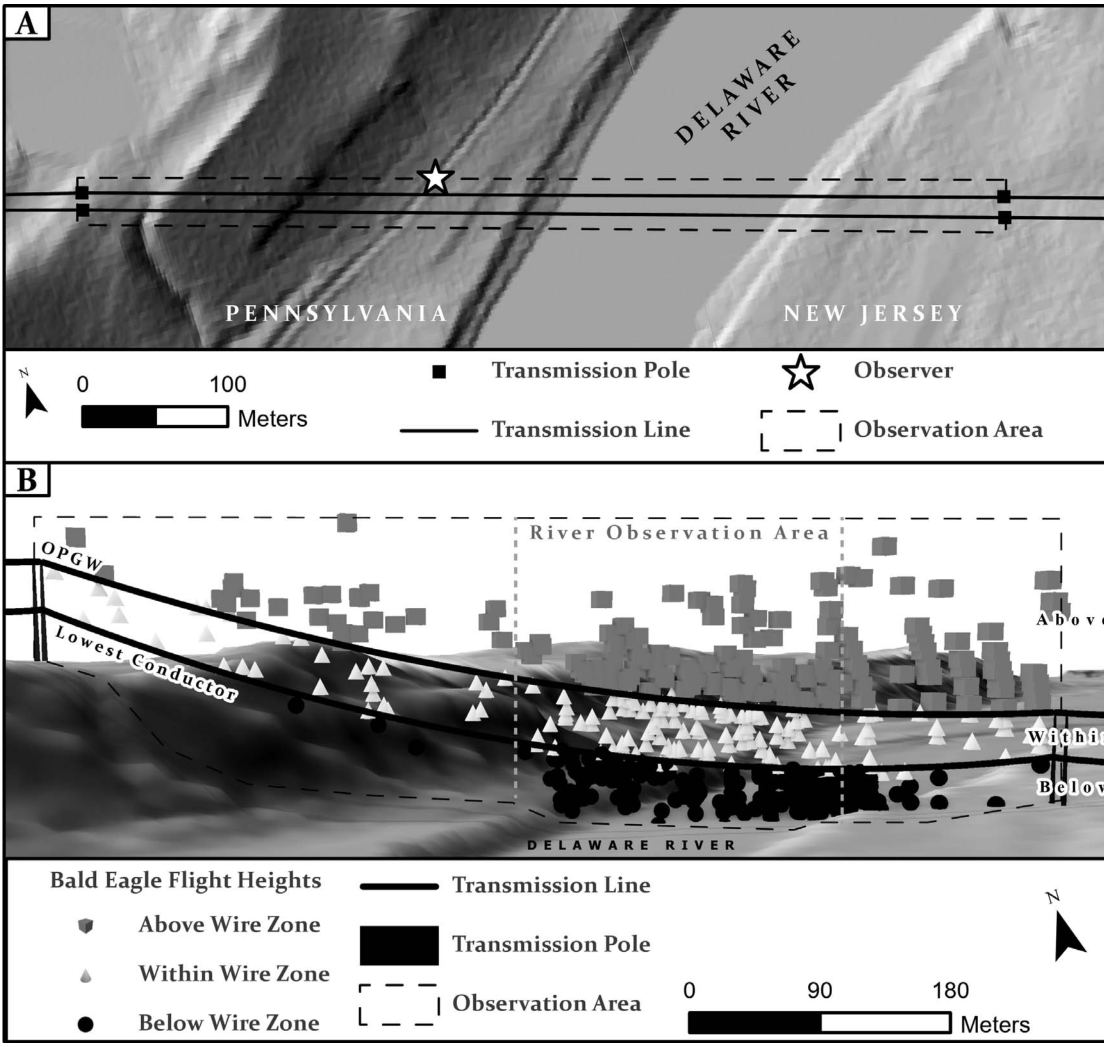

Figure 1. (A) Study area at the transmission lines crossing the Delaware River, (B) Bald Eagle flight positions while crossing a transmission line at the Delaware River as shown on an elevation model to show flight height relative to wires. Eagles crossed below the wires ($n = 250$) more than twice as much as expected based on available airspace, as expected within the wire zone ($n = 164$), and less than expected above the wires ($n = 188$).

were outside of the observation area and excluded from analyses because collision risk was assumed to be minimal.

We used a χ^2 goodness of fit test to compare the observed frequencies of eagles flying within the different wire zone heights in the observation area and river observation area. The proportion of observations within each wire zone was compared to the expected proportion based on available airspace in each wire zone category.

RESULTS

During 2014–2018, observers documented 602 transmission line crossings by Bald Eagles within the observation area during 1925 hr of observation. Eagles observed crossing included 408 immatures, 175 adults, and 19 eagles of unknown age. No line collisions were observed during the five field seasons of the study. Additionally, two Golden Eagle crossings were observed over land; one above the

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wires in January 2015 and one within the wires in March 2015.

Bald Eagles did not use the available airspace in the observation area proportionately when crossing the transmission line. Eagles crossed below the wires more than twice as often as expected based on available airspace, as often as expected within the wire zone, and less than expected above the wires ($\chi^2 = 206.0$, df = 2, $P < 0.0001$). In the river observation area, the disproportionate use of space was even more pronounced: eagles crossed below wires 3.7 times more than expected, within the wires as expected, and above the wires 2.6 times less than expected ($\chi^2 = 513.9$, df = 2, $P < 0.001$). After the first year, crossings below the wires increased and crossings decreased in the above and within categories ($\chi^2 = 18.17$, df = 8, $P = 0.02$). Flight height did not differ significantly between immature and adult eagles in the wire zone categories in the entire observation area ($\chi^2 = 2.22$, df = 2, $P = 0.3$) or within the river observation area alone ($\chi^2 = 2.21$, df = 2, $P = 0.3$).

Eagle crossings were observed southbound (away from the communal roost) more often in the morning and northbound toward the communal roost in the evening ($\chi^2 = 50.63$, df = 1, $P < 0.001$). Crossings in the morning were greatest below wires and shifted to above wires in the evening ($\chi^2 = 37.53$, df = 2, $P < 0.0001$).

Most eagles crossed the transmission line over the river (68.6%) vs. over land (31.4%). Overland crossings occurred as expected in each wire zone category based on available airspace ($\chi^2 = 3.8$, df = 2, $P = 0.15$). In addition, eagle crossings within the wire zone occurred more often over water than over land ($\chi^2 = 61.91$, df = 2, $P < 0.0001$). A small number of the 189 overland crossings were unexpectedly below the tree line, both within the wire zone ($n = 9$) and below the wire zone ($n = 24$).

Discussion

The transmission line intersecting a Bald Eagle movement corridor on the Delaware River did not pose a collision risk to the wintering population of eagles. Eagles successfully avoided collision primarily by flying below wires. Eagles moving locally around a transmission line may have a lower collision risk than migrating eagles, because local birds presumably become familiar with their surroundings and adjust their daily flight height in response to a predicable obstacle in their flight path. Observers at the Delaware River noted individual eagles made flight adjustments to avoid the wires as they crossed the transmission line. For example, some Bald Eagles initially approached the line and adjusted their flight paths by moving vertically or circling to gain altitude before crossing. A similar flight response was documented on the same transmission line where it crossed the raptor migration corridor on Kittatinny Ridge 4 km east of the study area; there migrating Bald Eagles increased their flight altitudes to cross above the wires (Luzenski et al. 2016).

In contrast to migrating eagles along the Kittatinny Ridge that flew above the wires, eagles wintering on the Delaware River flew predominantly below and within the wires. The bundled wires in this study could have acted as surrogate line markers by increasing the visual contrast of lines to flying eagles. Conductors are typically not marked because line markers cannot be placed on energized conductors >115 kV, as attached objects can cause negative corona effects to the line (Hurst 2004). Alternatives to traditional line marking are under development to make conductor and ground wires more visible to birds. Advances in collision-avoidance technology are being developed to specifically leverage unique aspects of avian physiology. For example, the Avian Collision Avoidance System (EDM International, Inc., Fort Collins, CO USA) uses wavelengths of light visible to birds but not visible to humans to illuminate power lines (Dwyer et al. 2019). Though this technology is potentially promising for mitigating raptor collisions, its effectiveness has only been demonstrated to date for the Sandhill Crane (*Grus canadensis*), so additional study is needed. Supplemental light shining on wires during low light periods around twilight or during inclement weather may further reduce collision risk for eagles.

We did not find differences in crossing height by eagle age but did see a shift in flight height over time. Data collected in year 1 was within the same winter season as final construction of the line; eagles presumably learned the wire locations and shifted their flights below the wires in years 2–5. Wire crossings could not be associated with individual eagles, so we were unable to further examine this idea. The fixed location of the line may have helped eagles learn to avoid it throughout the winter season or in subsequent years. It is possible the transmission line became less of a collision risk over time as eagles learned the landscape during the winter period.

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Although the electric industry recommends marking only the center portion of each span with line markers (Eskom 2005, APLIC 2012), the entire span of the OPGW was marked over the Delaware River. Eagle movements were concentrated over the river corridor, but more than one-third of eagles flew over land closer to the monopole towers. Although eagles were observed flying more often within the wire zone over the river than over adjacent forested shorelines, some within-wire crossings did occur over land. This suggests marking the entire span was an appropriate minimization measure to reduce risk of eagle collision across the entire width of the eagle movement corridor, not just the portion of the span over water. Additionally, eagles were documented crossing the transmission line while flying through the forest. We suggest eagles are more alert to flight obstacles while flying through the forest and therefore have lower collision risk.

Reducing collision risk for eagles is based on the premise that eagles see the line markers or wires and recognize them as flight obstacles. The influence of avian vision on collision risk in eagles and other birds is an emerging field of research. We are just beginning to understand how species-specific differences in field of view, position of blind spots, and head position during flight can affect collision risk for birds in flight (Martin 2011). For example, modeling of the visual field of vultures during foraging flights showed their vision is focused below them and vultures therefore are unable to readily perceive flight obstacles (Martin et al. 2012). Non-obligate scavengers have a blind sector above and behind the head (Potier et al. 2018), potentially increasing collision risk if the head is facing the ground during active foraging flight. Additional research is needed on visual perception in raptors and the influence of foraging behavior on collision risk during flight (Bernardino et al. 2018).

In summary, our study provides evidence Bald Eagles can successfully avoid transmission wires that intersect their regular movement corridors. Minimal collision risk could be attributed to acclimatization of eagles to a fixed flight obstacle or to increased visibility of wires from marking and bundling. Though annual collision estimates for transmission lines in North America are 2.5–57 million annually for all bird species combined (Rioux et al. 2013, Loss et al. 2014), collision risk for Bald Eagles appears to be low for both wintering (this study) and migrating eagles (Luzenski et al. 2016).

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Literature Cited

Amartuvshin, P., and S. Gombobaatar (2012). The assessment of high risk utility lines and conservation of globally threatened pole nesting steppe raptors in Mongolia. Ornis Mongolica 1:2–12.

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

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.

Church, K. J., S. Krych, A. Piner, and C. L. Schmidt (2014). Obtaining Bald and Golden Eagle Protection Act permits: A USFWS Region 3 Transmission Line Case Study. Environmental Concerns in Rights-of-Way Management 10th International Symposium, 30 September–3 October 2012, Phoenix, AZ (G. J. Doucet, Editor). Utility Arborist Association, Champaign, IL, USA. pp. 127–140.

Dwyer, J. F., A. K. Pandey, L. A. McHale, and R. E. Harness (2019). Near-ultraviolet light reduced Sandhill Crane collisions with a power line by 98%. The Condor 121(2):1–10. DOI:10.1093/condor/duz008.

Eakle, W. L., L. Bond, M. R. Fuller, R. A. Fischer, and K. Steenhof (2015). Wintering Bald Eagle count trends in the conterminous United States, 1986–2010. Journal of Raptor Research 49:259–268.

Eccleston, D. T., and R. E. Harness (2018). Raptor electrocutions and power line collisions. In Birds of Prey: Biology and Conservation in the XXI Century (J. H. Sarasola, J. M. Grande and J. J. Negro, Editors). Springer International Publishing, Cham, Switzerland. pp. 273–302.

EDM International (2014). Winter Monitoring Results at the Hogback Ridge Communal Bald Eagle Roost Site at Susquehanna – Roseland 500-kV Transmission Line (2013–2014). Unpublished report to PPL and PSE&G. EDM International, Inc. Fort Collins, CO, USA.

Eskom (2005). Transmission bird collision prevention guidelines. Eskom, Sandton, South Africa.

González, L. M., A. Margalida, S. Mañosa, R. Sánchez, J. Oria, J. I. Molina, J. Caldera, A. Aranda, and L. Prada

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(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.

Harness, R. E. (2008). Bald Eagle (*Haliaeetus leucocephalus*) electrocutions and artificial food sources in Alaska. In Environment Concerns in Rights-of-Way Management 8th International Symposium, 12–16 September 2004, Saratoga Springs, NY (J. W. Goodrich-Mahoney, L. P. Abrahamson, J. L. Ballard and S. M. Tikalsky, Editors). Elsevier, New York, NY, USA. pp. 383–387.

Harness, R. E., S. Milodragovich, and J. Schomburg (2003). Raptors and power line collisions. Colorado Birds 37:118–122.

Hurst, N. (2004). Corona Testing of Devices used to Mitigate Bird Collisions. Report 500-04-086F, EDM International, Inc. California Energy Commission, PIER Energy-Related Environmental Research, Sacramento, CA, USA. http://www.energy.ca.gov/reports/

Jenkins, A. R., J. 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.

Katzmire, J. L. (1989). The development of a wintering Bald Eagle population in the Delaware Water Gap National Recreation Area. M.S. thesis, East Stroudsburg University, East Stroudsburg, PA, USA.

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(7): e101565.

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.

Manosa, 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. (2011). Understanding bird collisions with man-made objects: A sensory ecology approach. Ibis 153:239–254.

Martin, G. R. (2012). Through birds' eyes: Insights into avian sensory ecology. Journal of Ornithology 153:S23–S48.

Martin, G. R., S. J. Portugal, and C. P. Murn (2012). Visual fields, foraging and collision vulnerability in *Gyps* vultures. Ibis 154:626–631.

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.

Olendorff, R. R., and R. N. Lehman (1986). Raptor Collisions with Utility Lines: An Analysis using Subjective Field Observations. Report to Pacific Gas and Electric Company, San Ramon, CA, USA. https://archive.org/details/raptorcollisions6801olen.

Potier, S., O. Duriez, G. B. Cunningham, V. Bonhomme, C. O'Rourke, E. Fernández-Juricic, and F. Bonadonna (2018). Visual field shape and foraging ecology in diurnal raptors. Journal of Experimental Biology 221:jeb177295.

Rioux, S., J.-P. L. Savard, and A. A. Gerick (2013). Avian mortalities due to transmission line collisions: A review of current estimates and field methods with an emphasis on applications to the Canadian electric network. Avian Conservation and Ecology 8(2):7.

Schomburg, J. W. (2003). Development and evaluation of predictive models for managing Golden Eagle electrocutions. M.S. thesis, Montana State University, Bozeman, MT, USA.

US Fish and Wildlife Service (2016). Eagle permits; revisions to regulations for eagle incidental take and take of eagle nests. Federal Register 81:91494–91554.

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.

Wheeler, B. K. (2003). Raptors of Eastern North America. Princeton University Press, Princeton, NJ, USA.

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