J. Raptor Res. 43(1):57–61

FACTORS CONTRIBUTING TO BALD EAGLE ELECTROCUTIONS AND LINE COLLISIONS ON ABERDEEN PROVING GROUND, MARYLAND

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KEY WORDS: *Bald Eagle*; Haliaeetus leucocephalus; *Chesapeake Bay*; *collision*; *eagle concentration area*; *electrocution*; *electrical line*; *mortality*.

Avian electrocution is a widespread conservation problem affecting many taxonomic groups worldwide (Bevanger 1998, Bayle 1999, Lehman et al. 2007). The specific biological and technical aspects of electrocution are well documented, particularly for raptors. Several factors influence the risk of bird electrocution or collision, including design of electrical poles and lines, weather, visibility, wingspan, and bird age and experience (Avian Power Line Interaction Committee [APLIC] 2006). Electrocution can occur when a bird perches on a crossarm and completes an electrical circuit with two or more body parts (APLIC 2006). Line collisions (birds flying directly into electrical lines) are increasingly documented as a cause of avian mortality (Olendorff and Lehman 1986, Bevanger 1994, Bevanger 1998, Bayle 1999). Birds die either from the impact of hitting the line or from electrocution when they contact two lines simultaneously and complete the electrical circuit (Harness et al. 2003).

Placement of electrical lines on the landscape is increasingly recognized as an important factor contributing to avian mortality (APLIC 1994, Bayle 1999, Schomburg 2003, APLIC and USFWS 2005, APLIC 2006, Lehman et al. 2007). Birds are more susceptible to line collisions if lines cross flight paths or movement corridors (Thompson 1978, Bevanger 1994). This could be compounded if vegetation surrounding the lines is not tall enough to reach the line, as with early successional habitat (Thompson 1978). A solid row of vegetation at or above the height of the line acts as a flight barrier to large birds, forcing flight paths above the electrical lines, thereby reducing the risk of collision (APLIC 1994, Bevanger 1994).

Our objective was to investigate the landscape factors that influence mortality of Bald Eagles (*Haliaeetus leucocephalus*) related to electrical lines. We hypothesized that line proximity to shoreline and surrounding vegetation height would affect the distribution of eagle mortality on the landscape. We suspected lines close to open water and not surrounded by vegetation would have the highest rates of electrocution and collision.

STUDY AREA

Our study was conducted on the U.S. Army's Aberdeen Proving Ground (APG) located on the shore of the upper Chesapeake Bay, Maryland (39°23′N, 76°13′W). Aberdeen Proving Ground is home to one of the largest concentrations of Bald Eagles on the east coast of North America (Watts et al. 2007). The property supports 42 resident pairs and seven known communal roosts used by migrants from the north and south during the winter and summer months respectively (Buehler et al. 1991, General Physics 2004, E. Mojica and B. Watts unpubl. data). This study focused on the Edgewood and Aberdeen areas of the installation (total ca. 16 000 ha). Shoreline habitat includes stands of mixed hardwoods, tidal marsh, human-maintained grasslands, and urbanized areas (Maryland Department of Natural Resources 2002).

The electrical infrastructure on Aberdeen Proving Ground is composed of three-phase distribution lines

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(≤40 kv) with three phases on a 6′ crossarm and one neutral line located 5′ below the energized wires (General Physics 2004, APLIC 2006). This pole configuration was not classified as ''avian-safe'' (APLIC 2006) and the wingspan of eagles is sufficient to touch multiple conductors and lines simultaneously (General Physics 2004). Of the approximately 1500 km of overhead lines on APG, 91 km run along shoreline areas, which are important foraging habitat for resident and migrant eagles (Buehler et al. 1991, General Physics 2004).

METHODS

We used records of dead or injured eagles to evaluate the influence of surrounding vegetation and proximity to shoreline on the likelihood that eagles would be killed by the electrical infrastructure. We initiated a database in 1985 to record the location and circumstances of eagle mortalities as part of the installation's Bald Eagle management plan. Data from 1985 to 2007 was included in this analysis. Dead or injured eagles were discovered during routine maintenance, but no systematic surveys were conducted. We included reports of carcasses in our analysis if the cause of the eagle's death was identified as electrocution through necropsy or examination, or if there was strong circumstantial evidence that death was due to the electrical infrastructure. We excluded from analysis any eagle with injuries unrelated to electrical lines or located outside of the main Edgewood or Aberdeen study areas of APG ($N = 15$). Reports of eagles whose death or injuries were associated with the electrical infrastructure were pooled for analysis ($N = 62$). We assumed that carcass detection rates were equal across the study area. We feel that this is a reasonable assumption because all lines were subject to regular maintenance and the majority of electrical lines parallel well-traveled roads with mowed grass beneath the lines.

We used a simple two-way design with proximity to shoreline and surrounding vegetation height to evaluate the influence of line characteristics on eagle electrocutions. We classified all electrical lines according to proximity to bay shorelines by overlaying shoreline buffers on an electrical line map using ArcMap 9.1 (E.S.R.I., Redlands, CA U.S.A.). We used three proximity categories including near shore (<300 m), mid-range (300 m–1000 m), and interior (>1000 m). We evaluated vegetation associated with electrical lines by visual inspection. We classified lines as ''exposed'' if there was no vegetation (except mowed grass) within 100 m of the lines, ''below'' if vegetation existed within the surrounding area but was lower than the height of the line, or ''concealed'' if vegetation within the surrounding area was even with or above the line height. We assumed APG staff maintained consistent vegetation heights around lines from 1985 to 2007 except where natural shoreline erosion kept vegetation low on areas of Spesutie Island and at the mouths of creeks where they entered the Chesapeake Bay. A majority (92%) of lines were within 100 m of heavily trafficked roads with 32–72 km/hr (25–45 m/hr) speed limits. A mowed grass corridor 3–10 m wide was maintained directly under the lines and aided in visual detection of dead or injured eagles.

We evaluated the influence of proximity to shorelines and vegetation on mortality by overlaying eagle electrocutions and collisions on electrical lines and grouping mortality events according to landscape characteristics surrounding the line. We compared the distribution of electrocutions according to proximity and vegetation categories with distributions expected based on the length of lines within these categories using χ^2 goodness-of-fit test. We hypothesized that eagle electrocutions and collisions were more likely to occur close to the shoreline as eagles sought perches near water. Because many of the mortalities were midline collisions, we also hypothesized that exposed lines may have a higher probability of being struck by flying eagles compared to concealed lines.

RESULTS

During 1985–2007, we documented 77 eagle mortalities and injuries on APG. We confirmed that 62 were directly related to the electrical infrastructure. Forty-five had visible signs of electrocution (burn marks on foot pads, bill, or feathers; $N = 24$;) or collision (feathers on lines directly above carcass, signs of blunt-force trauma; $N = 21$). We assumed an additional 17 eagles were killed after contacting electrical structures because they were found decomposed under an electrical line or pole. The single injury was witnessed by base staff and occurred when an eagle flew into a line and lay paralyzed on the ground after being shocked. We excluded eagle mortalities from disease ($N = 2$), intraspecific aggression ($N = 3$), nest tree collapse ($N = 2$), electrocution outside study area ($N = 3$), and unknown ($N = 5$). In addition to eagles, carcasses of an Osprey (*Pandion haliaetus*), owls, swans, and a Great Blue Heron (*Ardea herodias*) were found under electrical lines and poles.

Bald Eagle electrocutions and collisions on APG were not randomly distributed with respect to shoreline proximity or surrounding vegetation (Table 1). Significantly more detected mortality was associated with lines closer to shorelines compared to lines inland than was expected based on the relative line lengths ($\chi^2 = 119.71$, df = 2, $P < 0.001$). Lines falling within the near-shore and mid-range categories both accounted for a greater number of mortalities than expected based on the availability of line. In contrast, inland lines accounted for fewer mortalities than expected.

The characteristics of vegetation surrounding electrical lines had a significant influence on the likelihood that lines would be associated with mortality events ($\chi^2 = 11.54$, df = 2, $P < 0.005$). We documented a higher number of eagle deaths associated with exposed electrical lines than expected based on their relative lengths. The presence of vegetation appeared to significantly reduce mortality events. The likelihood of mortality was particu-

Table 1. Bald Eagle injuries and mortalities associated with electrical lines on Aberdeen Proving Ground, MD, 1985–2007. Mortality events were significantly higher than expected for exposed lines within 1 km of shorelines.

HABITAT VARIABLE	EAGLE MORTALITIES	ELECTRICAL LINE (km)	DEVIATION (%)
Vegetation height			
No vegetation (line exposed)	9	91.8	138
Vegetation below line	17	652.8	−37
Vegetation above line (line concealed)	36	758.7	15
Shoreline distance			
<300 m	16	75.0	417
300 m–1000 m	26	179.7	251
>1000 m	20	1248.6	−61

larly low when lines were concealed below the height of vegetation.

DISCUSSION

The location of electrical lines relative to both vegetation and the shoreline had a significant influence on Bald Eagle mortality patterns within APG. Detected mortalities were higher than expected along exposed lines with no vegetative cover than along lines partially or completely concealed by vegetation. Our findings supported the current view that vegetation shields the lines and forces flight paths safely above lines (APLIC 1994, Bevanger 1994). Mortalities were also higher than expected along lines within 1 km of the shoreline compared to those further inland. Eagles concentrate on shoreline habitat at APG to forage and perch (E. Mojica and B. Watts unpubl. data). Placement of lines within these high-use areas appears to increase the risk of eagle electrocutions and line collisions (Bayle 1999).

In addition to the general influence of vegetation height and shoreline proximity on eagle mortality, we believe that the placement of lines perpendicular to major flight lines contributed to mortality patterns within APG. This was illustrated by two areas on the installation where we documented relatively large mortality clusters. Exposed lines on Spesutie Island occurred between two communal roosts and a segment of shoreline that was heavily used for foraging and loafing. The shoreline vegetation on the island consisted of mid-successional trees and shrubs that were not preferred perching substrates. More than 48% of the installation's mortalities occurred here, over half of which were line collisions. This finding is consistent with other studies that have documented heavy mortality along lines that were placed between foraging and roosting habitat (Anderson 1978, Olendorff and Lehman 1986, APLIC 1994, Harness et al. 2003). A second mortality cluster occurred where a line was placed across the mouth of Watson Creek. This site accounted for 8.1% of the total mortalities. We believe that eagles used Watson and similar creeks as flight corridors between inland roosts and shoreline foraging areas.

Mortality studies can greatly underestimate mortality rates by using inadequate carcass detection methods (Thompson 1978). We did not systematically survey for carcasses. However, we believe that most eagle mortalities associated with the electrical infrastructure were documented. Within the APG, electrical lines generally run parallel and in close proximity to the roadways. Roadways are frequented by APG personnel several times per day at low vehicle speeds such that the likelihood of discovering a carcass is high. In addition, there is a heightened awareness of eagle mortalities on the property, which we believe increased the rate of detection. Although it is likely that some carcasses were not detected because they were removed by scavengers, and that some of the injured eagles were not counted because they were capable of moving away from lines (Thompson 1978, APLIC 1994); however, we do not believe that these circumstances represent systematic sources of bias that would invalidate the comparisons presented here.

Interactions between eagles and electrical lines can be expected to increase as additional lines are erected within eagle habitat (Anderson 1978, Newton 1979). However, raptor line collisions and electrocutions can be reduced on both new and existing facilities by using ''avian-safe'' construction designs and siting techniques (APLIC 1994, APLIC and USFWS 2005, APLIC 2006). Retrofitting existing poles with perches and guards was a successful mitigation technique at APG. Lines were fitted with orange balls and swinging plate diverters to increase line visibility (Harness et al. 2003, General Physics 2004). Even with these retrofitting measures, line collisions continued to occur at Spesutie Island, until the lines were moved underground.

The National Bald Eagle Management Guidelines recommend siting lines away from eagle foraging and roosting concentration areas (Thompson 1978, USFWS 2007). This would reduce the risk of exposing large numbers of eagles to the hazards of electrical lines, as would avoiding perpendicular placement of lines, particularly <1 km from shorelines. Vegetation height and distance to foraging and roosting areas may be important factors influencing line-related mortality at other eagle concentration areas in the Chesapeake Bay and throughout the species range. We recommend siting new power lines to minimize collision risk near eagle roosts, monitoring existing lines in eagle concentration areas, and retrofitting lines and poles as needed using accepted and effective methods (APLIC 1994, 2006).

FACTORES QUE CONTRIBUYEN A LAS ELECTROCUCIONES Y LAS COLISIONES CON LOS TENDIDOS ELÉCTRICOS DE *HALIAEETUS LEUCOCEPHALUS* EN ABERDEEN PROVING GROUND, MARYLAND

RESUMEN.—Evaluamos los factores que contribuyen a las electrocuciones y las colisiones con los tendidos eléctricos de *Haliaeetus leucocephalus* en Aberdeen Proving Ground, un área importante de concentración de águilas en la bahía de Chesapeake. Durante el período de 1985 a 2007, documentamos la ubicación de 62 águilas muertas o recuperadas heridas bajo tendidos eléctricos. Usando un diseño de dos vías simple, superpusimos la mortalidad de las águilas sobre segmentos del tendido, clasificados por su proximidad a la costa y por la altura de la vegetación circundante. Documentamos una mortalidad significativamente mayor asociada con los tendidos más cercanos a la costa comparada con los tendidos del interior que lo esperado con base en la longitud relativa del tendido ($\chi^2 = 119.71$, gl = 2, $P < 0.001$). Adicionalmente, el número de muertes de águilas asociado con los tendidos expuestos (sin vegetación que los oculte) fue mayor que el esperado con base a la longitud relativa del tendido ($\chi^2 = 11.54$, gl = 2, $P < 0.005$). La presencia de vegetación circundante a los tendidos eléctricos parece reducir significativamente los eventos de mortalidad. Los tendidos eléctricos a menos de 1 km de la costa y descubiertos de vegetación representan un riesgo significativo para las águilas. Recomendamos monitorear sistemáticamente los tendidos de alto riesgo en las áreas conocidas de concentración de águilas para determinar la necesidad de esfuerzos de mitigación.

[Traducción del equipo editorial]

ACKNOWLEDGMENTS

This work was funded by the U.S. Army. We thank the many Army personnel and game wardens who documented carcasses. Three anonymous reviewers provided comments and suggestions that improved the manuscript.

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Received 20 October 2007; accepted 15 October 2008
Associate Editor: James W. Watson