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POTENTIAL NEGATIVE EFFECTS OF COLLISIONS WITH TRANSMISSION LINES ON A BONELLI'S EAGLE POPULATION

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ABSTRACT.—The Bonelli's Eagle (*Hieraaetus fasciatus*) population decline in Europe has mainly been attributed to high levels of anthropogenic mortality. We evaluated the potential negative effects of collisions with transmission lines on a breeding population of Bonelli's Eagles in Catalonia, Spain. Between 1990–97, two of the 12 recorded deaths of breeding Bonelli's Eagles were caused by collisions with transmission lines. All transmission lines within a 5-km radius of 47 eagle nests were classified into two collision risk categories (low or high), depending on their locations and habitats. Pairs having high risk lines within 1 km of nesting territories had turnover rates twice as high as pairs with no such lines (0.16 ± 0.11 [±SD] vs. 0.08 ± 0.10). Greatest turnover rates were observed when high-risk lines occurred within 100 m of nesting territories. Our results suggest that transmission lines near Bonelli's Eagle nesting territories constitute a risk for eagles due to the danger of collisions. New transmission lines should avoid crossing areas near nesting territories and, as a precaution, those that are <1 km from eagle nests should be marked in some way.

KEY WORDS: *Bonelli's Eagle*; Hieraaetus fasciatus; *collision*; *conservation*; *endangered species*; *powerlines*.

Posible efecto negativo de la colisión con líneas de transporte eléctrico en una población de águila perdicera

RESÚMEN.—El declive del águila perdicera (*Hieraaetus fasciatus*) en Europa ha sido atribuido en parte a una elevada mortalidad de origen antrópico. Evaluamos el posible efecto negativo de la colisión con tendidos de transporte eléctrico en la población de águilas en Cataluña (España). Entre 1990–97, dos de las 12 muertes de águilas sobre las que se obtuvo información fueron causadas por la colisión con estos tendidos. Cada tramo de tendido situado en un radio de 5-km alrededor de 47 nidos se clasificó en dos categorías de peligrosidad (baja o alta), dependiendo de su localización y de las características del hábitat. Las parejas con tramos de alta peligrosidad a <1 km del nido presentaron tasas de recambio dos veces más altas que el resto de las parejas (0.16 ± 0.11 [±SD] vs. 0.08 ± 0.10). El efecto mayor se observó cuando las líneas transcurrían a <100 m de los nidos. Los resultados sugieren que la presencia de estas líneas cerca de los nidos podría constituir un riesgo para las águilas, quizás asociado al peligro de colisión. Los nuevos trazados deberían evitar las zonas cercanas a los nidos y los tendidos ya existentes a <1 km de los mismos deberían señalizarse.

[Traducción de Autores]

Casualties caused by powerlines result in the deaths of thousands of birds in the world each year (Bayle 1999). Electrocution on pylons appears to be the major cause of mortalities, but collisions with wires also cause many bird deaths (APLIC 1994, Bevanger 1994, 1998, Bevanger and Overskaug 1998). While electrocutions have been studied (Olendorff et al. 1981, Negro et al. 1989, Ferrer et al. 1991, APLIC 1994), the complex nature of collisions, as well as methodological and practical constrains, have limited our understanding of this problem (Bevanger 1994, Henderson et al. 1996). Although bird collisions are common on distribution lines that carry <66 kV (Brown and Drewien 1995, Fernández-García 1998), they seem to occur mostly on the larger >110 kV transmission lines and are probably related to the greater number of conductors, presence of earth wires, higher tower heights, and larger distances between poles (Fernández-García 1998). For these reasons, most of the research on bird collisions has focused on these high voltage transmission lines (Beaulaurier 1981, Alonso et al. 1994, Savereno et al. 1996).

Studies evaluating the impacts of collisions on bird populations are most often conducted by means of systematic searches under wires (Alonso et al. 1994, Savereno et al. 1996, Janss and Ferrer 1998). Most of these studies have found high numbers of waterbirds, gamebirds, storks, and cranes dead under transmission lines, but very few birds of prey have been reported (Alonso et al. 1994, Bevanger 1995, 1998, Savereno et al. 1996, Janss and Ferrer 1998, Bayle 1999). As a result, raptors are generally considered less susceptible to collisions with overhead wires than other groups of birds (APLIC 1994, Alonso et al. 1994, Fernández-García 1998, Alonso and Alonso 1999). The decreased susceptibility of raptors to collisions has been attributed to their acute vision and flight performance as well as their solitary habits and low population densities (R.E.E. 1993, APLIC 1994, Bevanger 1994). While the number of collision accidents involving birds of prey might be low, the conservation significance of such accidents can be high, especially when a species is endangered. In such a situation, reporting of a few deaths may be relevant enough to justify research on the effects of collisions at the population level (Bevanger 1998, Alonso and Alonso 1999) and the implementation of mitigation actions (APLIC 1994, Bevanger and Overskaug 1998).

The decline of the Bonelli's Eagle (*Hieraaetus fasciatus*) in Europe (del Hoyo et al. 1994, Real et al. 1994, Rocamora 1994) has been attributed to several factors including habitat loss and high adult and juvenile mortality. Demographic studies indicate that adult mortality (3.93–16.09% annual mortality rate) is the main cause of the population decline (Real and Mañosa 1997). Depending on the region, powerlines have been reported as responsible for 8–100% of the deaths of breeding eagles (Real and Mañosa 1997). Collisions of Bonelli's Eagles with powerlines have been reported by several authors (Real and Mañosa 1997, B. Arroyo and V. Garza unpubl. data), which suggests that the presence of transmission lines near nesting territories poses a potential danger to breeding Bonelli's Eagles. This danger has never been thoroughly evaluated because of difficulties associated with the estimation of casualty rates (Bevanger 1998) and the lack of demographic data concerning wild populations (Henderson et al. 1996). For Bonelli's Eagles, systematic searches under wires have been considered impractical due to the terrain and thick vegetation found in their nesting territories. To overcome such constraints, we undertook a different approach to evaluate the effects of powerline collisions on the population dynamics of the species. Our aim was to compile existing information on collisions of Bonelli's Eagles with transmission lines in Catalonia as a qualitative indication of the importance of collision casualties and to analyze the relationship between the presence of transmission lines in Bonelli's Eagle nesting territories and site-specific turnover rates.

STUDY AREA AND METHODS

The study was carried out in the littoral and prelittoral mountain ranges in Catalonia, northeastern Spain, where an estimated 70 Bonelli's Eagle pairs, approximately 10% of the European breeding population, are scattered over a 8000 km^2 area (Mañosa et al. 1998). Information was compiled on the causes of death (i.e., electrocution, collision with transmission lines, shooting, other, unknown) of Bonelli's Eagles that either we found dead or were received by rehabilitation centers and wildlife agencies in the area between 1990–97. Mortality was classified into two categories (collision with transmission lines and other) and birds into two status categories (breeding birds [adult or subadult birds found within a breeding area] and nonbreeding birds [all juvenile or immature birds, and subadult or adult birds found in a nonbreeding area]). During the last decade, the Catalan population of Bonelli's Eagles has been monitored to estimate site-specific turnover rates. Between 1990–97, nest sites have been checked every year for the presence of breeders and breeding individuals have been classified as young (<1 yr old), immature (1–2 yr old), subadult (2–3 yr old), and adult (>3 yr old), according to the plumage criteria (Parellada 1986). An estimate of the site-specific turnover rate of breeding birds was computed for 47 nesting territories in which at least 5 yr of monitoring data were available. The general computation procedure for turnover rate followed the method used by Real and Mañosa (1997) to estimate survival rates. At the start of every breeding season, we checked every territory and recorded if a breeding bird had disappeared or had been replaced by a younger bird. Birds were not marked and turnover was judged based on plumage characteristics which changed with age (Parellada 1986). This method gave a minimum estimate of turnover rate, since some changes in adult plumage would not have been detected. Because Bonelli's Eagles have high mate and site fidelity (Cheylan 1972, Cramp and Simmons 1980), we assumed that replacement or disappearance of

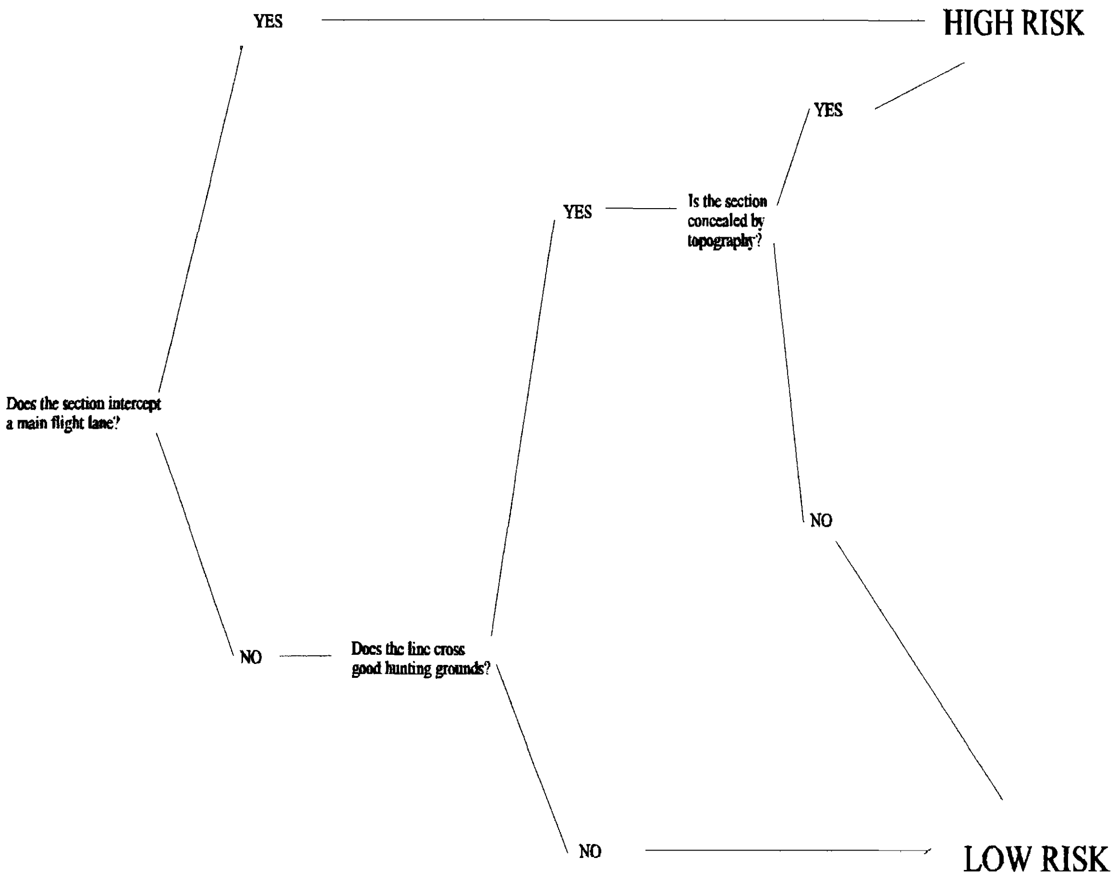

Figure 1. Decision rules followed to assign collision risk indexes to sections of transmission lines in the study area

breeders in territories was due to mortality within the territory, although some might have been caused by desertions or movement to other areas. To reduce the possibility of overestimating turnover rates in territories that were deserted, and to eliminate autocorrelation between high site-specific turnover rates and territory desertion, disappearances that resulted in site desertions were not considered in the calculations of site-specific turnover rates. Turnover rate for a given site was computed as the total number of individuals that were replaced or disappeared in relation to the total number of individuals and years considered.

Breeding areas were classified as having low turnover rates (i.e., only one change recorded during the study period or, if more, a turnover rate ≤0.10) or high turnover rates (i.e., more than one change recorded during the study period and a turnover rate >0.10).

Collision risks on a transmission line depends on the habitat characteristics and topographical features crossed by the line in relation to the behavior and habitat requirements of the target species (APLIC 1994). We visited every known Bonelli's Eagle breeding territory and plotted them on 1· 50 000 topographic maps showing transmission lines (110–400 kV) within a 5-km radius of every nest. Based on our knowledge of eagle behavior, we estimated the main flight paths of eagles and predicted which sections of transmission lines were more likely to be crossed by eagles regularly and posed the greatest collision threats. A total of 960 km of transmission lines were plotted, which were subsequently divided into segments of variable length, each one being classed as a High Collision Risk segment or Low Collision Risk segment by means of a decision tree (Fig. 1) which took into account whether (1) a given section of line crossed a "flight path" (Bevanger 1994) that eagles presumably followed in their nesting territories on a regular basis, (2) if a section of line crossed areas suitable for eagle hunting, and (3) if a section was concealed by topographic features.

Based on our experience, eagles typically fly along lines that follow nest cliffs and slopes, and cross mountain passes. We classified habitats under lines as either good for hunting (i.e., open forest, ecotones, bush and shrubs, traditional nonirrigated farmland) or not good for hunting (i.e., extensive woodland areas, compact urban areas, irrigated land, intensive irrigated farmland) (del Hoyo et al. 1994). Finally, sections of lines found in good hunting habitats were considered as being concealed by topographic features when they were behind mountain ridges or mountain passes, or in places where they did not stand out against the background. No consideration was made about powerline design because all of them had earth wires which are considered to be the main source of bird collisions in transmission lines (APLIC 1994).

The following variables of collision risk were measured within 0–1 km, 1–3 km, and 3–5 km radii of every nesting site: LR01—km of Low Collision Risk lines <1 km away, LR13—km of Low Collision Risk lines 1–3 km away, LR35—km of Low Collision Risk lines 3–5 km away, HR01—km of High Collision Risk lines <1 km away, HR13—km of High Collision Risk lines 1–3 km away, HR35—km of High Collision Risk lines 3–5 km of nest, T01—total km of transmission lines within <1 km of nesting territory, T13—total km of transmission lines 1–3 km of nesting territory, and T35—total km of transmission lines 3–5 km of nesting territory.

Turnover rates were correlated to collision-risk variables using Spearman rank correlation coeficients. Bonferroni adjustment for multiple test comparisons (Rice 1989) were conducted in multiple Spearman rank correlation tables (Table 1). Corrections where made considering three test families of size = 3 and adopting a global experiment-wise error of 0.1, following the indications of Chandler (1995). As a consequence, we set critical P-values for individual tests at 0.03. Mann-Whitney U tests were used to compare turnover rates between sites having transmission lines and those without them. When these comparisons were made for distances of 1–3 km and 3–5 km, sites having powerlines at shorter distances were excluded.

Table 1. Spearman rank correlation coefficient between turnover rates and the amount of Low Collision Risk transmission lines (LR), High Collision Risk transmission lines (HR), and Total transmission lines (T) present at increasing radii from Bonelli's Eagle nesting territories (N = 47 sites).

	r_s	P
LR01	0.11	0.47
LR13	0.03	0.83
LR35	0.16	0.27
HR01	0.33	0.02
HR13	0.02	0.91
HR35	0.02	0.87
T01	0.26	0.08
T13	0.03	0.81
T35	0.16	0.28

Kruskal-Wallis tests were used to compare average turnover rates between sites having High Collision Risk transmission lines at increasing distances from nests.

RESULTS

During the 7-yr study, a total of 502 individuals were monitored in 47 nesting territories. We recorded a minimum of 44 changes in breeding individuals, or turnovers of adults, at 27 nesting territories. At three of these territories, where 36 individuals had been monitored and 7 changes were observed, we actually found three dead eagles. Nine more eagles were reported dead in the study area, that could not be related to specific nesting territories. Of the 12 eagles found dead, collision with transmission lines was the cause of death of 2 (17%). Six (50%) died by electrocution, 3 (25%) were shot, and one died of unknown causes. Both Bonelli's Eagles that collided with transmission lines were males. One was found in March 1993, freshly dead under a 110-kV transmission line with its jaw and wing broken 900 m from a nest. The second dead eagle was found under a 400-kV transmission line in November 1994 with a broken wing, only 100 m from its nest. Neither bird appeared to be shot and lead pellets were not found in their bodies. We classified the section of transmission line where the first mortality occurred as Low Collision Risk and the second mortality occurred on a section of transmission line classified as High Collision Risk.

Annual turnover rates at nesting territories ranged from 0.00–0.40 ($\bar{x}$ = 0.10 ± 0.11, ±SD, N = 47). Median turnover rate was 0.07 and 25% of territories showed turnover rates >0.14. Site-specific turnover rates were positively correlated with the length of High Collision Risk transmission lines <1 km from the territory (Table 1). Territories having the greatest amount of High Collision Risk lines within a radius of 1 km showed significantly higher turnover rates (0.16 ± 0.11, N = 10) than those not having High Collision Risk lines (0.08 ± 0.10, N = 37) (Mann-Whitney test, U = 100.0, P = 0.02). For territories having High Collision Risk lines 0–1 km (turnover rate = 0.16 ± 0.11, N = 10), 1–3 km (turnover rate = 0.09 ± 0.13, N = 10), and 3–5 km (turnover rate = 0.04 ± 0.07, N = 10) away from nesting territories, turnover rates decreased significantly as lines occurred farther away (Kruskal-Wallis tests, χ^2 = 8.05, df = 2, P = 0.018). For the 10 nesting territories with High Collision Risk lines <1 km away, all of the sites with High Collision Risk transmission lines <100 m away had high turnover rates ($\bar{x}$ = 0.28 ± 0.02, N = 4). Only one of the six territories with transmission lines >100 m away had a high turnover rate ($\bar{x}$ = 0.11 ± 0.09, N = 6) (Fisher exact test, P = 0.024).

DISCUSSION

Although much more emphasis has been placed on the importance of electrocution on the mortality of birds of prey (Bevanger 1994, 1998), collisions between raptors and powerlines are known to cause high mortalities in such large and endangered species as the California Condor (*Gymnogyps californianus*) (Snyder and Snyder 1989). Our results show that, after electrocution and shooting, collisions by breeding eagles with transmission lines is the third most important cause of nonnatural mortality in Bonelli's Eagles in Catalonia causing as much as 17% of deaths in the population. Assuming an average annual mortality rate of 10% (Real and Mañosa 1997), collisions with powerlines causes 1.7% of the annual mortality in the population. In view of the fact that the annual adult mortality rate must not exceed 2–6% for the population to remain at equilibrium (Real and Mañosa 1997), our estimate indicates that collisions with powerlines poses a serious threat to the population.

Transmission lines near nests were associated with high site-specific turnover rates, which may indicate that they cause the deaths of adults when they collide with wires. Other studies have shown similar results for birds in the vicinity of powerlines (Bevanger 1995). Although eagles may become familiar with transmission lines within their territories (APLIC 1994), the need for them to increasingly cross powerlines near nests during the nesting season apparently increases their risk of collisions, particularly in bad weather or while hunting (APLIC 1994).

Other potential causes of mortality associated with transmission lines but not caused by collisions, such as the presence of access roads, increased human disturbance, shooting, habitat humanization, and reduced prey availability, did not appear to be important because the transmission lines typically crossed areas that were inaccessible to people and not inhabited. The fact that turnover rates were related to the amount and proximity of High-Collision Risk transmission lines, but not the total length of transmission lines within the territory, indicated that turnover was the result of a direct collision danger to eagles rather than to reduced habitat quality or higher interferences in areas crossed by powerlines.

Given the danger of transmission lines near Bonelli's Eagle nesting territories, new transmission lines should be constructed so that they avoid crossing <1 km of an eagle territory. In addition, all existing transmission lines within a radius of 5 km of a Bonelli's Eagle nesting territory should be carefully checked, evaluated for risk, and adequately marked if they interfere with flight paths of breeding eagles. Site-specific monitoring should follow these mitigation actions to confirm any potential reduction in mortality. More research is needed on the habitat use and behavior of Bonelli's Eagles to better evaluate the risks posed by specific sections of transmission lines, both near nests and in hunting areas, where collisions may also occur.

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