Rate of Bird Collision with Power Lines: Effects of Conductor-Marking and Static Wire-Marking (Tasa de Choques por Parte de Aves con Líneas del Tendido Eléctrico: Efecto de Marcadores de Conducción y Marcadores de Estática)

Author(s): Guyonne F. E. Janss and Miguel Ferrer
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RATE OF BIRD COLLISION WITH POWER LINES: EFFECTS OF CONDUCTOR-MARKING AND STATIC WIRE-MARKING

GUYONNE F. E. JANSS AND MIGUEL FERRER

Consejo Superior de Investigaciones científicas
Estación Biologica de Doñana
Av. de Maria Luisa s/n, Pabellón de Perú, 41013 Sevilla, Spain

Abstract.—The number of birds killed (per km) by collision with power lines in west-central Spain did not differ between one transmission line and two distribution lines. For all three power lines, we tested the ability of different markers to reduce bird collision by comparing marked spans to unmarked spans along the same power line. A spiral (30 cm × 100 cm) reduced collisions (static wire marking). Black crossed bands (35 cm × 5 cm) were also effective, but not for the vulnerable Great Bustard (*Otis tarda*) (conductor marking). The third marker, consisting of thin black stripes (70 cm × 0.8 cm), did not reduce mortality (conductor marking). The highest mortality from power-line collision was recorded for the Great and Little Bustard (*Otis tarda* and *Otis tetrax*).

TASA DE CHOQUES POR PARTE DE AVES CON LÍNEAS DEL TENDIDO ELÉCTRICO: EFECTO DE MARCADORES DE CONDUCCIÓN Y MARCADORES DE ESTÁTICA

Sinopsis.—No se encontró diferencia, entre el número de aves muertas (por kilómetro) causado por choques con líneas del tendido eléctrico entre torres con una o dos líneas de distribución de alto voltaje. Para diferentes tipos de arreglos de líneas eléctricas se utilizaron diferentes marcadores a diferentes distancias para determinar su efecto en la tasa de choques. Un espiral (30 × 100 cm) redujo los choques. Bandas negras transversales (35 × 5 cm) fueron efectivas para las aves con la excepción de *Otis tarda.* El tercer tipo de marcador, que consistió de bandas largas pero finas (70 × 0.8 cm) no redujo la mortalidad de las aves. La mortalidad más alta debido a las choques recayó en *Otis tarda* y en *O. tetrax.*

Collision with power lines is considered an important cause of death for some species of birds (Crivelli et al. 1988, Fiedler and Wissner 1980, Morkill and Anderson 1991). For most species involved in collisions, however, death rate at the population level is low (Beaulaurier 1981, Brown 1993, Faanes 1987, Hugie et al. 1993). Nevertheless, for rare or declining species power-line mortality can be an important concern for wildlife managers.

Over the years various marking schemes to reduce bird collisions with power lines have been published. Regretfully, many studies lack a convincing statistical treatment of data, in some studies probably due to the brief record of collision casualties (Beaulaurier 1981, Heijnis 1980, Koops and de Jong 1982). Only recently have rigorous studies been designed to test power line markers (Alonso et al. 1994, Brown and Drewien 1995, Morkill and Anderson 1991).

In this study, the number of collision casualties was recorded under three power lines, one transmission line with static wires (small, non-conducting, wires above the transmission line to intercept lightning) and two distribution lines without static wires. Subsequently, at each power line a different type of line marker was installed to test its ability to diminish mortality. The purpose of our analysis was to quantify the mortality

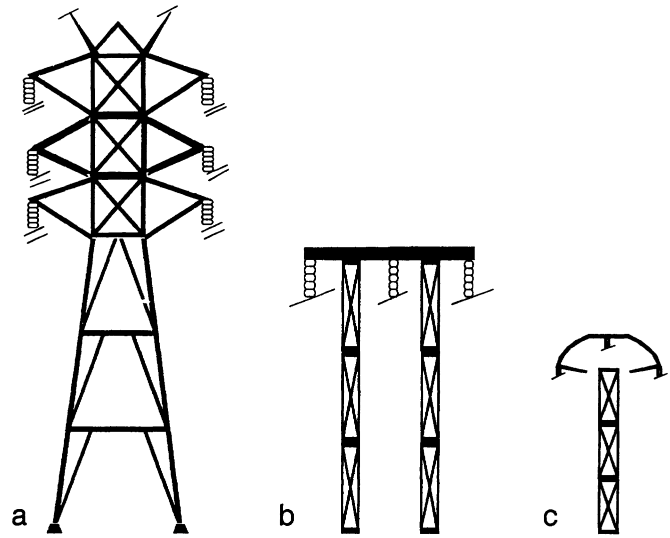

FIGURE 1. Tower design of the power lines studied for collisions.

recorded for the three power lines and to evaluate the effect of the three markers.

METHODS

Study areas and power lines.—The first power line (A) selected was a transmission line of 380 kV, double circuit with six duplex conductors forming three cable levels and with two overhead static wires (Fig. 1a). The distance between towers was about 500 m, and the towers were about 40-m high. Eight consecutive spans (4.5 km of power line) were studied. Power line A crossed a cultivated area with partial scrubland, grassland, and cereal crops in west-central Spain (39°20′N, 5°11′W, Badajoz). In this area the Common Crane (*Grus grus*) overwintered in great numbers and was considered a target species for this study; some waterfowl and White Storks (*Ciconia ciconia*) were also present in the area.

The second power line (B) selected was a distribution line of 132 kV, without static wires, simple circuit, with the three conductors on the same level (Fig. 1b). The towers, about 20-m high, were separated by 250 m. Fifteen consecutive spans were studied, totalling 3.9 km. Power line B crossed an area where one of the densest Spanish populations of the vulnerable Great Bustard (*Otis tarda*) was present (3 birds/km^2 in winter; Blanco and González 1992), an extended cultivated area in west-central Spain used for cattle-grazing and for cereal cultivation (39°25′N, 6°11′W, Cáceres). Also present in this area were the Little Bustard (*Otis tetrax*), the White Stork, and the Lapwing (*Vanellus vanellus*).

The third power line (C) was a distribution line of 13 kV, without static wires, simple circuit, with the three conductors practically at the same level (Fig. 1c). Tower separation was about 100 m, and tower height 9 m. Ten consecutive spans were checked for collision casualties (1.2 km of power line) in a protected river delta in southwest Spain with an important waterfowl population (37°14′N, 7°W, Huelva). The Greater Flamingo (*Phoenicopterus ruber*) was believed to be the most collision-vulnerable species in the area.

Searches for collision casualties.—Two persons searched on foot for dead birds underneath the power lines (an approximately 75-m wide zone centered along power line A and B, and a 40-m wide zone under line C). All bird remains (feathers, wings, etc.) were considered to be the result of collisions and were recorded as one casualty if no clear evidence was present that the remains belonged to more than one individual. During the surveys all bird remains were removed from the area to prevent double counting on subsequent searches.

Wire markers.—On Line A, white polypropylene spirals (1-m long, 30-cm maximum diameter, Fig. 2a) were rolled around the two static wires every 10 m, staggered between the static wires (producing a visual effect of a 5-m marking). On Line B, the marker consisted of two neoprene black crossed bands (35 cm × 5 cm) and a phosphorescent stripe (5 cm × 4 cm) fixed on an plastic peg (Fig. 2b). These pegs were fixed on the conductors every 20 m, staggered between the lateral conductors (producing a visual effect of a 10-m marking). Markers installed at Line C were a set of three thin plastic black stripes (70 cm × 0.8 cm, figure 1c) hanging every 12 m from the central conductor (Fig. 2c).

Study design.—The study was carried out over more than four years and consisted of two study periods. In the first period (1991–1993), no markers were placed on the study spans, and surveys for collision casualties were executed as follows. At Line A, seven surveys were conducted at 2-mo intervals, from February 1992–February 1993. At Line B, four surveys were conducted at 2-mo intervals (August 1992–March 1993) and four surveys were done monthly from July–October 1993. At Line C, seven surveys were conducted every 2 mo from August 1991–August 1992.

In the second period (1993–1995), line markers were erected in some of the study spans, while other study spans remained without markers. The markers were placed on alternate study spans, such that each marked span had an adjacent unmarked span. Some spans studied during the first period were left out of the surveys in the second period (Line A, one span; Line C, two spans). Under these spans no birds were found, and they were located at the ends of both study lines. Surveys for collision casualties were conducted monthly during the second study period, totalling a minimum of 13 searches in each area. At Line A, the surveys in the second period started in February 1994 and continued until February 1995 (13 searches) and involved three marked spans and four unmarked ones. At Line B, thirteen searches were carried out from December 1993–December 1994, including seven marked and eight unmarked spans. Under this line, complementary surveys were carried out during three consecutive months from June–August 1995. At Line C, surveys of four

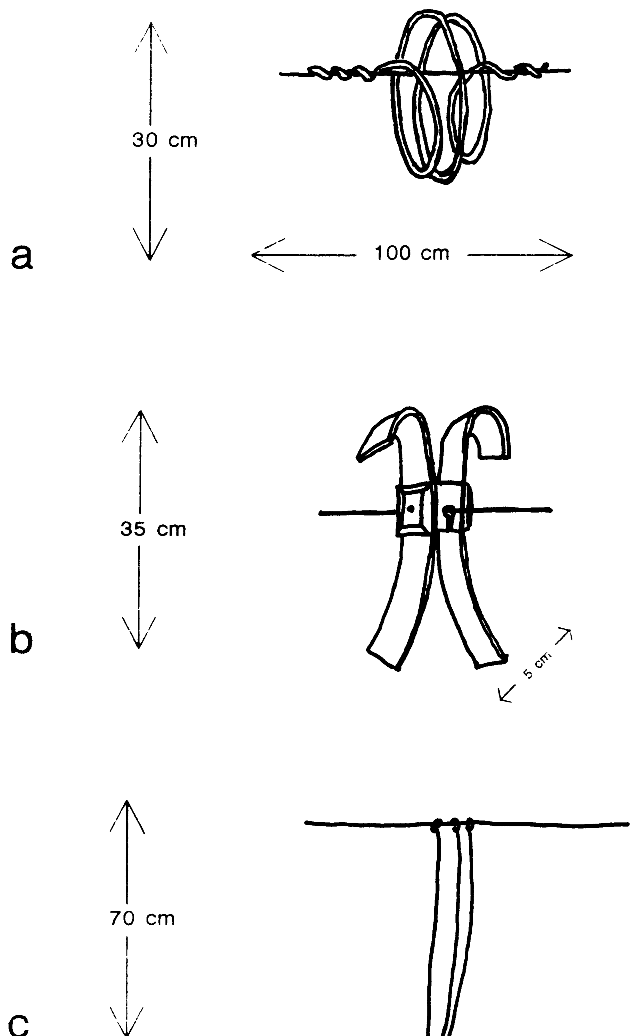

FIGURE 2. The three different wire markers studied: a. White spiral on static wire (30 cm × 100 cm), b. Black crossed bands on conductors (35 cm × 5 cm), and c. Black stripes on conductors (70 cm × 0.8 cm).

marked and four unmarked spans were conducted from August 1993–November 1995 (16 searches). In order to synchronize the time elapsed between surveys, the first survey at the beginning of the first period, and the first survey at the beginning of the second study period were omitted from analysis.

Data analysis.—The number of casualties per km and per survey for each of the three study lines were compared with a Kruskall-Wallis test, using all data from the first period and data for unmarked spans during the second period. The effect of markers was tested with one-tailed Fisher's exact test (Wells & King 1980) on collision frequencies for the "to be marked" and "to be unmarked" spans in the first period, and the marked and unmarked spans in the second period (2 × 2 table). Reduction in mortality was calculated from an expected mortality in the marked spans, assuming that the proportion of collisions from the spans "to be marked" and the spans "to be unmarked" in the first study period was the same in the second period. Statistical analyses were performed using the Statgraphics package (Manugistics 1992).

RESULTS

Collision rates.—In all, 150 casualties were found during the study, 64 of them during the first study period (under 9.6 km of power line), and 86 during the second period (60 in 4.6 km of unmarked lines, and 26 under 3.8 km of power lines equipped with markers). A total of 26 different species was found; Gruiformes (particularly Otidae) were the most common victims. Great and Little Bustards (*Otis tarda, Otis tetrax*) represented 15.3% and 17.3%, respectively, of all bird remains (Table 1). *Anas* spp. (8%) and Lapwings (*Vanellus vanellus*) (6.7%) were the only two species recorded under all three lines. Birds of prey were represented by only one individual (Table 1).

Line C had the greatest frequency of collisions (2.95 birds/km), followed by Line A (0.96) and B (0.84). No statistical differences could be detected among the three power lines in collision frequency per survey ($H = 0.2994$; $df = 2$; $P = 0.86$). A confounding effect could have been caused by the different survey frequency applied in the different study lines. Therefore, we repeated the analysis for only the second study period (when all surveys were conducted monthly). Frequencies of collisions in Line A, B, and C were 1.25, 0.65 and 2.50, respectively. No differences were detected among lines ($H = 0.333$; $df = 2$; $P = 0.847$).

White spirals.—The low number of individuals per species and the variety in species between the consecutive study periods did not permit an analysis for each species. White spirals reduced mortality when all species were considered (Fisher's exact; $P = 0.0198$, $n = 43$; Table 2). The results for Common Cranes were convincing (eight under unmarked spans, one under a marked span), but not significant (Fisher's exact; $P = 0.0518$, $n = 9$). The reduction in mortality for all birds was 81% (total mortality expected = 47.3, total mortality observed = 9).

Crossed bands.—Under Line B, two species dominated the casualties, Great and Little Bustards ($n = 72$; 67% of all birds found; Table 2). The total number of birds under marked spans was significantly less than unmarked spans after 12 searches (Fisher's exact; $P = 0.049$, $n = 54$). However, the Great Bustard was found only twice in these 12 mo, once under a marked and once under an unmarked span. Three more searches were done in summer 1995, but no statistical analysis could be obtained for

TABLE 1. Total number of species found per study line (A, B, C) for both study periods.

Species	A	B	C	Total
Ciconiformes				
Bubulcus ibis (Cattle Egret)	1	1		2
Ciconia ciconia (White Stork)	2	4		6
Phoenicopteriformes				
Phoenicopterus ruber (Greater Flamingo)			6	6
Anseriformes				
Anas platyrhynchos (Mallard)		2	2	4
Anas spp. (Dabbling ducks)	4	4		8
Falconiformes				
Falco tinnunculus (Kestrel)	1			1
Gruiformes				
Gallinula chloropus (Common Moorhen)		1		1
Fulica atra (Coot)			1	1
Grus grus (Common Crane)	13			13
Tetrax tetrax (Little Bustard)	1	25		26
Otis tarda (Great Bustard)		23		23
Charadriiformes				
Burrhinus oedicnemus (Stone Curlew)		1		1
Calidris spp.			4	4
Vanellus vanellus (Lapwing)	4	5	1	10
Himantopus himantopus (Black-winged Stilt)			1	1
Tringa totanus (Redshank)			1	1
Larus ridibundus (Black-headed Gull)			1	1
Chlidonia niger (Black Tern)			15	15
Columbiformes				
Columba palumbus (Woodpigeon)	5			5
Passeriformes				
Erithacus rubecula (Robin)		1		1
Turdus merula (Blackbird)	1			1
Phylloscopus spp.		2		2
Sylvia atricapilla (Blackcap)	3			3
Regulus ignicapillus (Firecrest)	1			1
Corvus corax (Raven)	1			1
Sturnus unicolor (Spotless Starling)	2			2
Passer domesticus (House Sparrow)	1			1
Emberiza calandra (Corn Bunting)	1	1		2
Unidentified	2	2	3	7
Total	43	72	35	150

the Great Bustard: five in marked and two in unmarked spans (Table 2). With the addition of these three searches, markers had no effect (Fisher's exact; $P = 0.080$, $n = 72$; Table 2). Leaving the Great Bustard out of the analysis, a positive effect of the marker was shown (Fisher's exact; $P = 0.02$, $n = 49$). The reduction in mortality for all birds ob-

TABLE 2. Number of casualties recorded per study span during the first and second study period. Study spans are identified as unmarked (U) or marked (M). Markers were put in place between the first and second periods. For line B, records are given with and without Great Bustards included.

Spans		Line A		Line B (without *Otis tarda*)		Line B (with *Otis tarda*)		Line C	
		First	Second	First	Second	First	Second	First	Second
1	U			1	2	1	0	0	1
2	M	0	—	4	1	0	2	1	2
3	U	0	3	3	3	1	0	0	7
4	M	1	4	0	2	2	2	0	2
5	U	0	10	1	1	0	2	0	2
6	M	5	2	2	0	2	0	0	1
7	U	2	7	2	5	2	0	16	2
8	M	3	3	1	1	0	1	0	1
9	U	2	1	0	3	1	0	0	—
10	M			0	0	2	0	0	—
11	U			0	4	0	0		
12	M			1	0	0	0		
13	U			2	1	0	0		
14	M			1	2	0	0		
15	U			0	6	5	0		
Total	U/M	4/9	21/9	9/9	25/6	10/6	2/5	16/1	12/6

tained with the crossed bands was 76% (mortality expected = 25, mortality observed = 6).

Black stripe.—After fifteen searches, there was not a significant reduction in mortality attributable to this marker (Fisher's exact; $P = 0.052$, $n = 35$; Table 2). This result approaches significance, but actually indicated a tendency for less mortality in the unmarked spans. In Line C, the number of casualties in the "to-be-unmarked" spans was high due to a group of 15 Black Terns (*Chlidonia niger*) found on one survey (Tables 1, 2). This event influenced considerably the probability calculated with the Fisher's exact test. Therefore, we repeated the analysis with data only from the second period, using expected values. This analysis also suggested that this marker did not reduce casualties ($\chi^2 = 2.00$; df = 1; $P = 0.157$).

DISCUSSION

Study design.—We compared two consecutive time periods and tested for an equal distribution of casualties for marked and unmarked spans. Biases that could influence the mortality rate between marked and unmarked spans (e.g., scavenger bias or habitat bias; Hugie et al. 1993, Brown and Drewien 1995) should vary equally between study spans during the two study periods. We accept that errors due to the assumption that all birds were victims to collision, should be the same for marked and unmarked spans.

Collision rates.—Victims of power-line collisions in the present study have been reported previously to be subject to striking power lines (Alonso et al. 1994, Brown and Drewien 1995, Hugie et al. 1993, Rensson 1975). Special concern should be given to the Great Bustard for which a considerable number of casualties was recorded, and no effective marker could be found. Collision impact on the Great Bustard received attention from Hellmich (1991) and Tucker and Heath (1994) due to this species' low population size. Birds susceptible to collision normally have a poor lift capacity (Mathiasson 1993), and this is certainly true of the Great Bustard. For this species, the collision rate (numbers of birds collided / numbers of birds crossing the line) is difficult to obtain, because its flies infrequently and, therefore, many hours of flight observation would be necessary. Nevertheless, the observations of low flight frequency and high number of casualties suggests that the collision rate must be high.

Avian mortality did not differ for the three power lines studied. This can partly be ascribed to the high variance in mortality among surveys, but it also indicates that distribution lines can cause considerable mortality through collision. These results raise the question of why, until now, little attention has been paid to the possible impact of distribution lines on birds susceptible to collisions. Brown and Drewien (1995) studied wire markers on distribution lines, but did not compare the mortality caused at transmission lines with that caused at distribution lines. Although collision rates are expected to be low (Beaulaurier 1981, Faanes 1987, Hugie et al. 1993), the network of distribution lines is much wider compared to the transmission line network and the total impact of collision with power lines of lower tension might be considerable.

White spirals.—The white spirals in this study were placed at 10-m intervals (staggered between adjacent lines) using both static wires. A red spiral with a diameter of 11 cm is mentioned by Heijinis (1980) as a poor marker, but no data about the distances between these markers were provided. Koops and de Jong (1982) demonstrated a positive result for three different spirals: spirals with a 5-cm diameter fixed at 5-m intervals (86%–89% reduction in mortality), the same spirals at a distance of 10 m (57%–58% reduction), and spirals with a 10-cm diameter set at every 15 m (65%–74% reduction). The authors did not give a statistical result, but we calculated a highly significant effect for all marking methods published in their study (Fisher's exact test: all $P < 0.0001$). A red spiral with the same dimensions as the spiral in this study was tested by Alonso et al. (1993) and gave positive results when placed at 10-m intervals (60% reduction). Finally, Brown and Drewien (1995) obtained statistically significant results from yellow spiral vibration dampers (1.27-cm diameter × 112–125-cm length), placed 3.3 m apart on distribution and transmission lines. Raevel and Tombull (1991) suggested that yellow or white colored markers might be more visible in low light, while red colored markers should be more adequate in full daylight (cited in Brown 1993). However, all colored markers eventually faded from ultraviolet radiation (Brown and Drewien 1995).

Crossed-bands.—Except for the Great Bustard, the crossed bands used on Line B were as effective as the spiral. This marker did not appear to be useful for the species we expected to protect, the Great Bustard. Because it is a vulnerable species, we recommend new power lines to be avoided in areas where it occurs. Until effective markers are found, alternative measures can be taken for the bird's protection. For example, preventing the birds from being disturbed in certain areas and periods, establishing suitable habitat in areas away from power line routes (new and old routes), or burying power lines (APLIC 1994). When these measures are taken, knowledge of the migration and dispersion patterns of the Great Bustard will be necessary.

Black stripes.—The stripes used in Line C cannot be considered a solution to diminish mortality due to collisions. Similar stripes (50-cm length) are mentioned by Heijnes (1980) as being ineffective in reducing collisions, although Heijnes (1980) presented no data.

Overall reduction in mortality for both the spiral and the crossed bands was more than 75% (excluding the Great Bustard), an encouraging result compared with other studies (Alonso et al. 1994, Beaulaurier 1981, Brown and Drewien 1995, Morkill and Anderson 1991), where reduction in mortality normally is about 50%. Eventually, to make a choice for the most appropriate marker other factors, such as price and durability, must be evaluated.

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