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Efficacy of different types of “bird flight diverter” in reducing bird mortality due to collision with transmission power lines

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ABSTRACT

Bird diverter devices were developed to improve power line visibility for birds and reduce their risk of collision. However, differences in efficacy between types of devices, and in some cases conflicting results, place in question the ability of these devices to reduce collision risk to birds. Here, we investigated the efficacy of three types of flight diverters in reducing avian collision with power lines: yellow spiral, orange spiral, and flapper, additionally we used unmarked spans as a control. We recorded bird collisions and estimated removal rates of bird casualties by scavengers in three different 400 kV transmission lines comprising 133 spans in southern Spain. A total of 131 dead birds from 32 species were found. The power line and the type of marker significantly affected avian mortality. The flapper flight diverter was responsible for a 70.2% lower mean avian mortality rate (95% Confidence Interval: 50–90%), followed by the orange spiral (mean = 43.7%, CI = 15.8–71.6%) and the yellow spiral (mean = 40.4%, CI = 2.8–78%), compared to control spans. Flappers were the only marker that showed greatest reduction in relation to non-marked spans. The flapper flight diverter showed the highest reduction in mortality and the narrowest confidence interval when tested in different environmental conditions, and thus may serve as a better alternative to the more commonly used spiral flight diverters.

1. Introduction

During the last 35 years, bird mortality caused by overhead electrical transmission and distribution lines has been an increasing concern for both conservationists and environmental management authorities. At the same time, the number of power lines has increased worldwide at an annual rate of approximately 5% (Jenkins et al., 2010). There are two main problems associated with birds and power lines (Ferrer, 2012): electrocution on distribution power lines (usually 20–32 kV of nominal tension, Ferrer et al., 1991) and collision with the wires (that could happen with any kind of power line or structure). Bird collisions with transmission power lines is a widespread problem, reported across Europe, Africa, Asia and the Americas

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(Alonso et al., 1994; Savereno et al., 1996; Janss and Ferrer, 1998; Royen and Ledger, 1999; Anderson, 2002; De La Zerda and Rosselli, 2003; Lehman et al., 2007; Murphy et al., 2009; Jenkins et al., 2010; Shaw et al., 2010a, 2010b; Calvert et al., 2013; Dashnyam et al., 2016). These accidents have been documented for approximately 350 bird species (Manville, 1999; Ferrer, 2012) with some rough estimates of the magnitude of the problem: 1 million birds per year in the Netherlands (Koops, 1994), 175 million per year in the United States (Manville, 2009), around 1 billion per year worldwide (Hunting, 2002). Beyond conservation, the collisions with power lines are also a problem for the power companies due to potential outages following collisions (Bevanger, 1999).

Several ideas have been proposed to mitigate bird collisions against transmission lines, including rerouting lines, burying cables, or marking them, particularly the ground wires (Jenkins et al., 2010). Until now, the most common and cost effective method has been the wire marking with bird diverter devices (Alonso et al., 1994; Janns and Ferrer, 1998). The main objective of bird diverter devices is to increases wire visibility for birds, thus reducing collision risk.

The most commonly used flight diverters are spiral PVC rolls around ground wires at regularly spaced intervals (Alonso et al., 1994; Janns and Ferrer, 1998, 2000; Anderson, 2002; De la Zerda and Rosselli, 2003; Frost, 2008). Their ease of application, durability, and lack of corona, or electrical discharge, makes them extremely popular for use in mitigating bird-related outages or collision-induced bird mortality (Hurst, 2004). However, the efficacy of these diverters in reducing avian collisions is still unclear (Brown and Drewien, 1995; Hunting, 2002; Barrientos et al., 2011; Bernardino et al., 2018, 2019), and after more than 35 years of their use, power line collision rates remain high, at least for certain species (Janss and Ferrer, 2000; Drewitt and Langston, 2008). For example, a reduction of up to 61% of mortality was reported for several kinds of markers (Brown and Drewien, 1995). Janns and Ferrer (1998) tested efficacy of PVC spirals and black crossed bands, and they found a reduction in mortality of 81% and 76%, respectively. Contrary, Anderson (2002) found no reduction in collisions in a study with spirals in South Africa.

Some recent reviews concluded that marking static wires reduces the overall number of bird casualties at power lines (Barrientos et al., 2011; Bernardino et al., 2019). In particular, Barrientos et al. (2011) highlighted the fact that there are a surprisingly small number of well-designed, peer-reviewed studies to support this). Due to the usual low number and Poisson distribution of observed mortalities by spans -increasing the risk of type II errors in analyses-there is a shortage of studies with a significant effect size, demonstrating efficacy of these devices.

Numerous other factors may influence collision rates such as different power line features, collision prone species, habitat characteristics, weather conditions, or species-specific behaviors; making it difficult to find an all-purpose anti-collision device (Janss and Ferrer, 2000; Martin and Shaw, 2010). Therefore, it is important to test different diverter types at different locations, under a wide variety of field conditions, and with a large enough sample size to understand potential efficacy. With this knowledge, power companies can make informed decisions on which diverters, if any, they should use on their lines in the future.

The purpose of the present study was to assess the efficacy of reducing avian collisions at three different transmission power lines, with three commonly used types of flight diverters: PVC yellow spiral, PVC orange spiral, and a recently developed “Bird flapper”, with the shape of a cross with orange and red sides, inserted with reflective stickers (Fig. 1).

2. Materials and methods

2.1. Markers used and experimental design

Ground wires were marked using three types of bird flight diverters: yellow PVC spiral, orange PVC spiral, and flapper. Both spirals of different colors consisted of polypropylene spirals (90-cm long, 30-cm maximum diameter). The flapper consisted of polypropylene blades with three sides with reflective stickers. Flappers were 21 cm long, apart from the chain, which is 9.5 cm long, and each side of the blade is approximately 12 cm wide. They hang from a cable by staples and can rotate (see Fig. 2).

The three types of markers were fixed to the two ground wires every 10 m, staggered between the two ground wires to produce a visual effect at the horizontal plane of the wires of a 5-m marking. Each span was marked or unmarked with one of the four marking categories (i.e. orange spirals, yellow spirals, flapper flight diverters, and control or no marking). Marked spans were selected at random, alternating control spans. In total, of the 133 spans studied (53.98 Km), 26 were marked with yellow spirals (10.53 Km), 33 with orange spirals (13.36 Km), 33 with flappers (13.49 Km) and 41 (16.60 Km) were control spans without markers. We made a total of 3606 visits to the spans during the study period.

2.2. Study area

In our study we included three different transmission power lines located in different areas in the region of Andalusia (southern Spain), in order to increase habitat variability, bird community composition, landscape features and weather variability. Using a relatively large number of spans, we try to reduce estimate uncertainty and increase statistical power in order to detect significant effects, if any, of flight diverters on mortality reduction under wide-ranging conditions. Although studies were conducted in different years, the survey methods and estimation of carcass removal were identical.

Line 1) 400 kV *Palos de la Frontera–Guillena:* Transmission line of 400 kV, double circuit with six duplex conductors forming three cable levels and two overhead ground wires. Towers are metallic, with an approximate height of 40 m, and

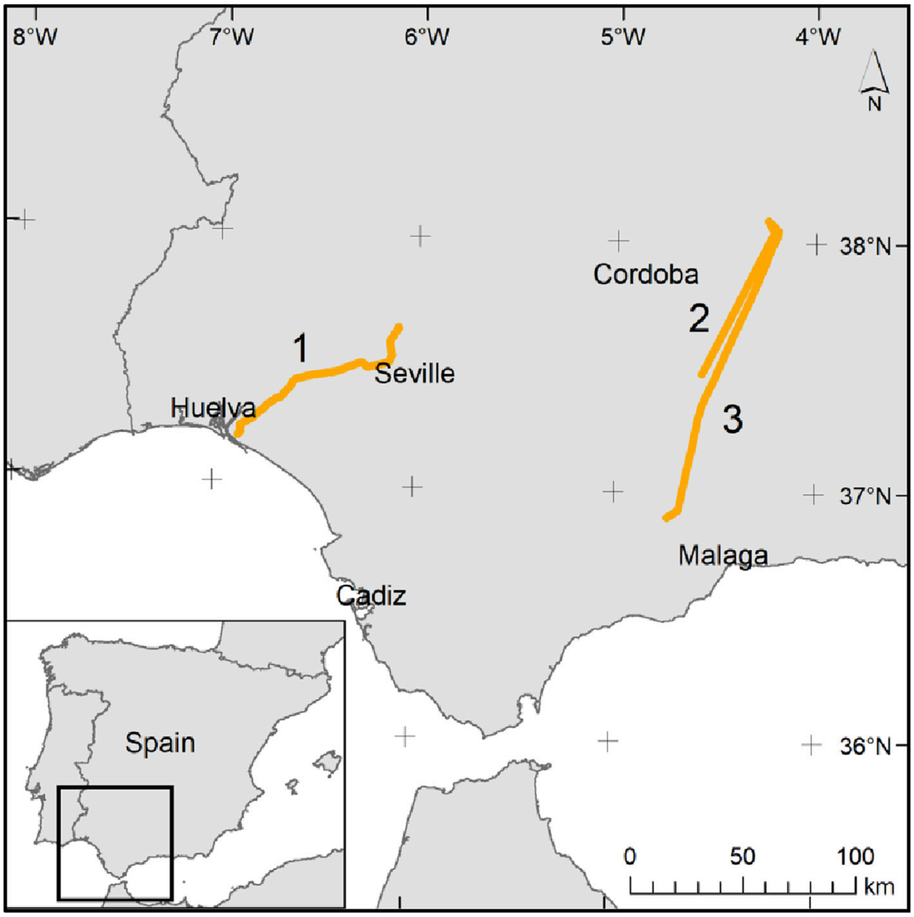

Fig. 1. Map with locations of lines and the sampled line sections for each line. Line 1) 400 kV Palos de la Frontera–Guillena, Line 2) 400 kV Cabra-Guadalquivir Medio, Line 3) 400 kV Guadalquivir Medio-Tajo de la Encantada.

spaced 438 m from each other (SD = 12.33, range = 435–443). We studied 26 spans, including 11 without markers, 5 with yellow spirals, 5 with orange spirals and 5 with bird flappers. The study of this line was carried out between October 2004 and October 2006 and between March 2008 and March 2009, totalling 28 searches (approximately every 40 days) along the line for carcasses (i.e. 728 visits to the spans). Searches were conducted always by two people. The line is located in Huelva, in the southwest of Spain, between the towns of Palma del Condado and Paterna del Campo, and is identified as an Important Bird Area (IBA; BirdLife International, 2020). It crossed a pseudo-steppe area (aprox. 37º27′N, 06º23′W) occupied by dry cereal crops, leguminous crops, and fallow lands. The crops are herbaceous annual plants with annual cycles that alternate between sowed, reaped, or fallow. The mosaic pattern is also determined by the Mediterranean climate, with a mean annual precipitation of 517 mm and mean temperature of 18.2 °C.

Line 2) 400 kV *Cabra-Guadalquivir Medio*: Transmission line of 400 kV, double circuit with six duplex conductors forming three cable levels and two overhead ground wires. Towers are metallic, having an approximate height of 32 m and spaced 380 m from each other (SD = 13.93, range = 366–411). We studied 61 spans, including 15 without markers, 15 with yellow spirals, 15 with orange spirals and 16 with flappers. This line is located in Cordoba and Jaen provinces, of southern Spain, close to the towns of Castro del Río and Bujalance and is identified as an IBA especially for steppe birds. We conducted the study from March 2009 to January 2012, totalling 20 searches (approximately every 40 days, i.e. 1220 visits to the spans). Searches were conducted always by the same two researchers. The area was mainly man-made steppes, occupied by dry cereal crops, with some spotted areas of olive trees and bushes, with a typical Mediterranean climate, characterized by hot and dry summers.

Line 3) 400 kV *Guadalquivir Medio-Tajo de la Encantada*: Transmission line of 400 kV, double circuit with six duplex conductors forming three cable levels and with two overhead ground wires. Towers are metallic, with an approximate height of 35 m, spaced 400 m from each other (SD = 11.07, range = 388–410). We studied 36 spans, including 15 without markers, 6 with yellow spirals, 13 with orange spirals and 12 with flappers. This line is located in Cordoba and Jaen provinces, south of Spain, close to the towns of Cañete de las Torres and Bujalance and is inside an IBA. We conducted the study from March 2009

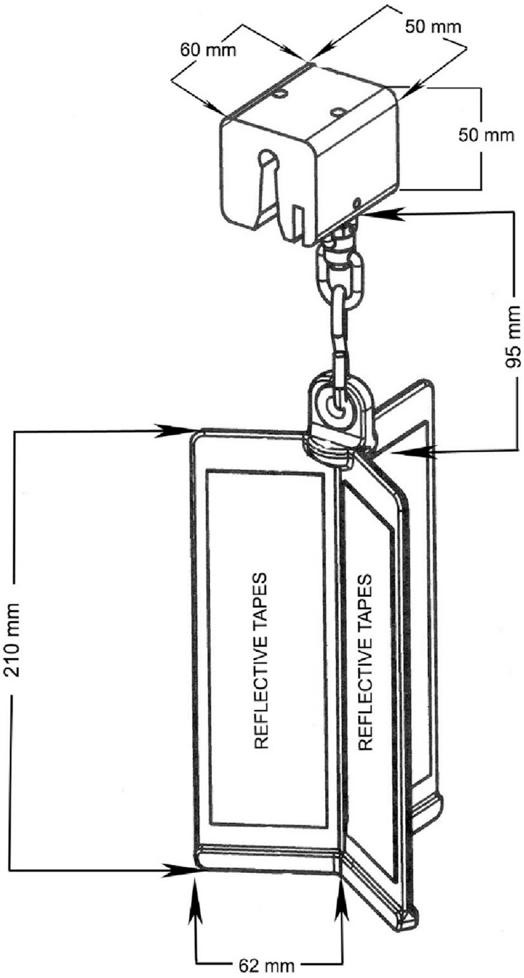

Fig. 2. Design with measures of “flapper flight” diverter installed on overhead wire.

to February 2012, totalling 20 searches (approximately every 40 days i.e. 720 visits to the spans). The area was mainly occupied by dry cereal crops with areas of olive trees and bushes, with a typical Mediterranean climate. Location of the three studied lines is show in Fig. 1.

2.3. Collision data

Two observers walked in parallel separately on either side of the power line, about 25 m from the vertical projection of the line and 50 m from each other to make power line inspections, covering a corridor of 100 m along the power lines. In each survey, all carcasses and animal remains were photographed and collected to avoid double recording. The remains were collected and stored in plastic bags for the identification of species, age, and sex. All birds found under or around the lines showing evidence of collision on their body (fresh remains with fractured bones, skin abrasions, or feather loss) were considered collision mortality. The same two observers were searching victims in the three lines during all the experiment. Both were experienced field ornithologists and, due to the experimental design, potential differences in the ability finding carcasses between them does not affect our results, as far as those potential differences are not related to the markers.

2.4. Estimating differences in losses among power lines

The size of the birds that collide with lines and the scavenger species present are important factors that influence carcass loss (Ferrer et al., 1991). To estimate how many birds we missed between censuses, we conducted a parallel experiment using hen carcasses, with a mean body mass between 250 g and 750 g. We deposited a total of 52 hens during autumn-winter and 67 in spring-summer in randomly selected sites beneath the studied lines and checked the carcasses every day until all of them disappeared, recording when each one disappeared. Assuming that the probability of death remains constant throughout the period between two inspections, we calculated a logarithmic loss function (Ferrer et al., 1991).

2.5. Statistical analysis

To analyze potential differences in the proportion of different bird orders found among different markers, we conducted a Kruskal-Wallis ANOVA by ranks test. For statistical procedures, we calculated bird collision rate as the mean number of victims found per span and year in each one of the spans. We use generalized linear models (GLMs) with Poisson distribution and logit link function to determine any possible relationship between mean number of birds that collided per span (dependent variable) and the power line location and the type of marker as explanatory variables. We do not included habitat type in this analyses because in the three studied lines, a mosaic with predominance of dry cereal crops, with some spotted areas of olive trees and bushes, was present. We also used Scheffe post hoc comparisons test to look for significant differences among each one of the markers. Tests of significance for effect sizes and powers were conducted with sigma-restricted parameterization and effective hypothesis decomposition. Statistica 13.0 software statistical package was used to perform statistical procedures, and we used an alpha value of 0.05 to assess significance of results.

3. Results

3.1. Collision victims

During our study, 131 dead birds were recorded. Thirty two different species were identified among the victims of collisions (Table 1), of which 17.5% were *Columbidae*, 15.3% were from *Alaudidae* and 14.5% were from other *Passeriformes* families, and 32.8% were a mixture of other orders (Table 2). Unmarked spans accounted for 34.3% of the victims. We found no significant differences in the percentage of birds found dead by bird groups among the three markers and control spans (Kruskal-Wallis test: $H_{(3,\ n=36)} = 0.0775$, $p = 0.9944$).

3.2. Removal rates

We found similar rates of carcasses removal in the three studied power lines. Assuming that the probability of death remains constant throughout the period between two inspections, we calculated a logarithmic loss function (Ferrer et al.,

Table 1
Complete list of identified bird species found collided against the wires during this study.

LIST OF SPECIES	Number of individuals
Bubulcus ibis	2
Anas platyrhynchos	2
Fulica atra	3
Burhinus oedicnemus	1
Vanellus vanellus	2
Larus cachinnans	1
Falco naumanni	2
Falco tinnunculus	4
Otis tarda	1
Alectoris rufa	4
Coturnix coturnix	4
Columba livia	12
Streptopelia decaocto	7
Streptopelia turtur	4
Athene noctua	1
Tyto alba	1
Caprimulgus europaeus	2
Emberiza calandra	6
Emberiza cirlus	3
Galerida cristata	7
Galerida theklae	5
Alauda arvensis	2
Melanocorypha calandra	7
Sylvia atricapilla	4
Hirundo rustica	2
Sturnus unicolor	5
Turdus merula	2
Carduelis carduelis	3
Carduelis chloris	1
Corvus monedula	2

Table 2
Number of individuals (and %) of different bird groups (Families and Orders) found dead under spans with different marker types (including non-marked spans) during the study period in the three power lines.

Order	Not marker	Yellow spirals	Orange spirals	Flappers	TOTAL
Passeriformes					
Family Alaudidae	9 (20%)	4 (11.1%)	4 (13.3%)	3 (15%)	20 (15.3%)
Other Passeriformes	7 (15.5%)	5 (13.8%)	5 (16.6%)	2 (10%)	19 (14.5%)
Columbiformes	6 (13.3%)	9 (25%)	4 (13.3%)	4 (20%)	23 (17.5%)
Galliformes	3 (6.6%)	3 (8.3%)	2 (6.6%)	1 (5%)	9 (6.9%)
Falconiformes	1 (2.2%)	3 (8.3%)	2 (6.6%)	0 (0%)	6 (4.6%)
Anseriformes	2 (4.4%)	1 (2.7%)	1 (3.3%)	1 (5%)	5 (3.8%)
Charadriiformes	3 (6.6%)	0 (0%)	1 (3.3%)	0 (0%)	4 (3%)
Strigiformes	1 (2.2%)	0 (0%)	0 (0%)	1 (5%)	2 (1.5%)
Others	13 (28.8%)	11 (30.5%)	11 (36.6%)	8 (40%)	43 (32.8%)
TOTAL	45 (34.3%)	36 (27.5%)	30 (22.9%)	20 (15.3%)	**131**

1991). According this function, the estimate percentage of total victims that we should find in a 40 days interval searches for autumn-winter and spring-summer periods was of 49% and 40% in line 1, 48% and 41% in line 2, and 51% and 40% in line 3, respectively. Including losses by scavengers, we estimate that the monitored power lines killed 194 birds during the study period.

3.3. *Factors affecting frequency of collision*

We found significant differences in mean number of victims per span among the three studied power lines (GLM, Wald statistic = 39.49, P < 0.0001), with those differences remaining significant when only non-marked spans were included (GLM, Wald statistic = 16.78, P = 0.0002). The most dangerous line was the line 1, with an average of 2.269 victims per span (5.60 per Km), followed by line 3 with 0.847 victims (2.09 per Km) and line 2 with 0.540 (1.33 per Km).

Globally, collision frequency was 52.4% lower on spans with markers (GLM, Wald statistic = 10.32, P = 0.0013). A GLM with mean victims per span, and power line, marker types and their interactions, showed highly significant differences among markers and power lines but not in their interaction (Table 3). Effect sizes were significant for power lines and markers type (Table 2). In comparison to non-marked spans, the flapper spans showed 70.2% (95% Confidence Interval: 50–90%) lower collision rates, followed by orange spirals (mean = 43.7%, CI = 15.8–71.6%) and yellow spirals (mean = 40.4%, CI = 2.8–78%; Fig. 3). Flappers not only showed the highest reduction of mortality but also the narrowest confidence intervals (Fig. 3). Flappers were the only markers that showed significant differences with unmarked spans in a Scheffe *post hoc* comparisons test (Table 4). Spiral markers and unmarked spans showed significant differences between the surveyed lines, while flappers showed a strong reduction in mortality rates independent of the power line where they were installed (Table 5).

4. Discussion

Our average number of birds killed from collision per span in our study was relatively low (0.984 per span and year, 2.42 per Km and year) compared with other studies (Alonso et al., 1994; Janss and Ferrer, 1998; Royen and Ledger, 1999; Anderson, 2002; Lehman et al., 2007; Murphy et al., 2009; Jenkins et al., 2010). In our case, we identified 32 different bird species, with *Passeriformes* and *Columbidae* groups accounting for nearly half of the total victims. We did not find taxonomic differences in

Table 3
Results from the GLM with Poisson distribution and logit link function, with mean mortality by span as dependent variable and power line, type of marker (including non-marked spans) and their interaction as explanatory variables. Significant terms are highlighted in bold. Both, line and marker showed significant effect, significant size effect and high power, but no the interaction.

Parameter	df	Wald - Statistic	*P*
Intercept	1	3.086	0.0489
Power Line	2	19.824	**<0.0001**
Type of marker	3	13.287	**0.0040**
Power Line*Type of Marker	6	1.000	0.9855

Effect Sizes, and Powers (alpha = 0.05)

	SS	df	MS	F	p	Partial eta-squared	Non-centrality	Observed power
Intercept	27.152	1	27.152	91.289	0.0000	0.430	91.289	1.000
Power line	4.015	2	2.007	6.749	**0.0016**	0.100	13.498	0.911
Marker	2.698	3	0.899	3.024	**0.0322**	0.069	9.072	0.699
Line*Marker	0.734	6	0.122	0.411	0.8703	0.019	2.468	0.166
Error	35.989	121	0.297					

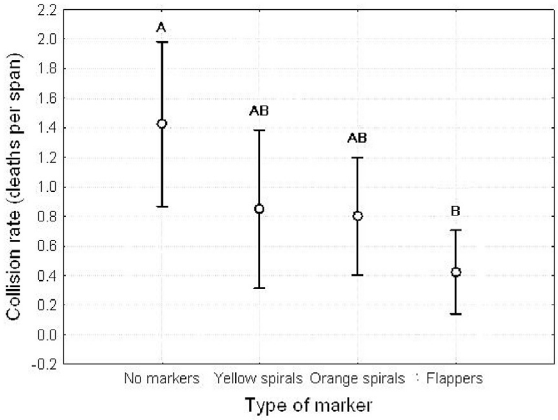

Fig. 3. Estimated marginal mean collision rates for the three types of markers plus non-marked spans (control) after adjusting for the effect of power line. Error bars indicate 95% confidence intervals for the marginal means. The only one showing significant differences with non-marked spans was the Flapper, with no overlapped confidence intervals.

collisions between the markers or the non-marked control spans, suggesting that, in our case, a given marker is equally effective across a broad range of avian taxa.

The loss caused by scavengers is one of the most important sources of errors in sampling victims of collisions (APLIC, 1994). Previous experiments of collision victim removal by scavengers reveal high rates of carcasses loss (Frost, 2008; Bevanger and Broset, 2001; Henderson et al., 1996; Ferrer et al., 1991; Balcomb, 1986; Wobeser and Wobeser, 1992). The removal rates can vary depending on the size of carcasses, density and diversity of scavengers, local environment, and topographical characteristics. In our case, experiments conducted in the three studied lines gave us similar results (range 49–60% of carcasses removal), allowing us to compare recorded number of victims without any estimation of losses. Estimations of total victims, using rate of removal by scavengers, would be necessary when comparing power lines with different disappearance rates, but implies a problem with those spans with zero victims found. In our case, due to the similarity of removal rates among the three studied power lines and because our main objective was to evaluate efficacy of markers equally represented in the three lines, instead of an estimation of real impact of the lines, we use an uncorrected number of victims in our analyses.

We found significant differences in mortality among the three lines, even when we only considered unmarked spans. Habitat features and the composition and structure of bird community have been proposed as the most dominant factors in collision frequency (Mathiasson, 1993, 1999; Janss, 2000; Jenkins et al., 2010; Martin and Shaw, 2010; Barrientos et al., 2011). Other potential factors are differences in removal rates of carcasses, detectability, disturbances, orientation of the line, tower and wire designs (Anderson, 1978; Janns and Ferrer, 2000; Ferrer, 2012). Local factors such as bad weather and visibility conditions may also explain differences in mortality rates (Anderson, 1978; McNeil, 1985; Janss, 2000; Kostecke et al., 2001). Some authors found that the frequency of casualties could be related more to species composition, flight behavior and ability to maneuver when approaching an obstacle (Bevanger, 1994, 1998; Janss, 2000; Janns and Ferrer, 2000; Drewitt and Langston, 2008). In addition, a narrow binocular visual field has been proposed as an explanation why some bird species seems more prone to collision than others (Martin and Shaw, 2010). However, as our main objective was to detect differences among markers, differences among lines in mortality rates do not affect our results.

Globally speaking, flight diverters showed significantly lower mortality rates when compared with unmarked control spans of around 52%, but those differences depends mainly on flapper flight diverters. The flapper showed the lowest mean mortality (70%), the narrowest confidence interval of all the tested markers, and a significant effect size, demonstrating a consistent reduction in collisions among different environments and bird communities. The flapper diverter was also the only marker showing a significant difference with unmarked spans in post hoc comparisons, and the only one obtaining similar reductions in mortality independently of the power line. Bernardino et al. (2019) also described an overall (but not significant) tendency for flappers to be more effective than spirals.

It is estimated that more than 65 million km of medium–high voltage power lines are currently in use around the world (ABS Energy Research, 2008). Several authors suggest that the risk of bird collision against power lines is subjected to multiple sources of variation and hence highly unpredictable, making general mitigation actions based on a single type of marker unlikely to be effective for all species in all situations (Yee, 2007; Murphy et al., 2009; Martin and Shaw, 2010; Barrientos et al., 2011). In our tests, yellow spirals showed a mean reduction (but not significant) in mortality of around 44% but with a confidence interval from 78% to as low as 2.8%. This wide interval can explain why some authors studying the efficacy of the same device found reductions of around 81% (Janns and Ferrer, 1998), 76% (Crowder, 2000), 50% (Stake, 2009), or no reduction at all (Anderson, 2002). Therefore, a better approach is to find markers showing the largest reduction in mortality with a concomitant low variation across different power lines, habitats, and bird communities. In our case the flapper diverter

Table 4
Results from pair-wise post hoc Sheffe tests between markers (including non-marked controls). The only marker showing a significant difference from non-marked spans was the flapper. Significant differences are highlighted in bold.

Type of marker	Yellow spirals	No markers	Flappers	Orange spirals
Yellow spirals	1.000			
No markers	0.449	1.000		
Flappers	0.650	**0.020**	1.000	
Orange spirals	1.000	0.419	0.567	1.000

Table 5
Differences in mortality among the three studied power lines by type of markers. Significant results are highlighted in bold. The only one showing non-significant differences in effectiveness among lines was the flapper.

	Wald statistic	p
No markers	16.78083	**0.0002**
Yellow spirals	8.05770	**0.0177**
Orange spirals	7.02195	**0.0298**
Flapper	1.16059	0.5597

showed the lowest mortality and the narrowest confidence interval when tested in different conditions and outperformed the more commonly used spiral diverters.

To propose the flapper as an effective and feasible bird flight diverter, we recommend conducting some endurance tests for vibrations or impact against other objects/surfaces as result of the wind influence and the resistance against loss color (exposure to ultraviolet rays) of the flappers as well. Even if these devices have been in use for some years, it is highly advisable to test its durability. Information about material durability (Dashnyam et al., 2016) is a critical factor for electrical power companies in order to invest in scientifically proven solutions for reducing bird mortality.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2020.e01130.

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