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Carcass removal by scavengers and search accuracy affect bird mortality estimates at power lines

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Abstract

Bird mortality as a result of collisions with power lines has been of increasing concern in recent decades, but the real impact on bird populations requires an experimental assessment of scavenger removal rates and searcher detection errors. Farmland and steppe birds, two of the most threatened avian groups, have been shown to be particularly vulnerable to collision with power lines, but few removal and detectability studies have been developed in cereal farmland habitats, and none in the Mediterranean region. We conducted five carcass disappearance trials in central Spain by placing 522 corpses of different sizes under power lines, and searching for remains four times during the following month. The influence of several factors was examined using multivariate approach. The accumulated number of carcasses removed by scavengers increased logarithmically, with 32% removed over the 2-day period after the initial placement, but only 1.5% removed on a daily basis by day 28. Small birds disappeared earlier and at a higher proportion than larger birds. Carcass removal rates were site-dependent, but were not influenced by carcass density or season. The detection rate increased with the observer's previous experience and carcass size. Carcass counts at power lines notably underestimate bird casualties. Our 4-week disappearance equations provide a full range of scavenging rates and observer efficiency correction factors for a wide range of bird weights. Fortnightly to monthly search frequencies may be adequate to detect medium- to large-sized corpses, but are insufficient for smaller birds. Finally, all personnel participating in carcass searches should be trained previously in this task.

Introduction

Electric power lines are known to be a cause of bird mortality, either through electrocution or through collision with the wires (Bevanger, 1994, 1998; Ferrer & Janss, 1999; Bevanger & Broseth, 2001; Erickson *et al*., 2001; APLIC & USFWS, 2005). This has generated increasing concern due to the negative effect it may have on some species that are particularly vulnerable to these mortality factors (Haas, 1980; Ferrer, de la Riva & Castroviejo, 1991; Alonso, Alonso & Muñoz-Pulido, 1994; Janss, 2000; Janss & Ferrer, 2000). The only efficient way to evaluate the impact of such mortality is to count dead birds in the power-line corridor (Beaulaurier, 1981; Faanes, 1987; Bevanger, 1999). However, because field researchers cannot continually monitor power lines, scavengers can be expected to find and remove a variable portion of the carcasses between the time of their deaths and the time the next search is conducted. Also, a number of the carcasses or their remains will be missed by the observers patrolling the line. Therefore, the results of carcass searches are affected by two main bias sources: (1) the rate at which carcasses are removed by scavengers; (2) the ability of observers to detect corpses or their remains in the field.

A recent review of birds found poisoned after agricultural pesticide treatment noted that the removal rates may vary widely, altering the mortality estimates that are based on carcass searches (Prosser, Nattras & Prosser, 2008). Among the possible factors influencing the removal rates are features affecting visibility of corpses such as their size and colour, or vegetation cover, and local and/or seasonal changes in scavenger abundance and activity (Heijnis, 1980; Beaulaurier, 1981; Wobeser & Wobeser, 1992; Bevanger, 1999; Morrison, 2002; Ward *et al*., 2006). Searcher efficiency has been shown to differ extensively with the vegetation type and the size of the bird (Wobeser & Wobeser, 1992; Bevanger, 1999; Morrison, 2002). Scavenger removal rates and efficiency of field workers should therefore be known to ensure that these sources of bias can be corrected to obtain accurate estimates of bird mortality rates.

The objectives of this study were to (1) determine the carcass removal rate of birds killed as a result of power-line collisions and observers' search bias by means of a series of trials simulating collisions of birds with power lines in a farmland area in central Spain; (2) examine the influence of various potentially relevant factors such as study site and season, carcass size and density, and vegetation height and cover, using a multivariate approach. The aims were to (1) obtain correction factors for these two bias sources that may be used to improve bird fatality estimates at power lines (although the correction factors obtained should be applied with caution by researchers working in areas with different habitat characteristics); (2) suggest acceptable periodicities to conduct future carcass searches at power lines in farmland habitat. Various studies have carried out similar carcass removal experiments (Prosser *et al*., 2008, and references therein), but few have attempted to analyse simultaneously the influence of several factors. Most of these carcass removal studies have been carried out to estimate mortality after pesticide treatment in North America or northern Europe (reviewed in Prosser *et al*., 2008) and some at wind turbines (reviewed in Morrison, 2002; Siriwardena *et al*., 2007), and a few analogous studies have been published in relation to mortality at power lines (e.g. Bevanger, Bakke & Engen, 1994), although there may be unpublished reports produced by private companies that are not available. To our knowledge, this is the first study carried out specifically to assess the scavenger removal rates and search efficiency of birds found dead at power lines in Mediterranean farmland habitats, using a multivariate approach to deal simultaneously with several underlying variables.

The two most commonly recognized sources of error affecting bird mortality estimates at power lines or wind turbines are carcass removal by scavengers and observer detection error (e.g. Bevanger, 1999; Siriwardena *et al*., 2007). A widely used estimator of adjusted bird mortality (M_A) is therefore $M_A = M_U/R \times p$, where M_U is the unadjusted mortality expressed as the number of fatalities per kilometre of power line, or wind turbine per year, R is the proportion of carcasses remaining since the last fatality search and p is the proportion of carcasses found by observers searching for dead birds. Here, we provide a full range of correction factor values for R and p for 1 month after the fatality by conducting 4-week-long carcass disappearance trials and developing carcass removal and searcher efficiency equations for four different carcass sizes used. From these equations, the correction factors for these two main sources of bias can be calculated for any search periodicity up to 1 month between consecutive search surveys, and covering a wide range of bird weights (*c*. 50–1000 g). Other minor adjustments relating to birds injured by power lines but that die elsewhere and remaining undetected (crippling bias), and natural mortality not caused by collision with the wires (background mortality) are not quantified because they are usually assumed to be relatively small.

Farmland areas host many endangered bird species that have suffered alarming population decreases during the last few decades, due mostly to agricultural intensification but also due to other human-induced causes (Tucker & Heath, 1994; Siriwardena *et al*., 1998; Donald, Green & Heath, 2001; Wretenberg *et al*., 2006). Among these causes, the ever-increasing number of power lines built on farmland areas, where terrain conditions are more suitable for the installation of these utility structures, is currently an issue of great concern. Farmland and steppe species are indeed at present the most threatened bird groups, with 83% of the species being of Threatened or Near-Threatened status (BirdLife International, 2004; Burfield, 2005; Santos & Suárez, 2005). Many of these steppe birds have significant yet endangered or declining populations in the Iberian Peninsula (Madroño, González & Atienza, 2004; Santos & Suárez, 2005), and some of them are particularly vulnerable to the negative effects of power lines (e.g. common cranes *Grus grus* or great bustards *Otis tarda*, for which collision with power lines has been identified as the main cause of adult mortality; Alonso & Alonso, 1999; Janss & Ferrer, 2000; Palacín *et al*., 2004).

Materials and methods

Study area

The study was conducted in five important bird areas (IBAs) in Madrid Province, along with a small area in Guadalajara Province, central Spain. In each of these areas, we selected 1–2-km-long sectors of power lines covering 14 km of 11 different power lines in total (Fig. 1). The terrain is flat to slightly undulating, with a mean elevation of 740 ± 83 m a.s.l. The area is primarily dedicated to cereal cultivation (mainly wheat *Triticum aestivum* and barley *Hordeum*

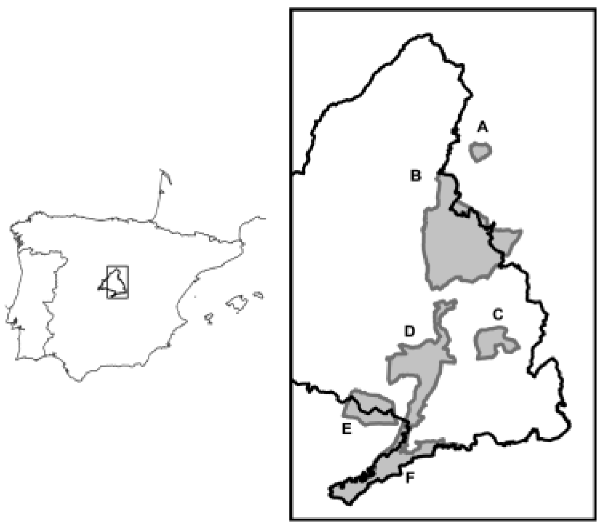

Figure 1 Location of the study area in the Madrid region and number of power lines surveyed (in parentheses). A, Casa de Uceda (1); B, IBA 074 Talamanca-Camarma (5); C, IBA 075 Alcarria de Alcalá (1); D, IBA 073 Cortados y graveras del Jarama (2); E, IBA 393 Torrejón de Velasco-secanos de Valdemoro (1); F, IBA 072 Carrizales y sotos de Aranjuez (1).

spp.), with minor fields of legumes (*Vicia* spp. and *Medicago sativa*), olive *Olea europaea* groves and grapevines *Vitis vinifera*. Most cereal is grown in a traditional 2-year rotation system that creates a dynamic mosaic of ploughed, cereal and stubble patches over the region. The climax vegetation of evergreen oak trees *Quercus ilex* and *Retama* sp. and *Thymus* sp. scrubland has been generally cleared up to small open-wooded tree plots interspersed within the dominant farmland. White poplars *Populus alba* are also found in the IBAs, although as in the case of oaks, always as single trees or as small groups.

Cereal fields are harvested during late June to early July. Stubbles and fallows are also used for sheep grazing. These areas hold populations of threatened bird species such as great bustard (*c*. 1500 individuals; Alonso *et al*., 2003), little bustard *Tetrax tetrax* (*c*. 2600 individuals; García de la Morena *et al*., 2006) pin-tailed sandgrouses *Pterocles alchata* and black-bellied sandgrouses *Pterocles orientalis* (*c*. 112 and 100 individuals, respectively; Suárez *et al*., 2006), and montagu's harrier *Circus pygargus* (*c*. 100 pairs; Arroyo & García, 2007).

Carcass detection and removal by scavengers

Between November 2007 and August 2008, we carried out five carcass disappearance trials, respectively, in November, December, February, April and August. Each trial started by placing the bird carcasses on the ground under a power line (20 and 5 carcasses/km for November and the other months, respectively). The line was then surveyed four times during the month following placement (on days 2, 7, 22 and 28; in December, it was not possible to carry out the survey on day 28 due to unfavourable weather conditions). We searched at uneven intervals because most of the disappearances are known to occur during the first days after the collisions (e.g. Balcomb, 1986; Prosser *et al*., 2008). With the aid of a global positioning satellite (GPS) system, we went to each site where we had placed a carcass and looked for it or its remains, recording any track or trace left by scavengers. On the last survey day of each trial, we removed all carcass remains.

In total, 522 carcasses were placed 0–20 m from the line beneath the central conductor wire of the power line to simulate natural collisions (Henderson, Langston & Clark, 1996; Janss, 2000). Of these carcasses, 130 were female common pheasants *Phasianus colchicus*, 130 red-legged partridges *Alectoris rufa*, 130 common quail *Coturnix coturnix* and 132 halves of common quail carcasses. We chose these species because they are found in the study area; pheasants were intended to represent a bird of size and plumage similar to great bustards, the largest species, while common quail halves should represent small passerines. The use of four size classes (pheasants were large, partridges were medium, quail were small and half-quail were very small) allowed us to explore the effect of carcass size on removal probability. All carcasses used were from wild birds hunted and later sold for human consumption; they were thus free from the smell characteristic of poultry farm birds, which might have influenced the removal rate by scavengers (Bevanger, 1999). For this reason, we preferred wild common quail halves to any other small farm bird such as small chicken or ducks. Significant weight differences existed between the four size category used [$P<0.001$ in all cases; (mean ± SD) common pheasants: 1008.9 ± 125 g, $n = 20$; red-legged partridges: 406.3 ± 42.0 g, $n = 25$; common quail: 109.5 ± 14.2 g, $n = 25$; common quail halves: 54.1 ± 6.3 g, $n = 24$]. All carcasses were aired in a ventilated and cold room for 24 h before placing it under the power line to eliminate as much as possible any artificial smell remains but avoiding decomposition due to temperature, which may reduce attractiveness to vertebrate scavengers.

We considered that a carcass had been detected by a scavenger when it had been moved from the initial location, partially eaten or completely removed. A carcass disappeared when the remains found comprised fewer than five feathers, because a very low number of feathers found during searches for collision casualties cannot be interpreted as a collision, as these few feathers could have been lost by a bird during preening, moulting or fighting (e.g. Bevanger, 1999). We searched for carcasses up to 30 m away from the initial location to account for possible dragging of the carcass by scavengers. To look at possible differences in the removal rate due to changes in the density of the carcasses (see, for example, Linz *et al*., 1991; Wobeser & Wobeser, 1992; Ward *et al*., 2006), we placed them at 50-m (20 carcasses km^{-1}) and 200-m intervals (5 carcasses km^{-1}) in two winter trials. As no differences were found, in all other trials, we placed carcasses at 200-m intervals. The placement order of the four size classes was random. For each carcass placed, we recorded UTM coordinates via GPS (Garmin, ± 3 m error), and vegetation cover and average height (estimated visually in a circle of 3 m radius around the carcass). Before placing the carcass we made a cut on its ventral side to simulate the injury caused by the collision with the cable and to avoid differences with respect to the quail halves used for the smallest size class.

Carcass detection by observers

We explored the influence of the observer's experience on carcass detectability during the first two experiments (141 carcasses). Experience was defined as the total kilometres surveyed under power lines by each observer before the present study. Four observers different from those who had placed the carcasses surveyed the power lines searching for remains. Each of these surveys was conducted by two observers, one after another separated by *c*. 50 m, walking at a slow, regular pace and parallel to the wires of power lines at a distance no more than 15 m from the central conductor wire. Visibility was good along all the power line corridors due to low vegetation height; thus, the observer was able to find all the remains to a distance up to 50 m. The first observer searched for remains without knowing where the carcasses had been placed; the second observer followed behind recording both the remains discovered and those not found by the first observer.

Statistical analyses

To establish the factors influencing the carcass disappearance rate, we used a generalized linear model with a binary response (carcass or its remains disappeared vs. present on day 28 after placement). As factors, we included each one of the power lines, month, carcass size and vegetation cover and height, after appropriate transformations for vegetation variables [natural logarithm (height + 1) and arcsine ($\sqrt{}$cover)], to attain equal variance and normality (Sokal & Rohlf, 1987; Fowler, Cohen & Jarvis, 1998). To explore the relative importance of each explanatory variable, we used the corrected Akaike's information criterion (ΔAICc <2) to select the best models from a set of candidate models with different combinations of predictor variables (Anderson & Burnham, 1999) and interactions among them.

Once the relevant factors were identified, we performed univariate analyses to further explore their influence on the carcass disappearance rate. Non-parametric tests were used because we were interested in several questions about the different power lines (11) and months (5) that were considered as independent experiments: (1) Mann–Whitney *U*-tests to investigate the importance of carcass density, by comparing the number of carcasses that disappeared between the high-density (November) and the low-density experiments; (2) χ^2-tests to search for differences among power lines due to variable carcass density; (3) Kruskal–Wallis tests to check for seasonal differences between experiments carried out on different months; (4) Kruskal–Wallis and Mann–Whitney *U*-tests to explore differences due to carcass size; (5) χ^2-tests with Yates correction when necessary (Fowler *et al.*, 1998) to investigate removal rate differences between months or power lines. Finally, to describe the removal rate as a function of carcass size, we adjusted a logarithmic equation to disappearance data for each carcass size.

To investigate the effect of the observer's experience on carcass detectability, we performed a second generalized linear model with logit link function and a binary response (carcass or remains found vs. not found), using observer, carcass size, vegetation height and vegetation cover as factors. We applied the same variable transformations and model selection criteria as those used in the previous analysis. Univariate analyses were carried out to explore (1) whether large carcasses were detected with a higher probability than small carcasses; (2) differences between observers in their ability to find the remains that could be attributed to their previous experience. Experience was defined as above. We finally adjusted logarithmic equations to detectability data for each observer.

Results

Carcass detection and removal by scavengers

On the first survey, 2 days after leaving the carcasses under the power lines, 67.2% of them had been detected by scavengers, with no differences among bird sizes ($\chi^2 = 0.94$, d.f. = 3, $P<0.82$). The detection rate increased to 93.7% during the second survey (day 7), with no size differences ($\chi^2 = 0.12$, d.f. = 3, $P<0.99$), and to 99.8 and 100%, respectively, for the third and fourth surveys (days 22 and 28).

The accumulated number of carcasses removed by scavengers increased logarithmically from the day they were placed (Fig. 2). On day 2, 32% of the carcasses had already disappeared. An additional 20% of the carcasses disappeared between days 2 and 7, a further 16% between days 7 and 22 and only 3% between days 22 and 28. The disappearance rates for each survey date did not change between experiments carried out on different months ($P>0.08$ in all cases). On day 28 after the placement of the carcasses under the power lines, 71.5% of the initial sample had disappeared. This carcass disappearance rate was not influenced by carcass density, either considering all power lines together in a sample [$Z = 1.35$, $P<0.18$, November vs. all other months; $\chi^2 = 0.6625$, d.f. = 1, $P<0.42$ between two winter tests (November and February) to control for a possible seasonal effect] or testing each power line separately ($P>0.18$ in all cases).

The result of the generalized model showed that carcass disappearance on day 28 was influenced by carcass size (higher rate for smaller carcasses) and power line, with no significant effects of other variables or interactions among them (Table 1). There were three power lines where disappearance rates differed from the rest: Belvis–Cobeña and El Casar–La Cueva, where the disappearance rate was 23 and 19% lower than average, respectively, and Pinto–San Martín de la Vega, where it was 20% higher. The model was highly significant ($\chi^2 = 133.016$, d.f. = 19, $P<0.001$), explaining 39.5% of the total deviance. Carcass size was included in the first eight models selected as the best subsets (all eight were highly significant, $P<0.001$, Table 2), confirming its higher relevance as compared with power line (included in models 1–4 and 9–11). Vegetation height and

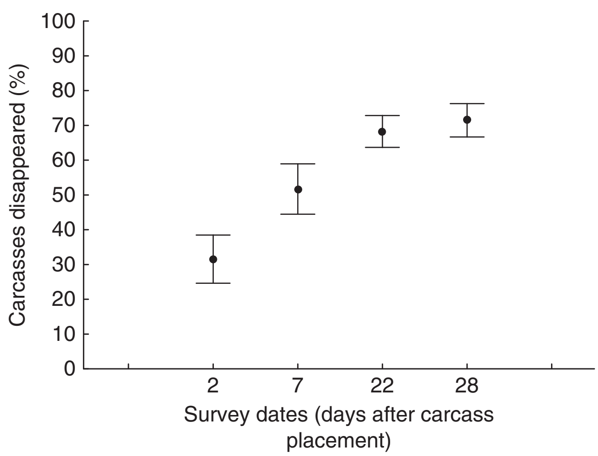

Figure 2 Cumulative percentage of carcasses that had disappeared on the different survey dates (= day after carcasses were placed under the power line). Means and standard deviations are given.

cover appeared in models 2 and 3, respectively, as well as in various successive models, all of them with ΔAICc > 2 (Table 2).

The function describing the disappearance rate through the first month for each carcass size is shown in Fig. 3. On survey day 28, 42.5% of large, 62.1% of medium-sized, 86.9% of small and 93% of very small carcasses had disappeared, with significant differences among these values ($H_{3,16} = 13.08$, $P < 0.005$). The differences were significant between large and medium ($Z = -2.31$, $P < 0.021$), and between medium and small ($Z = -2.32$, $P < 0.020$), but not between small and very small carcasses ($Z = -1.15$, $P < 0.25$). The disappearance rates for each carcass size did not change with carcass density ($P > 0.54$, > 0.47, > 0.46 and > 0.50, respectively, from large to very small) or power line ($\chi^2 = 0.28 <$ P 0.99). Using the weights of the four size classes, we obtained an equation predicting the disappearance rate at 28 days as a function of weight (Fig. 4).

Carcass detection by observers

On average, an observer discovered 53% of the carcasses present. However, there were significant differences in their ability to find the remains ($\chi^2 = 3.88$, d.f. = 1, $P < 0.05$; observers A, B, C and D found 25, 57.1, 68.4 and 70.4% of the carcasses, respectively). The generalized model showed that carcass detectability was influenced by carcass size and observer, with no significant effect of vegetation height or cover and their interaction (Table 3). The model was highly significant ($\chi^2 = 38.56$, d.f. = 7, $P < 0.001$), explaining 20.0% of the total deviance. Large carcasses were detected in a higher proportion (71.7%) than the other sizes (55.8, 32.1 and 33.3% for medium-sized, small and very small carcasses, respectively, $\chi^2 = 0.03$, d.f. = 1, $P < .05$), with no differences among medium to very small sizes ($P > 0.08$ in all cases). Fifteen significant candidate models were obtained, the first two of which had ΔAICc < 2 and included observer (not in model 2), carcass size and vegetation height (Table 4). Using the kilometres of power line surveyed by each observer before this study as an index of their experience in detecting carcasses, this factor explained 92% of the variation in the detection rate (Fig. 5).

Discussion

Our results indicate that the removal of carcasses by scavengers reduced the number of dead birds placed initially under power lines. The number of carcasses present followed a logarithmically decreasing trend through the days following trial start. Second, searcher efficiency biased the number of carcasses to a lower level by a variable extent, depending on previous personal training. Third, these two sources of bias increased with decreasing carcass size, and the removal rate was also site-dependent. The corresponding corrections should be taken into account when using carcass surveys to calculate bird mortality estimates due to electrocution or collision at power lines.

The above conclusions can be drawn despite the following methodological limitations, which could have affected the scavenging rates obtained. For example, our presence in the area and handling of the carcasses when placing them may have either attracted or deterred scavengers. Scavengers could have followed human trails to carcasses or,

Table 1 Results of the generalized linear model for carcass disappearance on the last survey date (day 28 after placing carcasses)

Variable	Partial deviance	*P*
Carcass size	76.43	0.001
Power line	28.17	0.001
Month	4.34	0.226
Month × carcass size	2.37	0.498
Vegetation height	0.00	0.961
Vegetation cover	0.10	0.749

Table 2 Models selected as best significant subsets by the generalized linear model for carcass disappearance (see Table 1), ranked according to ΔAICc

Model number	AICc	ΔAICc	w_i[a]	K[b]	P[c]
1 Carcass size – power line	426.78	0	0.534	13	0.001
2 Carcass size – power line – vegetation height	428.88	2.10	0.187	14	0.001
3 Carcass size – power line – vegetation cover	428.90	2.12	0.185	14	0.001
4 Carcass size – power line – vegetation height – vegetation cover	430.99	4.21	0.065	15	0.001
5 Carcass size	433.86	7.08	0.015	3	0.001
6 Carcass size – vegetation height	435.84	9.06	0.006	4	0.001
7 Carcass size – vegetation cover	435.89	9.11	0.006	4	0.001
8 Carcass size – vegetation height – vegetation cover	437.74	10.96	0.002	5	0.001
9 Power line	528.95	102.17	0.000	12	0.027
10 Power line – vegetation height	531.01	104.23	0.000	13	0.041
11 Power line – vegetation cover	531.05	104.27	0.000	13	0.041

[a]Model weight.
[b]Number of parameters.
[c]Significance of the model.
AIC, Akaike's information criterion.

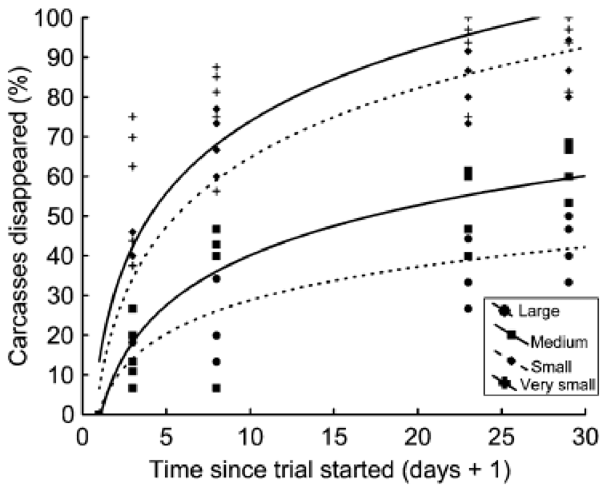

Figure 3 Cumulative percentage of carcasses of each size that had disappeared over the four surveys (days 2, 7, 22 and 28; survey dates were transformed as $x = \text{day} + 1$). For each carcass size, five data corresponding to the five trials conducted on different months are represented (November, December, February, April and August; in December it was not possible to carry out the survey on day 28 due to unfavourable weather conditions). The curves represent the logarithmic models that fitted best to these monthly disappearance figures. Large size: $y = 0.744 + 28.063 \times \log10\ (x)$ ($r = 0.83$); medium size: $y = -1.751 + 41.880 \times \log10\ (x)$ ($r = 0.88$); small size: $y = -6.623 + 58.111 \times \log10\ (x)$ ($r = 0.84$); very small size: $y = 13.538 + 60.342 \times \log10\ (x)$ ($r = 0.75$). $P < 0.001$ in all cases.

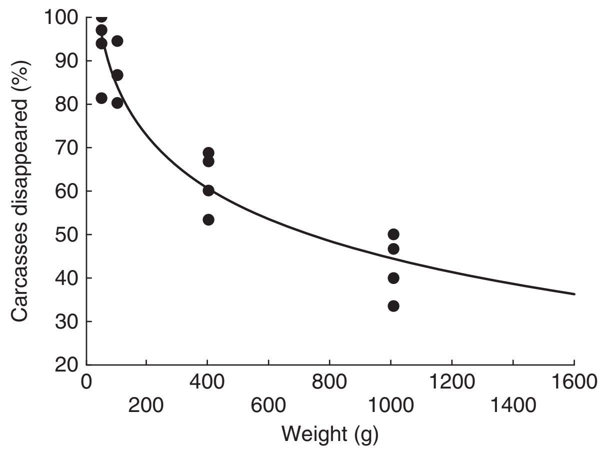

Figure 4 Percentage of carcasses that had disappeared on the last survey (day 28) for each bird weight class. Black dots are the values for the four trials (November, February, April and August). The curve represents the logarithmic equation adjusted to these values: $y = 166.295–40.567 \times \log10\ (x)$ ($r = 0.93$, $P < 0.001$).

alternatively, shy species might have avoided carcasses or sites tainted with human scent (Wobeser & Wobeser, 1992). We believe, however, that these effects were negligible because in our study area, scavengers are likely to be used to human presence due to the frequent occurrence of human activities such as farming, sheep herding and hunting. We attempted to minimize other possible sources of error based on carcass odour or conspicuousness. The results of previous studies have suggested that brighter-coloured corpses may be more conspicuous and easier to be detected by aerial scavengers (e.g. Balcomb, 1986; Prosser *et al*., 2008). This, however, would not influence the removal rates by mammalian scavengers, which mostly search by scent and are nocturnal. More frequently, researchers have drawn attention to the removal rates, between wild bird carcasses and those of artificially reared species (Balcomb, 1986; Young Jr *et al*., 2003; Prosser *et al*., 2008). We used exclusively wild birds shot by hunters to minimize these odour-based effects. Moreover, we left corpses to air in a ventilated and cold room for 1 day before placing them to eliminate any scent from handling by hunters and suppliers. Also, the species we used belonged to the local fauna and were similar in plumage colour and pattern to most other steppe-birds living in the study area. Another source of variation in removal rate may be carcass placement density. Obviously, in carcass removal trials carcass density is higher than in most natural events, in order to make searches and calculations feasible within reasonable time and space limits. Some researchers have suggested that greater than normal carcass abundance may attract scavengers and either increase the removal rate (Bevanger *et al*., 1994), decrease it due to satiation (Linz *et al*., 1991) or produce no observable effects (Wobeser & Wobeser, 1992; Prosser *et al*. 2008). Other studies carried out in the same power lines by us showed that around eight wild dead birds per kilometre were found under them during 1 year of sampling (one each month); hence, if we consider that many of the collision or electrocuted victims may have been moved by scavengers or not found by the observers (as we have demonstrated in the present work), we can assume that we have not significantly increased the density of dead birds with respect to normal casualties. But to test for this possibility in this experiment, we compared our standard density with a four-fold density, and found no differences in the removal rate.

Table 3 Results of the generalized linear model for carcass detectability

Variable	Partial deviance	*P*
Carcass size	16.42	0.001
Observer	8.38	0.039
Vegetation height	2.26	0.133
Vegetation cover	0.00	0.965
Vegetation height × vegetation cover	1.87	0.140

Carcasses were removed by scavengers with the highest intensity immediately after placement. Later, the removal rate decreased regularly through a period varying between a few days and several weeks. The accumulative disappearance curves best fitting the data were logarithmic and similar in shape for all four size classes tested, but smaller carcasses disappeared earlier and at a higher proportion than larger carcasses. Our results show that the removal rate increased

Table 4 Models selected as best significant subsets by the generalized linear model for carcass detection rate (see Table 1), ranked according to ΔAICc

Model number	AICc	ΔAICc	w_i[a]	K[b]	P[c]
1 Observer – carcass size – vegetation height	171.18	0	0.431	7	0.001
2 Carcass size – vegetation height	173.07	1.89	0.166	4	0.001
3 Observer – carcass size – vegetation height – vegetation cover	173.42	2.25	0.140	8	0.001
4 Observer – carcass size – vegetation cover	173.43	2.26	0.140	7	0.001
5 Carcass size – vegetation height – vegetation cover	175.15	3.98	0.059	5	0.001
6 Observer – carcass size	176.15	4.98	0.036	6	0.001
7 Carcass size–vegetation cover	176.84	5.67	0.025	4	0.001
8 Observer – vegetation height	185.42	14.24	0.000	6	0.001
9 Carcass size	185.75	14.58	0.000	3	0.001
10 Observer – vegetation cover	186.24	15.07	0.000	6	0.001
11 Observer	186.99	15.82	0.000	5	0.001
12 Observer – vegetation height – vegetation cover	187.60	16.42	0.000	7	0.001
13 Vegetation height	188.60	17.42	0.000	3	0.001
14 Vegetation height – vegetation cover	190.58	19.41	0.000	4	0.006
15 Vegetation cover	190.64	19.47	0.000	3	0.004

[a]Model weight.
[b]Number of parameters.
[c]Significance of the model.
AIC, Akaike's information criterion.

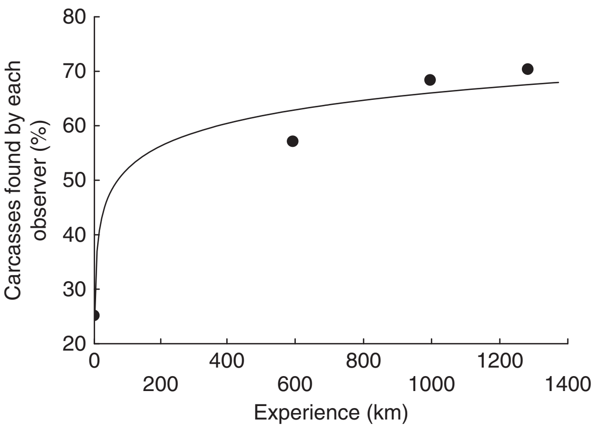

Figure 5 Detection ability of the four observers participating in the detectability trial (black dots), as a function of their experience (defined as the number of kilometres of power line surveyed before the present study). The curve represents the equation adjusted to the four detection ability values: $y = 24.461 + 13.827 \times \log10\ (x)$ ($r = 0.961$, $P < 0.04$).

with decreasing carcass size, except for the two smallest size classes, that were removed at similar rates. These smaller carcasses were most frequently removed without leaving any remains (66.7% of small and 85.7% of very small carcasses removed on day 2), in contrast to larger corpses, which were normally partially eaten on the spot (on day 2, 78.8% of medium and 73.6% of large corpses; all size differences significant, $P < 0.02$). The remains of larger corpses were easily recognized through the entire series of search surveys, most often ending up as a pile of feathers that usually remained for several weeks on the spot, indicating past scavenger activity. These facts suggest that a wider spectrum of scavenger species were able to feed on and remove corpses below a certain size, whereas potential predators able to remove larger carcasses at once were much scarcer, and these large corpses were discovered and as a rule incompletely devoured by the same scavengers as those feeding on the smaller corpses. Common scavengers in our study area include mammals such as red fox *Vulpes vulpes*, feral dogs *Canis familiaris*, feral cats *Felis silvestris catus* and black rat *Rattus rattus*, and birds such as black and red kites *Milvus migrans* and *Milvus milvus*, corvids such as magpies *Pica pica*, jackdaws *Corvus monedula*, ravens *Corvus corax*, white storks *Ciconia ciconia* and black-headed and black-backed gulls *Larus ridibundus* and *Larus fuscus*. The fact that we did not find differences among carcass sizes in the scavenger detection rate (which includes both disappeared and partially eaten carcasses) indicates that corpses were found opportunistically, and not due to their visibility. This suggests that the most frequent scavengers in our study area were probably mammals, which mostly hunt by scent (see also Kostecke, Linz & Bleier, 2001 for the same interpretation based on the results confirmed through photographic evidence). Smallwood *et al*. (2008) found that 74 and 63% of the carcasses were detected and removed, respectively, by mammals, although in these, study differences among carcass sizes were found. However, identification of all scavenger species and their relative contribution to the disappearance of carcasses were not among our objectives.

Previous studies have also found decelerating removal rates (Balcomb, 1986; Ward *et al*., 2006), and very high initial removal rates among smaller carcasses, most of which disappeared within the first days (Heijnis, 1980; Wobeser & Wobeser, 1992; Prosser *et al*., 2008). However, few of these studies followed carcasses for more than 1 week, which makes estimation of the eventual fate of certain carcasses difficult, particularly of the larger ones, which usually survive longer. Here, we surveyed power lines for 4 weeks after placement, because one of our main objectives was to determine the frequency with which carcass searches should be conducted to determine fatalities at power lines. Although most mortality studies at power lines are based on weekly to monthly survey frequencies, such periodicity is usually fixed without a well-founded basis. The disappearance curves obtained in our study over a month for various bird sizes offer the opportunity to determine an acceptable search frequency, depending on the bird species for which removal rates are required. An interesting result not found in most previous studies was that for all four carcass sizes tested, further removals were recorded even over 20 days after placing the corpses.

The second factor influencing the removal rate was the power line. No significant effects were found from other variables such as season or vegetation structure, suggesting a relatively uniform scavenger pressure through the year and among different substrate types. Changes in scavenger density have been suggested to be the main reason for the differences in the removal rate found among sites (Kostecke *et al.*, 2001), seasons (Bevanger *et al.*, 1994; Linz *et al.*, 1991; Johnson *et al.*, 2003; Prosser *et al.*, 2008) or areas with different vegetation structures (Bevanger *et al.*, 1994; Bevanger, 1995; Siriwardena *et al.*, 2007). In the present study, only three power lines showed unusual removal rates. The Pinto – San Martín de la Vega line was close to a huge rubbish dump, where large numbers of black kites and white storks are found in spring and summer, and black-headed and lesser black-backed gulls aggregate by thousands, mainly in winter. Individuals of all these species have wide home-ranges and could have easily contributed to the higher carcass removal rate recorded at this power line. The two power lines with the lowest removal rates were located in close proximity to villages, which might have led to a lower density of scavengers and therefore a lower removal rate. However, the purpose of our study was to explore only the relative amount of local or seasonal differences and their effect on removal rate, not to investigate the causes of such differences. Based on the significant differences found in three of 11 lines, we conclude that scavenger rates are probably site-dependent in most cases. Moreover, although seasonal differences in the removal rate did not reach statistical significance in our study, the range of values obtained for different months was quite wide, which suggests that seasonal variation could be an important factor to be considered in future studies. A similar conclusion can be drawn for vegetation structure, which did not appear to affect the removal rate significantly, but appeared on some of the candidate models selected in our analyses. Overall, this suggests that local, seasonal and other differences due to vegetation structure may affect scavenger removal rate to a variable extent, and therefore, the figures given in the present study should be considered with care. For example, a more dense, diverse or higher vegetation could be an influential variable in studies focusing on small birds. The correction indices derived from our trials could probably be applied to estimate mortality from power-line collisions in similar habitats within the Mediterranean region, being less useful for areas differing considerably in geographical location, habitat structure or scavenger community. Studies similar to the present one should be conducted in areas with completely different climatic conditions, that is where the ground is covered with snow through several months in winter, or the vegetation and habitat structure are quite different, in order to determine the importance of weather and vegetation variables and obtain more reliable correction factors.

Finally, the four observers participating in this study differed notably in their ability to find carcasses (25–70.4%). A similar range in detectability values has also been reported in previous studies (e.g. 35–85% in Morrison's, 2002 review). Lower detection rates have been attributed to a higher (Philibert, Wobeser & Clark, 1993) or denser (Wobeser & Wobeser, 1992) vegetation. In our farmland study area, changes in vegetation structure were probably not sufficient to determine significant variations in detectability. The two factors that we found to influence detectability were carcass size and previous experience of the observer. Larger carcasses were detected at a higher proportion than smaller carcasses, as reported in Siriwardena *et al.*'s (2007) review of mortalities caused by wind turbines. The correlation found in our study between the detection rate and previous experience of the observer specifically conducting these kinds of searches at power lines is an important new result that highlights the importance of a training period for field workers participating in carcass searches intended to estimate mortality rates at power lines. We cannot exclude that other factors, for example personal motivation, may influence the search detection rate. Finally, the results should be interpreted with caution, due to the small number of observers who participated in the experiment.

Conclusions and management implications

Carcass counts at power lines will notably underestimate the number of bird casualties, the bias being higher for smaller birds. Mortality estimates should incorporate correction factors based on scavenging rates and observer efficiency. Conservation authorities and power-line operators should be aware of these sources of bias and adjust past and future estimates before using them to assess bird mortality resulting from collisions with power lines. Scavenger removal rates differed to a huge extent with carcass size, being much higher for small birds. A high proportion of these small carcasses had disappeared 2 days after placement and *c.* 90% after 2 weeks. This indicates that fortnightly to monthly search frequencies may be adequate to detect casualties of medium to large species, but are insufficient for smaller species. For the latter, a higher search frequency is recommended, in order to reduce the uncertainty interval implicit in extrapolations from equations such as those presented here. Although site-related and seasonal differences found in our study did not reach statistical significance, the range of values obtained for a sample of 55 surveys (5 months $\times$ 11 power lines) was considerable. This suggests that, if precise mortality estimates are required, scavenger removal trials should be carried out simultaneously with searches aiming to estimate collision mortality. We recommend carrying out such complementary removal trials whenever possible. Alternatively, the equations presented here may be used to obtain mortality estimates in Mediterranean farmland. Figures may vary substantially between this and other farmland habitats at different latitudes. Therefore, similar studies are needed in these habitats to evaluate the effects of various sources of bias affecting the scavenger removal rates there. Finally, all personnel participating in carcass searches should be trained previously in this task, in order to minimize detection errors due to lack of experience.

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