Bird Conservation International (2017) 27:431–439.
doi:10.1017/S0959270916000460

Testing for errors in estimating bird mortality rates at wind farms and power lines

MIGUEL ÁNGEL FARFÁN, JESÚS DUARTE, JULIA E. FA, RAIMUNDO REAL and JUAN MARIO VARGAS

Summary

Wind power, as an alternative to fossil fuels, is increasingly common, and is expanding worldwide. Wind farms cause mortality of flying animals through collision with moving rotor blades, and from electrocution on associated power lines. Avian mortality rates have been estimated from birds collected under turbines over varying time intervals. However, without adequate and frequent monitoring, dead birds may be removed by scavengers and thus cause an underestimation of fatalities. In this paper, we tested experimentally for possible errors arising in avian mortality caused by the removal of carcasses by scavengers. At two different wind farms and associated power lines in southern Spain, we placed pigeon and quail carcasses to determine their disappearance rate. All dead pigeons were radio-tagged to estimate distances taken by scavengers. We found significant differences in carcass disappearance rates of pigeons and quails, and between wind farms and power lines but not between habitats. All quails and 45% of pigeon carcasses had disappeared by the third and fourteenth day, respectively. Less than half (40%) of the carcasses were found < 100 m from where they were deposited. While scavenging losses may vary according to the location of the wind farm or power line, here we propose a method to estimate correctly the number of fatalities at any wind farm and power line. Using this method, we can improve our understanding of the real impact of wind structures on adjacent bird communities, and adopt appropriate measures to ensure their conservation.

Introduction

Since the 1980s, wind farms have become an economically attractive energy option (ITDG 2005), often receiving substantial governmental support in many countries (Carrete *et al.* 2009). As a result, wind farms have proliferated worldwide and this trend is expected to continue (Ledec *et al.* 2011). In Spain, the rise in the number of wind farms is unprecedented. The country is now the fifth producer of wind energy in the world, with an installed capacity of 22,988 MW distributed at 1,077 wind farms by the end of 2015 (AEE 2016). However, because Spain is along an important flyway for many birds migrating between Europe and Africa, the potential negative impact of wind farms can be substantial and therefore needs adequate study.

Wind farms have negative environmental impacts on the landscape and can cause high mortality in birds and bats (May *et al.* 2015, Peste *et al.* 2015). Birds are often killed by collisions and electrocutions (Drewitt and Langston 2008, Lucas *et al.* 2012), but they can also be displaced from their nesting sites, foraging areas, as well as have their daily transit and migration routes disrupted (Drewitt and Langston 2006). For some species, deaths caused by turbine collisions can be significantly high, and may negatively impact their populations (Johnson *et al.* 2002). In particular, long-lived species such as vultures, eagles and other birds of prey, are more vulnerable (Carrete *et al.* 2009, Sanz-Aguilar *et al.* 2015).

Generally, in most countries, environmental authorities require wind developers to monitor sites for 1–2 years after the start of operations of wind farms and power lines post-construction to assess the impact on birds. Around these structures, bird mortality is frequently estimated by direct measurement of bird collisions. However, there is no legislation stipulating a standard monitoring frequency. Often, monitoring is arbitrarily decided by the individual environmental authorities for each specific case. The most common procedure is for bird carcass searches to take place every 1–2 weeks within a 50–100 m radius around turbines or under power lines in the monitored wind farms (Ferrer *et al.* 1991, Osborn *et al.* 2000, Lucas *et al.* 2004, Drewitt and Langston 2008, Farfán *et al.* 2009, Lasch *et al.* 2010). There is no scientific evidence supporting this monitoring frequency or search area radius.

Studies of bird mortality around wind farms and power lines usually report relatively low rates (Alonso and Alonso 1999, Erickson *et al.* 2001, Langston and Pullan 2003, Percival 2005, Farfán *et al.* 2009, Gue *et al.* 2013). Such low impact levels may reflect a mismatch between the location of the wind farm or power line and the concentrations of birds (Carrete *et al.* 2012), but may also be the result of a relatively low coverage of sites. Moreover, most studies report body counts without taking into account carcass detectability due to habitat differences, search efficiency and effort, or removal of carcasses by scavengers (Scott *et al.*1972, Morrison 2002, Erickson *et al.* 2005, Smallwood 2007, Drewitt and Langston 2008, Carrete *et al.* 2009). Although all these factors are sources of error and variation when determining wind farm bird mortality (Gehring *et al.* 2009, Longcore *et al.* 2012), carcass removal by scavengers is likely to considerably bias estimates. This is so because removal of carrion is quick and prevalent in most habitats (Kostecke *et al.* 2001, Prosser *et al.* 2008, Ponce *et al.* 2010, Smallwood *et al.* 2010). In particular, if the time interval between carcass searches is more than the permanence of a carcass in an area, then observers will only detect a small percentage of these.

The persistence of animal carcasses at wind farms or power lines has been investigated by some authors. For example, Ferrer *et al.* (1991) showed that 70% of rabbit *Oryctolagus cuniculus* carcasses placed under pylons and power lines, disappeared within one month after placement. In contrast, Lucas *et al.* (2008) indicated that large bird carcasses, equivalent to or larger than a black kite *Milvus migrans* could remain for months or even years untouched by scavengers. However, information on how long small to medium-sized birds (such as kestrels, pigeons, or small passerines) killed at wind farms remain, is still limited (Drewitt and Langston 2008).

In this paper, we experimentally examine the rates of removal by scavengers of pigeon (representing medium-sized birds) and quail carcasses (representing small birds) placed at wind farms and power lines in southern Spain. We quantified permanence rates of these two different sized birds. In addition, we placed radio transmitters on some pigeon carcasses to calculate dispersal distances caused by scavengers. From the data obtained in our study we developed a useful metric to correct potential errors arising in the estimation of avian mortality rates at wind farms and power lines caused by carcass removal by scavengers

Methods

Study area

The study wind farms, "Puerto de Malaga" and "Sierra de Baños", and their associated power lines, were located in Malaga province, southern Spain (UTM 30SUF38). Both wind farms were situated on a W-E oriented mountain ridge and were contiguous. In total there were 13 wind turbines (150 m apart along 1,800 m), evenly distributed along a continuous row, 555–727 m above sea level. The power line was located along the westernmost part of the wind farms and run in a N-S direction; a total length of 23,000 m. We studied the 5-km stretch nearest to the wind farms (Figure 1).

Vegetation in the study area was dominated by Mediterranean-type scrubland. The most representative species are *Phlomis purpurea*, *Phlomis lychnitis*, *Quercus coccifera*, *Chamaerops humilis*,

https://doi.org/10.1017/S0959270916000460 Published online by Cambridge University Press

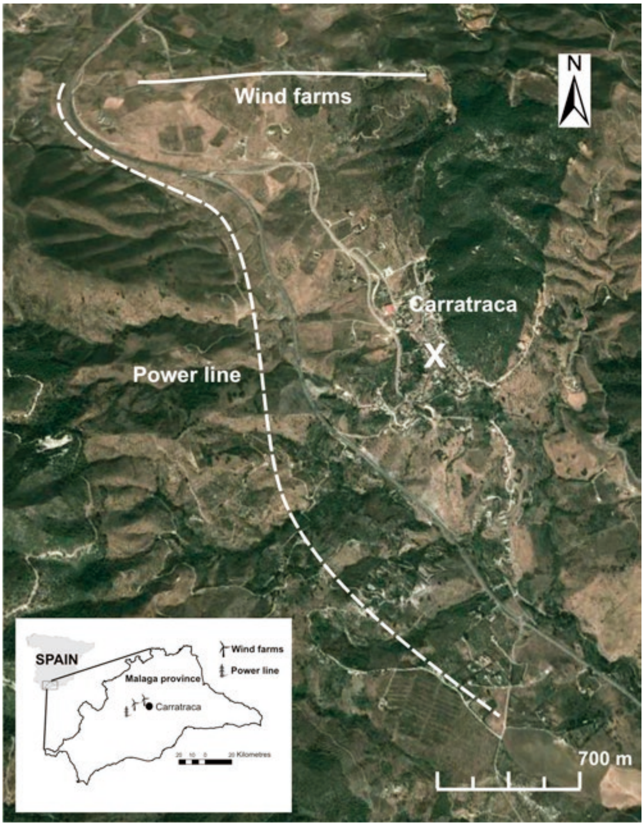

Figure 1. Location of the study area. X: geographic reference (36° 51′ 9″N; 4° 49′ 12″W)

Rosmarinus officinalis, *Cistus albidus*, and *Ulex parviflorus*. There were also scattered Aleppo pine trees *Pinus halepensis* along the eastern section of the wind farms. In the lower western area, scrubland was found mixed with cereals and olive groves.

The vertebrate community in the study area is represented by several bird and mammal species (Martí and Del Moral 2003, Palomo *et al.* 2007). The main scavengers present in the area were Common Raven *Corvus corax*, red fox *Vulpes vulpes* and Egyptian mongoose *Herpestes ichneumon*. Feral cats and dogs were also very common (pers. obs.).

Field methods

Our study lasted between May and September 2009. We placed a total of 57 bird carcasses (22 domestic pigeons *Columba livia f. domestica* and 35 Common Quails *Coturnix coturnix*) at the two wind farms, and on the 5-km associated power line along nine different series (Table 1). All carcasses were positioned between 08h00 and 10h00. At the wind farms, carcasses were randomly distributed around a maximum radius of 70 m from a wind turbine, but were randomly placed under pylons and power lines. Bird carcasses were spread far apart to avoid an increase in removals caused by a higher carcass density (Bevanger *et al.* 1994, Stevens *et al.* 2011). We also placed carcasses in the two different habitats found in the study area: crops and scrubland. All carcasses were inspected daily, as recommended by Smallwood (2007). We estimated the Kaplan-Meier product limits to measure the disappearance rate of carcasses (White and Garrott 1990).

Table 1. Distribution of pigeons and quails placed in the two wind farms and power line. The date and habitat used in the nine series are shown.

Date	Pigeons		Quails		Habitat
	Wind farm	Power line	Wind farm	Power line	
19/05/2009		3			crop (3)
01/06/2009		3			scrubland (3)
11/06/2009		4			crop (2), scrubland (2)
06/07/2009	6				crop (4), scrubland (2)
14/07/2009	4				crop (1), scrubland (3)
04/08/2009	2				scrubland (2)
24/08/2009			5	5	crop (4), scrubland (6)
07/09/2009			7	8	crop (7), scrubland (8)
25/09/2009			5	5	crop (5), scrubland (5)

We attached a 27-g TW 3 brass collar transmitter (Biotrack, UK) to all dead pigeons. To locate the carcasses, we employed a GPS eTrex Vista Cx (Garmin, USA), a portable Yagi-antenna, and a Yaesu VR-500 receiver (Wagener Telemetrie, Germany). The homing-in technique was used to locate all carcasses (White and Garrott 1990). The dispersal distance (in metres) of each carcass was estimated as the span between the point where the carcass was placed and the point where it was discovered or radio transmitter found.

Statistical approach

We used a GLM with Poisson error distribution and a log-link function model (Crawley 1993) to analyse whether type of carcass (quails *vs* pigeons), habitat type (crops *vs* scrubland) and placement site (wind-power plant *vs* power line) affected the permanence time (in days), the dependent variable.

All mean values of analysed parameters are given with their standard error.

To calculate the mortality rate linked to the studied wind farms and associated power line, we employed the following equation:

$$EMR = \frac{OCB}{ED} \tag{1}$$

where *EMR* is the estimated daily mortality rate, *OCB* is the observed number of carcasses, and *ED* is the number of equivalent days, i.e. the number of days in which the collision of birds yielded the observed carcasses if the disappearance rate was zero. *ED* was calculated by adding the proportion of daily persistence for quail and pigeon carcasses, respectively.

From equation (1) it follows that the estimated mortality during a specific period of time results from the *EMR* multiplied by any number of days between successive monitoring days.

Bias in estimating bird mortality

We used disappearance rate and dispersal distances of pigeons obtained in this study to show that the current monitoring schemes approved by the environmental authorities (at a frequency of 1–2 weeks and over a surface of 50–100 m) may underestimate mortalities of medium-sized birds.

Results

As revealed by radio tagging, most carcasses (60%) were taken from where they were first deposited to distances of > 100 m. The GLM model showed a good fit to the Poisson distribution (0.931) and explained 71.4% of the deviance. The model revealed that carcass type and placement site had the highest explanatory power (highest Wald statistic values); both variables had a significant effect on permanence time (Table 2). Permanence time was positively affected by carcass type, higher for pigeons (4.6 ± 0.7 days) than for quails (1.5 ± 0.3 days), but negatively affected by placement site. Permanence was less around wind turbine sites compared to the power line regardless of carcass type (wind turbines: pigeons: 4.1 ± 1.1 days, quails: 1.0 ± 0.3 days; power line: pigeons: 5.1 ± 1.0 days, quails: 2.1 ± 0.5 days).

The disappearance rate of quails was 55% on the first day, 85% on the second day, and 100% on day 3. Disappearance rate was less for pigeons; 10% on the three first days and 45% until day 14 (Figure 2).

Using the disappearance rates for quails and pigeons, the daily mortality rate was estimated as:

1. Quails:

$$ED_{\text{quails}} = 1.00 + 0.45 + 0.16 = 1.61$$

$$EMR = \frac{OCB}{1.61}$$

2. Pigeons:

$$ED_{\text{pigeons}} = 1.00 + 0.89 + 0.89 + 0.89 + 0.55 + 0.55 + 0.55 + 0.55 + 0.55 + 0.55 + 0.55 = 7.52$$

$$EMR = \frac{OCB}{7.52}$$

At both seven and 14 days, the proportion of pigeons remaining on the placement sites was 55% (12 carcasses) but the remaining 45% (10 carcasses) were spread by scavengers. Scavengers displaced three carcasses < 50 m, and one other up to distances of 50–100 m. Monitoring with a frequency of 7–14 days and a sampled surface area of 50 and 100 m underestimated bird mortality by 31.8% and 27.3%, respectively.

Discussion

Previous studies on the impact of wind farms on birds have focussed on documenting mortality by collisions on wind farms, by recording species found dead under turbine blades (Martínez-Abrain *et al.* 2012). Small birds and bats may have been overlooked in previous carcass searches (Kunz *et al.* 2007) due to cryptic colouration, small body size, rough topography, or thick vegetation, among other factors. The practice of counting dead birds in wind farms has been considered to underestimate fatalities due to air currents blowing carcasses away from the collision site, and to an unknown impact of scavengers removing carcasses (Desholm *et al.* 2006). In this paper, we show that the reported low mortality rates currently used to dispel any concerns about wind energy may be seriously affected by the removal of carcasses by scavengers. We demonstrate that, at least in spring and summer, the disappearance rate of dead animals is greater than the search

Table 2. Results of the GLM model analysing factors affecting the permanence time (in days) of two types of carcasses. Factors included in the model were type of carcass (1, pigeon or 2, quail), type of placing site (1, wind-power plant or 2, power line) and type of habitat (1, crops or 2, scrubland).

Source of variation	B ± SE	df	Wald	*P*
Experimental carcass	1.099 ± 0.1697	1	41.950	< 0.001
Placing site	-0.402 ± 01693	1	5.627	0.018
Habitat	0.054 ± 0.1693	1	0.102	0.749

https://doi.org/10.1017/S0959270916000460 Published online by Cambridge University Press

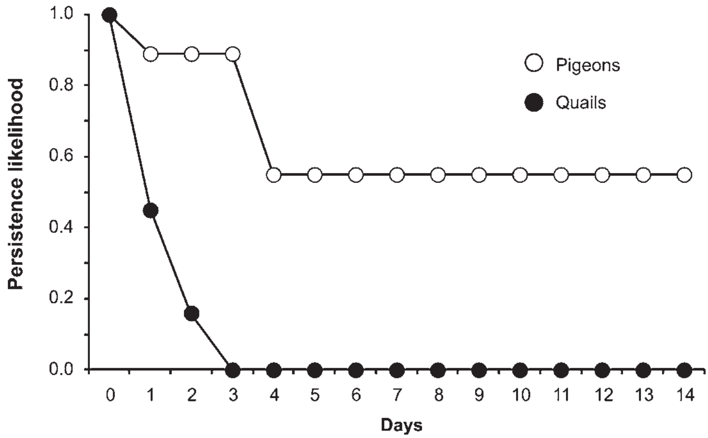

Figure 2. Kaplan-Meier disappearance functions for pigeon and quail carcasses experimentally deposited under wind farms and power line in the study area.

intervals usually proposed by environmental authorities (periods of 7–14 days), hence clearly underestimating the number of dead animals.

Our results, alongside those of other authors, indicate that scavengers can remove carcasses within a few days. Prosser *et al.* (2008) found removal rates of up to 32% (winter) and 91% (summer) within four days, Kostecke *et al.* (2001) up to 66% within five days, and Ponce *et al.* (2010) up to 66.7% of small birds (represented by quails) and 85.7% of very small birds (represented by quail halves) within two days after placement. In contrast, Smallwood *et al.* (2010) found that scavengers took away large-bodied raptor carcasses within 15 days; none during winter and 67% in summer. Urquhart *et al.* (2015) showed that 85% of Buzzard *Buteo buteo* carcasses could remain for up to a period of 95 days. These results indicate that the recommended monitoring period of 7–14 days for carcass search surveys is insufficient, especially when recording the impact on small-sized birds. Our study demonstrates that scavengers can remove quails (representing small birds) faster than they remove pigeons (representing medium-size birds). Other authors have also found that scavengers will remove small birds in very short periods of time (Kerlinger *et al.* 2000, Lekuona and Ursúa 2007, Ponce *et al.* 2010, Stevens *et al.* 2011), while raptor carcasses may persist longer than non-raptors (Smallwood 2007, Urquhart *et al.* 2015).

The lower permanence of experimental carcasses under wind farms compared to the power line obtained in this study can be explained by the differences in the abundance of scavengers at these sites. From our own observations, we suggest that feral cats and dogs may have been more abundant in wind farms. However, we have not performed any analyses to determine whether there was a significant effect of this factor.

Our results also show that there were more carcasses dispersed at distances of > 100 m. These observations suggest that it is highly unlikely for monitors employed by environmental authorities to discover dead animals within the currently used radius of 50–100 m around wind farms and power lines therefore underestimating bird mortality. We further argue that monitoring bird mortality every 7–14 days and around a 50–100 m radius will severely underestimate medium-sized bird mortality, as shown by our pigeon data. Although we did not radio-tagged quails, representing small birds, the disappearance rate indicates that for this species, monitoring every 7–14 days and within a 50–100 m radius, also underrepresents small bird mortality.

From our results, we are confident in suggesting, as Drewitt and Langston (2008) do, that the currently reported bird mortality rates at wind farms is only the minimum number of actual fatalities. If our study is confirmed in other sites, given the proliferation of wind farms and associated power lines worldwide, there is a pressing need to improve the methods used in fatality studies.

It is fundamental to determine the real impact of these structures on flying fauna, and ensure the conservation of the most vulnerable species.

A key challenge in wildlife mortality surveys is, among other factors, the control of errors caused by not taking into account the impact of scavengers. Accounting for the fact that these losses are specific to wind farms or power line, a first step would be to correct the estimation of fatalities for each wind farm and associated power line. In the present study, we propose a method that could be applied to any wind farm and power line in different habitats, bird communities or scavenger communities. If the correction of the number of fatalities is not applied, increasing search effort can minimize biases. Environmental authorities must demand shorter periods for search surveys as the current recommended period of 7–14 days is clearly insufficient. As we discuss, scavenging losses are wind farm and power line-specific but the number of days during which small and medium sized (non-raptor) birds persist is very short. Thus, according to our results, and in line with Kostecke *et al.* (2001), we consider it reasonable to recommend that in spring and summer, when a higher proportion of carcasses are likely to be removed by scavengers (Prosser *et al.* 2008, Ponce *et al.* 2010), searches are undertaken daily for small birds and at 3-day intervals for medium-sized birds. By implementing such carcass search frequencies will no doubt improve the mortality rate estimation of, until now, a fairly neglected group of organisms affected by the wind power industry.

Acknowledgements

We thank to Gonzalo Zubieta and IBERDROLA, the property developer of "Sierra de Baños" and "Puerto de Málaga" wind farms respectively, for allowing us to carry out the present study on their properties. This work has been partially supported by the Spanish Ministry of Agriculture, Food and Environment, Spanish National Parks Network, project 1098/2014. We are grateful to Jose Tella and two anonymous reviewers for their insightful comments on our paper.

References

Alonso, J. A. and Alonso, J. C. (1999) Collision of birds with overhead transmission lines in Spain. Pp. 57–82 in G. F. E. Janss and M. Ferrer, eds. *Birds and powerlines. Collision, electrocution and breeding*. Madrid: Quercus.

AEE (2016) Asociación Empresarial Eólica http://www.aeeolica.org

Bevanger, K., Bakke, O. and Engen, S. (1994) Corpse removal experiment with Willow Grouse (*Lagopus lagopus*) in power-line corridors. *Ecol. Birds* 16: 597–607.

Carrete, M., Sánchez-Zapata, J. A., Benítez, J. R., Lobón, M. and Donázar, J. A. (2009) Large scale risk-assessment of wind-farms on population viability of a globally endangered long-liver raptor. *Biol. Conserv.* 142: 2954–2961.

Carrete, M., Sánchez-Zapata, J. A., Benítez, J. R., Lobón, M., Montoya, F. and Donázar, J. A. (2012) Mortality at wind-farms is positively related to large-scale distribution and aggregation in griffon vultures. *Biol. Conserv.* 145: 102–108.

Crawley, M. J. (1993) *GLIM for ecologists*. London, UK: Blackwell.

Desholm, M. A., Fox, D., Beasley, P. D. L. and Kahlert, J. (2006) Remote techniques for counting and estimating the number of bird–wind turbine collisions at sea: a review. *Ibis* 148: 76–89.

Drewitt, A. L. and Langston, R. H. W. (2006) Assessing the impacts of wind farms on birds. *Ibis* 148: 29–42.

Drewitt, A. L. and Langston, R. H. W. (2008) Collision effects of wind-power generators and other obstacles on birds. *Ann. New York Ac. Sci.* 1134: 223–266.

Erickson, W. P., Johnson, G. D., Stricland, M. D., Young, D. P., Sernka, K. J. and Good, R. E. (2001). *Avian collisions with wind turbines: A summary of existing studies and comparisons to other sources of avian collisions mortality in the United States*. Washington, DC: National Wind Coordinating Committee (NWCC), Resource Document.

Erickson, W. P., Johnson, G. D. and Young, D. P. (2005) *A summary and comparison of bird mortality from anthropogenic causes with an emphasis on collision. USDA Forest Service General Technical Report PSW-GTR-191* (pp. 1029–1042).

Farfán, M. A., Vargas, J. M., Duarte, J. and Real, R. (2009) What is the impact of wind farms on birds? A case of study in southern Spain. *Biodivers. Conserv.* 18: 3743–3758.

Ferrer, M., de la Riva, M. and Castroviejo, J. (1991) Electrocution of raptors on power lines in southwestern Spain. *J. Field Ornithol.* 62: 181–190.

Gehring, J., Kerlinger, P. and Manville, A. M. (2009) Communication towers, lights, and birds: successful methods of reducing the frequency of avian collisions. *Ecol. Appl.* 19: 505–514.

Gue, C. T., Walker, J. A., Mehl, K. R., Gleason, J. S., Stephens, S. E., Loesch, C. R., Reynolds, R. E. and Goodwin, B. J. (2013) The effects of a large-scale wind farm on breeding season survival of female Mallards and Blue-Winged Teal in the Prairie Pothole Region. *J. Wildl. Manage*. 77: 1360–1371.

ITDG (Intermediate Technology Development Group) (2005) *Practical action – Wind electricity generation*. Warwickshire, UK: Schumacher Centre for Technology and Development.

Johnson, G. D., Erickson, W. P., Strickland, M. D., Shepherd, M. F., Shepherd, D. A. and Sarappo, S. A. (2002) Collision mortality of local and migrant birds at a large-scale wind-power development on Buffalo Ridge, Minnesota. *Wildlife Soc. B.* 30: 879–887.

Kerlinger, P., Curry, R. and Ryder, R. (2000) *Ponequin wind energy project: reference site avian study*. Golden, Colorado: National Renewable Energy Laboratory. (NREL/SR-500–27546).

Kostecke, R. M., Linz, G. M. and Bleier, W. J. (2001) Survival of avian carcasses and photographic evidence of predators and scavengers. *J. Field Orinthol.* 73: 439–447.

Kunz, T. H., Arnett, E. B., Erickson, W. P., Hoar, A. R., Johnson, G. D., Larkin, R. P., Strickland, M. D., Thresher, R. W. and Tuttle, M. D. (2007) Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. *Front. Ecol. Environ.* 5: 315–324.

Langston, R. H. W. and Pullan, J. D. (2003) *Wind farms and birds: an analysis of the effects of wind farm on birds, and guidance on environmental assessment criteria and site selection issues*. Report written by Birdlife International on behalf of the Bern Convention. Council Europe Report T-PVS/inf.

Lasch, U., Zerbe, S. and Lenk, M. (2010) Electrocution of raptors at power lines in Central Kazakhstan. *Waldökologie, Landschaftsforschung und Naturschutz* 9: 95–100.

Ledec, G., Rapp, K. and Aiello, R. (2011) *Greening the wind: environmental and social considerations for wind power development*. Washington, DC: World Bank Studies.

Lekuona, J. and Ursúa, C. (2007) Avian mortality in wind power plants of Navarra (Northern Spain). Pp. 177–192 in M. Lucas, G. F. E. Janss and M. Ferrer, eds. *Birds and wind farms: Risk assessment and mitigation*. Madrid, Spain: Quercus.

Longcore, T., Rich, C., Mineau, P., MacDonald, B., Bert, D. G., Sullivan, L. M., Mutrie, E., Gauthreaux Jr., S. A., Avery, M. L., Crawford, R. L., Manville II, A. M., Travis, E. R. and Drake, D. (2012) An estimate of avian mortality at communication towers in the United States and Canada. *Plos ONE* 7(4): e34025. doi: 10.1371/journal.pone.0034025

Lucas, M., Janss, G. F. E. and Ferrer, M. (2004) The effects of a wind farm on birds in a migration point: The Strait of Gibraltar. *Biodivers. Conserv.* 13: 395–407.

Lucas, M., Ferrer, M., Bechard, M. J. and Muñoz, A. R. (2012) Griffon vulture mortality at wind farms in southern Spain: distribution of fatalities and active mitigation measures. *Biol. Conserv*. 147: 184–189.

Lucas, M., Janss, G. F. E., Whitfield, D. P. and Ferrer, M. (2008) Collision fatality of raptors in wind farms does not depend on raptor abundance. *J. Appl. Ecol.* 45: 1695–1703.

Martí, R. and Del Moral, J. C., eds. (2003) *Atlas de las aves reproductoras de España*. Madrid, Spain: Dirección General de Conservación de la Naturaleza-Sociedad Española de Ornitología.

Martínez-Abraín, A., Tavecchia, G., Regan, H. M., Jiménez, J., Surroca, M. and Oro, D. (2012) Effects of wind farms and food scarcity

on a large scavenging bird species following an epidemic of bovine spongiform encephalopathy. *J. Appl. Ecol.* 49: 109–117.
May, R., Reitan, O., Bevanger, K, Lorentsen, S. H. and Nygård, T. (2015) Mitigating wind-turbine induced avian mortality: Sensory, aerodynamic and cognitive constraints and options. *Renewable and Sustainable Energy Reviews* 42: 170–181.
Morrison, M. (2002) *Searcher bias and scavenging rates in bird/wind energy studies*. Golden, Colorado: National Renewable Energy Laboratory. (NREL/SR-500–30876).
Osborn, R. G., Higgins, K. F., Usgaard, R. E., Dieter, C. D. and Neiger, R. D. (2000) Bird mortality associated with wind turbines at the Buffalo Ridge Wind Resource Area, Minnesota. *Am. Midl. Nat.* 143: 41–52.
Palomo, L. J., Gisbert, J. and Blanco, J. C. (2007) *Atlas y Libro Rojo de los mamíferos terrestres de España*. Madrid, Spain: Dirección General para la Biodiversidad-SECEM-SECEMU.
Percival, S. (2005) Birds and wind farms: what are the real issues? *Brit. Birds* 98: 194–204.
Peste, F., Paula, A., da Silva, L. P., Bernardino, J., Pereira, P., Mascarenhas, M., Costa, H., Vieira, J., Bastos, C., Fonseca, C. and Pereira, M. J. R. (2015) How to mitigate impacts of wind farms on bats? A review of potential conservation measures in the European context. *Environmental Impact Assessment Review* 51: 10–22.
Ponce, C., Alonso, J. C., Argandoña, G., García Fernández, A. and Carrasco, M. (2010) Carcass removal by scavengers and search accuracy affect bird mortality estimates at power lines. *Anim. Conserv.* 13: 603–612.
Prosser, P., Nattrass, C. and Prosser, C. (2008) Rate of removal of bird carcasses in arable farmland by predators and scavengers. *Ecotox. Environ. Safe.* 71: 601–608.
Sanz-Aguilar, A., Sánchez-Zapata, J. A., Carrete, M., Benítez, J. R., Ávila, E., Arenas, R. and Donázar, J. A. (2015) Action on multiple fronts, illegal poisoning and wind farm planning, is required to reverse the decline of the Egyptian vulture in Southern Spain. *Biol. Conserv*. 187: 10–18.
Scott, R. E., Roberts, L. J. and Cadbury, C. J. (1972) Bird deaths from power lines at Dungeness. *Brit. Birds* 65: 273–286.
Smallwood, K. S. (2007) Estimating wind turbine-caused bird mortality. *J. Wildl. Manage.* 71: 2781–2791.
Smallwood, K. S., Bell, D. A., Snyder, S. A. and Didonato, J. E. (2010) Novel scavenger removal trials increase wind turbine-caused avian fatality estimates. *J. Wildl. Manage.* 74: 1089–1096.
Stevens, B., Reese, K. P. and Connelly, J. W. (2011) Survival and detectability bias of avian fence collision surveys in Sagebrush steppe. *J. Wildl. Manage.* 75: 437–449.
Urquhart, B., Hulka, S. and Duffy, K. (2015) Game birds do not surrogate for raptors in trials to calibrate observed raptor collision fatalities. *Bird Study* 62: 552–555.
White, G. C. and Garrott, R. A. (1990) *Analysis of wildlife radio-tracking data*. London: Academic Press.

MIGUEL ÁNGEL FARFÁN[1,2]*, JESÚS DUARTE[1,2], JULIA E. FA[3], RAIMUNDO REAL[2], JUAN MARIO VARGAS[2]

[1]*Biogea Consultores, Calle Navarro Ledesma 243, Portal 4, 3° C, 29010 Málaga, Spain.*
[2]*Departamento de Biología Animal, Facultad de Ciencias, Universidad de Málaga, Campus de Teatinos, 29071 Málaga, Spain.*
[3]*Division of Biology and Conservation Ecology, School of Science and the Environment, Manchester Metropolitan University, Manchester M1 5GD, UK.*

**Author for correspondence; e-mail: mafarfan@biogea-consultores.com*

Received 6 August 2015; revision accepted 3 October 2016;
Published online 9 January 2017