Environmental Impact Assessment Review 64 (2017) 8–15

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

# Differential recovery of habitat use by birds after wind farm installation: A multi-year comparison

M.A. Farfán [a,b,*], J. Duarte [b,c], R. Real [b], A.R. Muñoz [b,d], J.E. Fa [e], J.M. Vargas [b]

[a] Biogea Consultores, Calle Navarro Ledesma 243, Portal 4, 3° C, 29010, Málaga, Spain
[b] Departamento de Biología Animal, Facultad de Ciencias, Universidad de Málaga, Campus de Teatinos, 29071, Málaga, Spain
[c] Ofitecma, Calle Colombia 5, 29400 Ronda, Málaga, Spain
[d] Departamento de Botànica, Facultad de Farmacia, Universidad de Valencia, Avda. Vicente Andrés Estellés s/n, Burjassot, Valencia, Spain
[e] Division of Biology and Conservation Ecology, School of Science and the Environment, Manchester Metropolitan University, Manchester M1 5GD, UK

ARTICLE INFO

*Article history:*
Received 21 June 2016
Received in revised form 31 January 2017
Accepted 1 February 2017
Available online 6 February 2017

*Keywords:*
Assessment collision
Bird abundances
Environmental impact
Flight behaviour
Mortality
Renewable energy

ABSTRACT

Onshore wind farms remain one of the most widely used technologies for the production of renewable energy. These are known to affect birds through disturbance or collision. Most research focus on the impact of wind farms on raptors or other large bird species, especially those of conservation concern. However, limited information exists on the effect of wind farms on small birds. Recovery of large *versus* small bird populations impacted by wind farms is also largely unstudied. A reason for this is the lack of long-term datasets based on standardized, systematic assessments. We monitored birds in the vicinity of a wind farm in an upland habitat in southern Spain (Malaga province), immediately after installation and 6.5 years post-construction. During both study periods, we observed 11 raptor and 38 non-raptor species (including 30 passerines). We found differences in recovery rates between raptors and non-raptors. Raptors showed an upturn in numbers but non-raptor abundance fell significantly.
Greater attention should be paid to the recovery of wildlife after initial impact assessments than at present. This study confirms that regulatory authorities and developers should consider the likely impacts of wind farms on small bird populations. Mitigation measures focused particularly on non-raptor species should be considered and implemented as a means to reduce these negative effects.



## 1. Introduction

Wind energy has gained prominence among renewable resources and has become an increasingly important sector of the energy industry. Wind farms have thus grown rapidly throughout the world, and are expected to continue to increase in future years (Ledec et al., 2011). Spain is among the five largest markets for wind power worldwide alongside China, USA, Germany, and India (WWEA, 2015). By the end of 2015, Spain had an installed capacity of 22,988 MW distributed among 1077 wind farms (AEE, 2016).

Adverse impacts of wind energy facilities on wildlife, particularly on individual birds and bats have been well documented, especially direct mortality caused by collisions (Barrios and Rodriguez, 2004; Thelander and Smallwood, 2007; Drewitt and Langston, 2008; De Lucas et al., 2012). Although low collision rates are typical in most wind farms, high mortality rates have been recorded in some installations (Erickson et al., 2001; De Lucas et al., 2008). Wind farms also cause displacements or exclusion of individual birds, including the modification of their territories (Larsen and Guillemette, 2007). Habitat loss or damage from the construction of wind turbines and associated infrastructure is likewise possible (Langston and Pullan, 2003).

The potential for biologically significant impacts continue to be a source of concern. Bird populations overlapping with wind energy facilities may experience long-term declines owing to habitat loss and fragmentation, but may also increase mortality from numerous anthropogenic activities (Drewitt and Langston, 2008). However, long-term studies that focus on the impact of wind farms on wildlife populations based on continuous, standardized, and systematic assessments are less common, though fundamental. In the European Union, wind farms are subject to environmental impact assessments (EIAs) before installation (Article 2, Directive 85/337/EEC). However, the absence of agreed fixed baseline surveys has meant that only a few studies have been undertaken comparing pre-construction mortality predictions with post-construction actual mortality data (but see Ferrer et al., 2012) or population changes over time.

Most wind farm impact studies have focused on raptors or other large bird species, especially those of conservation concern (*e.g.* Larsen and Guillemette, 2007; Hill et al., 2011; Mammen et al., 2011; Muñoz et al.,

* Correspondence author at: Biogea Consultores, Calle Navarro Ledesma 243, Portal 4, 3° C, 29010, Málaga, Spain.
*E-mail addresses:* mafarfanaguilar@hotmail.com (M.A. Farfán), jddofitecma@gmail.com (J. Duarte), roman@uma.es (A.R. Muñoz), jfa949@gmail.com (J.E. Fa).

http://dx.doi.org/10.1016/j.eiar.2017.02.001
0195-9255/

2011; Martínez-Abraín et al., 2012; Reid et al., 2015). There is thus limited information on collision rates or disturbances caused by wind farms on small birds (but see Bastos et al., 2016; García et al., 2015). This is arguably due to a combination of lower detection rates of the smaller birds, rapid scavenger removal (Lekuona and Ursúa, 2007; Ponce et al., 2010), or less interest on these species compared to the more charismatic taxa.

In this paper, we examine long-term effects of a wind farm on a bird community. We separately analyse the impact of disturbance and mortality on raptors, passerines and non-passerines. By taking advantage of already existing information (Farfán et al., 2009) we compare changes in total abundances and flight behaviour of the three bird groups around the wind farm during its placement, and six and half years after installation. We discuss management implications for large and small birds in the light of our observations.

## 2. Material and methods

### 2.1. Study area and wind farm facility

This study was undertaken at the "Sierra de Aguas" wind farm, located on a SW-NE oriented mountain ridge in southern Spain (Malaga province) (Fig. 1). The climate is typically Mediterranean, with a mean annual rainfall ranging from 400 to 659 mm and annual temperatures between 9.7 and 24.7 °C. The area is covered by scrub, with some rocky areas and small patches of young holm oaks (*Quercus rotundifolia*) and Aleppo pines (*Pinus halepensis*). The community of birds in the area is dominated by open-habitat Mediterranean species, at relatively low densities probably due to the predominant vegetation type. Although the wind farm is roughly 100 km from the Strait of Gibraltar, a major flyway for migratory birds (Bildstein and Zalles, 2000), the area is not a concentration point for migratory species.

The wind farm started operation in March 2005, at first consisting of 16 wind turbines (850 KW). Turbines were arranged along two continuous rows separated by a 400-m corridor (the lower row 1800 m long, and the upper one 1600 m), 815–940 m above sea level. During mid-2009, two extra turbines, similar to those originally fitted, were installed at a lower altitude, thus raising the total output to 15.3 MW. Each turbine was separated from each other by a 90-m corridor (see Fig. 1). The composition and structure of the vegetation around the wind farm was left relatively unmodified after construction.

### 2.2. Data collection and analysis

The study period stretched from November 2000 to August 2011 and covered 5 separate time phases: a) Period 1 (November 2000–October 2001): one year of observation prior to the construction of the wind farm; b) Period 2 (March 2005–February 2007): two years of observation immediately after start of operation; and c) Period 3 (September 2009 to August 2011): two years of observation six and a half years after installation.

Data from Period 1 were taken from an unpublished report on raptor abundance, allowing us to study this bird group for the 11-year period. However, for the other two groups we were only able to gather data for Periods 2 and 3. The following information was collected for all bird groups during Periods 2 and 3.

#### 2.2.1. Bird abundances, flight behaviour and collision risk

Abundance and flight behaviour of birds were recorded by two observers along a pre-established area around the wind farm (Farfán et al., 2009). Observations were made from two fixed points located along the upper row of the wind farm. Bird movements were monitored during a total of 555 h (Period 1: 153 h; Period 2: 209 h; Period 3: 193 h).

Following Farfán et al. (2009), for each month, we calculated the total number of observations/hour as well as the total birds abundance/hour. Number of observation was calculated using each individual or group of birds observed in the wind farm, whereas total bird abundance employed the total number of birds registered during each bird observation. We applied a Kruskal-Wallis test to examine annual differences (Sokal and Rohlf, 1981).

We examined bird flight behaviour in the wind farm according to the following parameters: a) Height: a - under the blades; b - same height as the blades; c - above the blades; b) Flight direction: p - parallel or t - transversal to the wind turbine rows and c) Combined height and flight direction. We used a $\chi^2$ (chi-square) test to determine whether there were significant differences in flight behaviours (Sokal and Rohlf, 1981).

We used the Specific Risk Index (SRI) described by Lekuona and Ursúa (2007) to determine the collision risk of all bird species in our study. In this way we took into account the relationship between the total number of individuals of each species detected in the area and the number of birds exposed to collision, *i.e.* the number of birds in the transversal direction to the blades, at the same height, and within the blade radius. For each

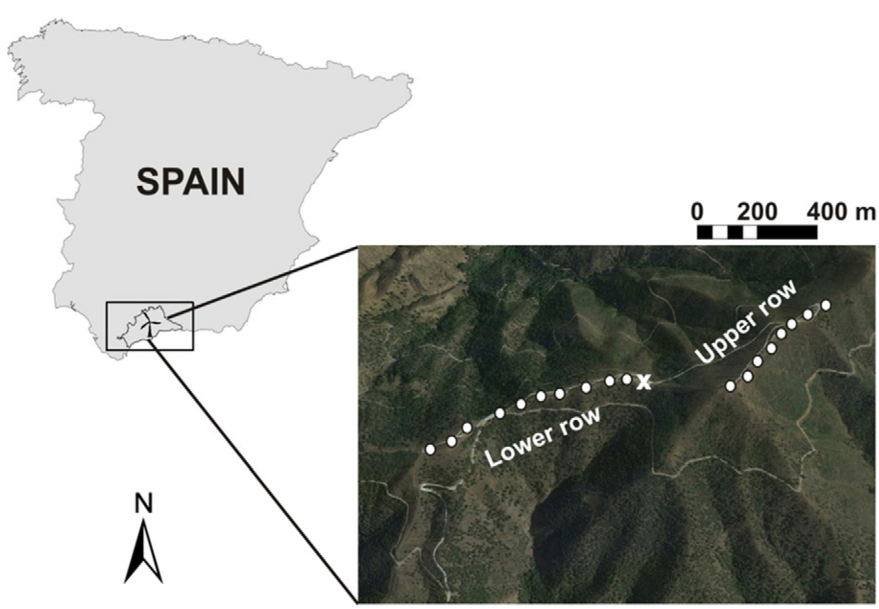


**Fig. 1.** Location of the study area. O: wind turbine; X: geographic reference (36° 51′ 18″N; 4° 46′ 43″W).

species, SRI was calculated using the following equation:

SRI = (number of birds exposed to collision/total number of individuals) ∗ 100

where SRI values of > 10% are considered high, and values of ≤9.9% as low (Lekuona and Ursúa, 2007).

*2.2.2. Bird mortality*

We searched for bird carcasses on a weekly basis for a total of 367 h during the study period (Period 2: 186 h; Period 3: 181 h). We walked a 70-m radius around each wind turbine searching for dead birds. We used a protocol similar to those employed by Morrison and Sinclair (1998), De Lucas et al. (2004), Carrete et al. (2009) and Farfán et al. (2009). All bird carcasses and body parts found were noted as fatalities. We identified the species of dead birds, their sex, age, injuries, position relative to the nearest wind turbine, date and time of discovery, as well as the estimated date of death. Although several authors have investigated different methods to evaluate actual mortality rates (Huso, 2011; Korner-Nievergelt et al., 2011, 2015; Huso et al., 2015) we used the methodology proposed in Farfán et al. (in press) to correct for potential errors caused by carcass removal by scavengers. Based on the experimental evidence of removal of dead birds, Farfán et al. (in press) use a correction factor of 45%, for the seven first days, to estimate the disappearance rate of medium-sized birds.

## 3. Results

*3.1. Bird observations*

We recorded a total of 1533 observations and 2380 birds (of at least 49 different species) during the operational phase of the wind farm (Periods 2 and 3) (Table A1). The number of observations and total bird abundance were significantly higher in Period 2 compared to Period 3 (observations: $\chi^2 = 182.54$; df = 1; $P < 0.01$; birds: $\chi^2 = 127.10$; df = 1; $P < 0.01$).

The annual number of observations (Table A2) was not statistically different between the first and the second year of Period 2 (Kruskal–Wallis test, χ2 = 1.143, df = 1, NS). However, for Period 3 statistical differences were found in the annual number of observations (Kruskal–Wallis test, $\chi^2 = 4.698$, df = 1, $P < 0.05$). Observations were higher in the second year of Period 3.

In Periods 2 and 3, there were no statistical differences in the annual bird abundances (Period 2: Kruskal–Wallis test, $\chi^2 = 0.368$, df = 1, NS; Period 3: Kruskal–Wallis test, $\chi^2 = 2.260$, df = 1, NS).

The annual number of observations and bird abundance for Period 2 were significantly different to Period 3. Number of observations and bird abundance were lower in the Period 3 than immediately after construction of the wind farm (Observations Period 2 *vs* Period 3: Kruskal-Wallis test, $\chi^2 = 22.466$, df = 3, $P < 0.01$; Birds Period 2 *vs* Period 3: Kruskal-Wallis test, $\chi^2 = 13.622$, df = 3, $P < 0.01$).

Abundance of raptors (raptors/100 h) around the wind farm declined during Period 2 compared to Period 1 (Fig. 2). During the first and second year of Period 2 raptor abundance fell by 9.5% and 58.6%, respectively, although differences were statistically significant for the second year only (Period 1 *vs* first year of Period 2: $\chi^2 = 0.46$, df = 1, NS; Period 1 *vs* second year of Period 2: $\chi^2 = 24.13$, df = 1, $P < 0.01$). By contrast, compared to Period 1 the abundance of raptors increased during the first year of period 3 (4.3%) and declined during the second year of period 3 (11.3%). Both cases differences were not statistically significant (Period 1 *vs* first year of Period 3: $\chi^2 = 0.091$, df = 1, NS; Period 1 *vs* second year of Period 3: $\chi^2 = 0.67$, df = 1, NS).

Once the wind farm was operational, the abundance of raptors recorded in the Period 3 increased 46.2% compared to Period 2. Difference in the abundance of raptors was statistically significant (Period 2 *vs* Period 3: $\chi^2 = 5.69$, df = 1, $P < 0.05$) (Fig. 2).

For non-raptor species, abundance recorded in Period 3 compared to Period 2 decreased by 40.6%; this difference was statistically significant (Period 2 *vs* Period 3: $\chi^2 = 65.54$, df = 1, $P < 0.01$) (Fig. 2).

*3.2. Flight rates*

Monthly observations varied from 1.0 observation/h in February 2010 to 10.7 observations/h in June 2006 (see Table A2) (mean monthly value of 3.8 ± 2.0 observations/h). Overall, observation rates were higher during Period 2 than Period 3. Differences in the annual values were statistically significant (Kruskal-Wallis test, $\chi^2 = 25.247$, df = 3, $P < 0.01$).

The total monthly flight rate varied significantly between 1.3 birds/h in December 2009 and February 2010, and 26.4 birds/h in August 2010 (see Table A2) (mean monthly value of 6.0 ± 4.4 birds/h). There were significant differences in flight rates, higher in Period 2 than in Period 3 (Kruskal-Wallis test, $\chi^2 = 16.266$, df = 3, $P < 0.01$).

For raptors, species monthly flight rate ranged from 0.0 bird/h in different months (Apr-05, Dec-05, Jan-06, May-06, Nov-06, Jan-07, Feb-07, Dec-09 and Apr-11) and 4.5 birds/h in August 2010 (Fig. 3, see Table A2). Annual flight rate differences were not statistically significant (Kruskal-Wallis test, $\chi^2 = 3.939$, df = 3, NS).

In Period 1, annual flight rate for raptors was 1.1 birds/h. However, during Period 2, the annual flight rate of raptors decreased to 0.7 raptors/h, but during Period 3, it increased to 1.0 raptors/h (Fig. 3). In all cases, differences were not statistically significant (Period 1 *vs* Period 2: Kruskal-Wallis test, $\chi^2 = 3.073$, df = 1, NS; Period 1 *vs* Period 3: Kruskal-Wallis test, $\chi^2 = 1.013$, df = 1, NS; Period 2 *vs* Period 3: Kruskal-Wallis test, $\chi^2 = 2.782$, df = 1, NS).

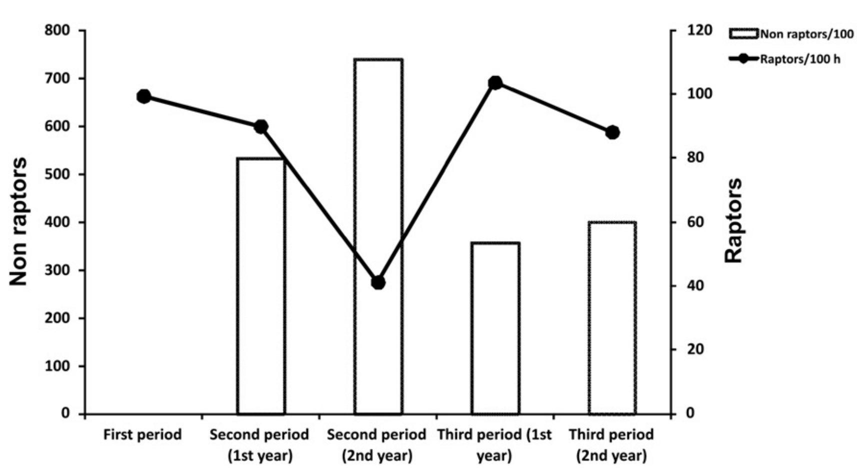


**Fig. 2.** Raptor and non-raptor variation abundance (individuals/h) during the study period.

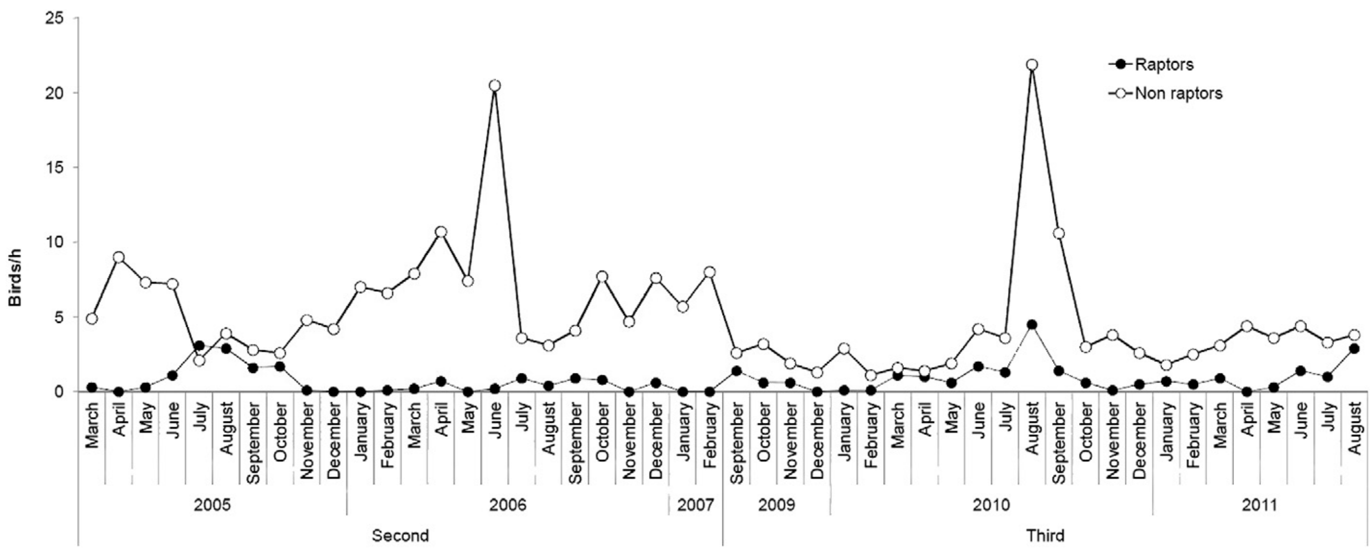


**Fig. 3.** Monthly flight rates (birds/h) for raptors and non-raptors during Periods 2 and 3.

During Period 2, raptors flight rate (raptors/h) made up around 10% of the total flight rate values (birds/h), half of the observed value in Period 3, although differences were not statistically significant (Period 2 *vs* Period 3: $\chi^2 = 3.300$, df = 1, NS).

For non-raptor species, monthly flight rate also varied significantly between 1.1 birds/h in February 2010 and 21.9 birds/h in August 2010 (Fig. 3, see Table A2) (5.2 ± 4.2 birds/h). Overall, total flight rates were significantly higher in Period 2 than in Period 3 (Kruskal-Wallis test, $\chi^2 = 16.396$, df = 3, $P < 0.01$).

### 3.3. Flight behaviour and collision risk

Flight behaviour for passerines and non-passerines (Table 1) showed that the most frequent observations were below the blades (passerines: 83.0% for Period 2 and 93.9% for Period 3; non-passerines: 78.4% and 81.3% for Period 2 and Period 3, respectively). For raptors, the most frequent observation occurred below the blades in the Period 2 (82.8%), while in Period 3 most observations were below and above the blades (36.1% in each case). We found significant differences for the three groups in the distribution of observations according to height (raptors: $\chi^2 = 73.134$; df = 2; $P < 0.01$; passerines: $\chi^2 = 1518.755$; df = 2; $P < 0.01$; non-passerines: $\chi^2 = 97.152$; df = 2; $P < 0.01$).

Most birds flew transversally to the wind turbine rows (61.1%) ($\chi^2 = 75.851$; df = 1; $P < 0.01$) (Table 2). However, for raptors, the most frequent observations occurred parallel to the wind turbines (68.8%), while passerines flew in a transversal direction (67.4%). For non-passerines, observations in a parallel and transversal direction were similar (48.5% and 51.5%, respectively) (Table 2). The differences were statistically significant only for raptors and passerines (raptors: $\chi^2 = 31.500$; df = 1; $P < 0.01$; passerines: $\chi^2 = 147.177$; df = 1; $P < 0.01$; non-passerines: $\chi^2 = 0.091$; df = 1; NS).

The most frequent type of flight recorded for raptors was parallel to the wind turbines row and under the blades (Period 2: 67.2%; Period 3: 32.4%) (Table 2). Most flights were observed in the transversal direction and under the blades for passerines (Period 2: 57.9%; Period 3: 63.3%). For non-passerines the most frequent flight was below the blades and evenly divided between parallel and transversal (Table 2). Differences were only statistically significant for raptors (raptors: $\chi^2 = 42.23$; df = 5; $P < 0.01$; passerines: $\chi^2 = 9.78$; df = 5; NS; non-passerines: $\chi^2 = 1.733$; df = 5; NS).

During Periods 2 and 3, we recorded only nine cases in which birds (passerines in all cases) avoided crossing the wind turbine rows, and 83 observations in which birds flew transversally at the same height as the blades. A quarter of these flights (24.1%) took place within the blade radius. Given that we recorded 1533 observations during Periods 2 and 3, observations with a high risk of collision represented only a very small percentage (1.3%).

For raptors percentage observations with a high risk of collision was similar to all birds pooled. We recorded 224 observations of raptors with only three (two *Falco tinnunculus* and one *Accipiter gentilis*) flying under risk of collision (1.3%).

By species, the SRI during the study period was high for *Accipiter gentilis* (100.0%), *Delichon urbica* (39.8%) and *Ptyonoprogne rupestris* (30.1%), but low for *Falco tinnunculus* (1.6%), and *Galerida theklae* (2.1%). For all other species, the observed Specific Risk Index was zero.

### 3.4. Bird mortality

During the entire study period we only found some feathers of a *Falco tinnunculus* (adult male) located near a wind turbine. Taking into account that the disappearance rate of medium-sized birds in zones close to our study area is 45% on the first seven days, we can assume that the actual mortality rate in the wind farm is roughly double the one we have detected. Therefore the actual mortality rate in the wind farm would be 0.03 birds/turbine/year.

**Table 1**
Distribution of the observations grouped by passerines, non-passerines and raptors based on the flight height. (a): under the blades. (b): equal height as the blades. (c): over the blades. The numbers in brackets indicate percentage.

| | | Passerines | | | Non-passerines | | | Raptors | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | a | b | c | a | b | c | a | b | c |
| 2nd period | N | 717<br>(83.0) | 85<br>(9.8) | 62<br>(7.2) | 40<br>(78.4) | 5<br>(9.8) | 6<br>(11.8) | 96<br>(82.8) | 14<br>(12.1) | 6<br>(5.2) |
| 3rd period | N | 325<br>(93.9) | 18<br>(5.2) | 3<br>(0.9) | 39<br>(81.3) | 1<br>(2.1) | 8<br>(16.7) | 39<br>(36.1) | 30<br>(27.8) | 39<br>(36.1) |

**Table 2**
Distribution of the observations according to height and flight direction relative to wind turbine rows. a: below the blades. b: at the same height as the blades. c: above the blades. T: transversal. P: parallel. The numbers in brackets indicate percentage.

| | Height | Direction | Passerines N | Non-passerines N | Raptors N |
|---|---|---|---|---|---|
| 2nd period | a | T | 500 (57.9) | 17 (33.3) | 18 (15.5) |
| | | P | 217 (25.1) | 23 (45.1) | 78 (67.2) |
| | b | T | 46 (5.3) | 1 (2.0) | 4 (3.4) |
| | | P | 39 (4.5) | 4 (7.8) | 10 (8.6) |
| | c | T | 32 (3.7) | 3 (5.9) | 4 (3.4) |
| | | P | 30 (3.5) | 3 (5.9) | 2 (1.7) |
| 3rd period | a | T | 219 (63.3) | 23 (47.9) | 4 (3.7) |
| | | P | 106 (30.6) | 16 (33.3) | 35 (32.4) |
| | b | T | 17 (4.9) | 1 (2.1) | 14 (13.0) |
| | | P | 1 (0.3) | 0 (0.0) | 16 (14.8) |
| | c | T | 2 (0.6) | 6 (12.5) | 26 (24.1) |
| | | P | 1 (0.3) | 2 (4.2) | 13 (12.0) |

## 4. Discussion

The main motivation for our research was to determine the long-term effect of the presence and operation of a wind farm on a bird community. According to our results the number of bird species recorded six and a half years after the wind farm was put into operation is slightly higher than previously reported for the same area immediately after the installation of the wind turbines (Farfán et al., 2009). This may reflect the negative impact during wind farm construction, as shown by Pearce-Higgins et al. (2012) for some upland species. These negative effects may dwindle during the following years. However, here we show that the abundance of birds and the flight rates are significantly lower after installation, probably caused by disturbances and operational effects, as also demonstrated in other studies (Leddy et al., 1999; Pearce-Higgins et al., 2009; Rees, 2012). This decrease in the overall abundance and flight rates of birds suggests that a reduction in habitat use and probably habitat quality may have occurred around the wind farm. This is also supported by the fact that there was no evidence of significant bird mortality, since collisions were rare in this wind farm as typical in other wind farms (this study, Erickson et al., 2001; Percival, 2005; Farfán et al., 2009). Nonetheless, although we cannot confirm that this drop in bird numbers was caused exclusively by the presence and operation of the wind farm, this significant decrease is similar to results shown by other authors for other species groups under the same circumstances (Petersen et al., 2004; Stewart et al., 2005; Larsen and Guillemette, 2007; Eichhorn et al., 2012; Fijn et al., 2012).

We observed distinctly contrasting trends when we separately analysed abundance and flight rates of raptors and non-raptors. Raptor abundance in Period 3 was significantly higher than previously observed in the same area immediately after installation of the wind turbines (Period 2) (Farfán et al., 2009), but slightly lower than the abundance before the construction of the wind farm (Period 1). These results suggest a recovery in habitat use by raptors. The population of cliff and forest raptor species in the surroundings of the wind farm remained stable when we compare the preconstruction period and current data. It includes two pairs of Bonelli's Eagles (*Aquila fasciata*), one pair of Golden Eagle (*Aquila chrysaetos*), one pair of Short-toed Snake Eagle (*Circaetus gallicus*), approx. 20 pairs of Griffon Vultures (*Gyps fulvus*), and three pairs of Eagle Owls (*Bubo bubo*); although we do not have accurate information on the Common Kestrel this species continues to be common in the area (see Jiménez and Muñoz, 2008; Muñoz and Real, 2013; Muñoz et al., 2015; unpublished data). Given this, we hypothesize that a certain habituation to the presence of turbines may have happened. Our results agree with those presented by Madsen and Boertmann (2008) for Pink-footed Geese (*Anser brachyrhynchus*), by Devereux et al. (2008) for wintering farmland birds, and also with the idea that birds may become habituated to the presence of wind farms (Langston and Pullan, 2003). Although various studies demonstrate that raptors are especially susceptible to wind turbine collisions (*e.g.* Barrios and Rodriguez, 2004; Baisner et al., 2010; De Lucas et al., 2012; Martínez-Abraín et al., 2012; Dahl et al., 2013), other studies report low fatality rates (Percival, 2003; Farfán et al., 2009; Hernández-Pliego et al., 2015) as in this study. By contrast, the recovery of the presence of raptors in our study area differs from the conclusions drawn by Stewart et al. (2005) who maintain that operational time had a significant impact on bird abundances, with longer operating times resulting in greater declines. In relation to the abundance and flight rates of non-raptor species the results of this study showed a significant decrease, which is consistent with the claims made by other authors (Stewart et al., 2005; Larsen and Guillemette, 2007; Fijn et al., 2012).

During the operational phase of the wind farm we only found one dead bird as a result of the collision with wind turbines - although this result may underestimate the actual mortality rate in the wind farm because we have not considered the effect due to dead birds being overlooked or removed by scavengers (Drewitt and Langston, 2008). However, our result is consistent with the small percentage of observations with a high risk of collision and the SRI calculated in this study for all species in the wind farm; this is in agreement with most studies on collisions caused by wind farms (Erickson et al., 2001; De Lucas et al., 2004; Gue et al., 2013). As indicated by Fijn et al. (2012) our study shows that although the collision risk for birds with wind turbines was low, wind farms can result in a diminished use of habitat, at least for some groups of birds, since the presence of the wind farm can make the area less attractive to birds and could reduce its carrying capacity.

The most frequent flights observed for passerines and non-passerines were transversal to the alignment of the wind turbines. This result demonstrates that the "Sierra de Aguas" wind farm is not a barrier for these bird groups. In contrast, at least for raptors, the wind farm may act as an obstacle because the most frequent type of flight after construction were in parallel to both wind turbine rows, whereas previous to the construction of the wind farm transversal flights were more frequent (Farfán et al., 2009). Most of transversal flights occurred for raptors during operational phase through the corridor between the two rows or outside the last wind turbines along the lines. Although "Sierra de Aguas" wind farm is a barrier for raptors, it has had no significant impacts on populations and this may be due to the rows being short, and also because of the existence of a corridor between them. However, the barrier effect should not be underestimated as there are circumstances that might lead indirectly to population level impacts as longer wind turbine rows effectively block a flight line or where several wind farms cumulatively interact to create an extensive barrier (Drewitt and Langston, 2006).

## 5. Conclusions and recommendations

A weakness of our results is that they lacked any measure of a control area, what makes difficult to extensively confirm that the decrease observed in the overall abundance and flight rates of birds is a direct consequence of the disturbances and operational effects of the wind farm. Nonetheless, the use of three study periods for raptors, one of them previous to the start of operation, can be a good approximation as a reference situation. For further studies we encourage the establishment of control areas to strengthen the methodological design and reinforce the results attained.

Having said this and with the required prudence our results demonstrate that caution must be exercised when analysing the effects of wind farms on bird communities, especially in the absence of long term studies to confirm impact trends. The current situation in "Sierra de Aguas" (Period 3) is substantially different from that presented by Farfán et al. (2009) for the same wind farm immediately after it was put into operation (Period 2). This difference is important given that environmental agencies in Spain do not usually require any monitoring of wind farms beyond two years, unlike the wind farm we have studied (although there are some exceptions in other wind farms of the same region, *e.g.*

De Lucas et al., 2012). Hence, we recommend two basic modifications to the currently established monitoring protocols for wind farms in Spain. First, as proposed by Natural England (2010), before-after-control-impact (BACI) studies of the effects of wind farms must be undertaken routinely for all new installations to conclusively assess effects of wind farms relative to pre-construction conditions. Second, in combination with a before-after study, a post-construction monitoring should continue during the life span of the wind farm to evaluate the persistence and distribution of species, and to mitigate and compensate negative environmental consequences of wind energy development in the area. The post-construction fieldwork should preferably collect baseline data on population trends by following a common methodology, even adapted to the habitat characteristics of every wind farm. For example, Hernández-Pliego et al. (2015) used a long term monitoring data set to conclude that the Montagu's Harriers, a ground-nesting raptor, was not adversely affected by the construction, operation and maintenance of wind farms in southern Spain.

Our final recommendation is to suggest that environmental authorities, in collaboration with industry and researchers, should design and implement a detailed monitoring protocol that is mandatory for all new wind farms. In this manner, we can ensure that surveys are undertaken and reported appropriately to provide an information source that can be analysed together to determine whether any significant impacts on birds, at the local or population level, are being addressed.

## Disclaimer

Some of this work appears already on the following website http://www.biogea-consultores.com, which is owned by the authors and therefore infringes no copyright in being reproduced in this article.

## Acknowledgements

We thank Gonzalo Zubieta, the property developer of the "Sierra de Aguas" wind farm, for allowing us to use and publish the information contained in the present study. This work has been partially supported by the Spanish Ministry of Agriculture, Food and the Environment, Spanish National Parks Network, project 1098/2014. ARM was supported by Juan de la Cierva program (FJCI-2014-20653), of the Spanish MECD.

## Appendix A

**Table A1**
Number of observations and total bird abundance for the operational phase of the wind farm (Periods 2 and 3).

| Species | Observations (N) | | Observations (%) | | Bird abundances (N) | | Bird abundances (%) | |
|---|---|---|---|---|---|---|---|---|
| | 2nd period | 3rd period | 2nd period | 3rd period | 2nd period | 3rd period | 2nd period | 3rd period |
| Raptors | | | | | | | | |
| *Pernis apivorus* | 1 | 2 | 11.3 | 21.5 | 1 | 25 | 9.4 | 20.2 |
| *Aquila chrysaetos* | 1 | 1 | | | 1 | 1 | | |
| *Accipiter gentilis* | 0 | 1 | | | 0 | 1 | | |
| *Aquila pennata* | 4 | 0 | | | 5 | 0 | | |
| *Gyps fulvus* | 2 | 20 | | | 2 | 64 | | |
| *Circus pygargus* | 1 | 0 | | | 1 | 0 | | |
| *Falco tinnunculus* | 95 | 64 | | | 111 | 73 | | |
| *Circaetus gallicus* | 4 | 13 | | | 7 | 13 | | |
| *Milvus migrans* | 2 | 0 | | | 2 | 0 | | |
| *Accipiter nisus* | 5 | 3 | | | 5 | 3 | | |
| *Aquila fasciata* | 1 | 4 | | | 2 | 5 | | |
| Passerines | | | | | | | | |
| *Lanius meridionalis* | 0 | 2 | 83.8 | 68.9 | 0 | 2 | 80.1 | 56.0 |
| *Garrulus glandarius* | 0 | 11 | | | 0 | 12 | | |
| *Delichon urbica* | 12 | 17 | | | 22 | 86 | | |
| *Ptyonoprogne rupestris* | 23 | 0 | | | 73 | 0 | | |
| *Anthus pratensis* | 3 | 2 | | | 9 | 3 | | |
| *Sylvia melanocephala* | 15 | 31 | | | 22 | 34 | | |
| *Turdus torquatus* | 0 | 1 | | | 0 | 1 | | |
| *Parus major* | 0 | 3 | | | 0 | 3 | | |
| *Sturnus unicolor* | 1 | 0 | | | 1 | 0 | | |
| *Galerida theklae* | 348 | 36 | | | 384 | 44 | | |
| *Phoenicurus ochruros* | 2 | 5 | | | 2 | 6 | | |
| *Muscicapa striata* | 2 | 0 | | | 2 | 0 | | |
| *Cecropis daurica* | 2 | 0 | | | 2 | 0 | | |
| *Emberiza cia* | 115 | 90 | | | 150 | 124 | | |
| *Cyanistes caeruleus* | 0 | 2 | | | 0 | 2 | | |
| *Carduelis carduelis* | 9 | 9 | | | 75 | 17 | | |
| *Motacilla alba* | 0 | 19 | | | 0 | 19 | | |
| *Turdus merula* | 0 | 3 | | | 0 | 3 | | |
| *Aegithalos caudatus* | 0 | 1 | | | 0 | 1 | | |
| *Carduelis cannabina* | 32 | 10 | | | 66 | 18 | | |
| *Hippolais polyglotta* | 2 | 0 | | | 2 | 0 | | |
| *Sylvia undata* | 15 | 4 | | | 16 | 4 | | |
| *Monticola solitarius* | 0 | 1 | | | 0 | 1 | | |
| *Saxicola torquatus* | 68 | 32 | | | 91 | 35 | | |
| *Serinus serinus* | 0 | 2 | | | 0 | 2 | | |
| *Luscinia megarhynchos* | 1 | 0 | | | 1 | 0 | | |
| *Turdus* sp. | 1 | 3 | | | 3 | 3 | | |
| *Erithacus rubecula* | 0 | 2 | | | 0 | 2 | | |
| *Fringilla coelebs* | 58 | 29 | | | 72 | 39 | | |
| *Loxia curvirostra* | 12 | 4 | | | 12 | 4 | | |

(continued on next page)

**Table A1** (*continued*)

| Species | Observations (N) | | Observations (%) | | Bird abundances (N) | | Bird abundances (%) | |
|---|---|---|---|---|---|---|---|---|
| | 2nd period | 3rd period | 2nd period | 3rd period | 2nd period | 3rd period | 2nd period | 3rd period |
| Non-identified | 143 | 27 | | | 169 | 47 | | |
| Non-passerines | | | | | | | | |
| *Merops apiaster* | 5 | 1 | 4.9 | 9.6 | 17 | 3 | 10.5 | 23.8 |
| *Caprimulgus ruficollis* | 0 | 1 | | | 0 | 1 | | |
| *Alectoris rufa* | 24 | 34 | | | 56 | 81 | | |
| *Picus viridis* | 0 | 2 | | | 0 | 2 | | |
| *Columba palumbus* | 1 | 3 | | | 1 | 4 | | |
| *Upupa epops* | 1 | 0 | | | 1 | 0 | | |
| *Tachymarptis melba* | 1 | 1 | | | 2 | 1 | | |
| *Apus* sp. | 19 | 6 | | | 77 | 126 | | |
| Total | 1031 | 502 | | | 1465 | 915 | | |

**Table A2**
Monthly number of observations and bird abundance, and monthly variation of the observation and flight rates.

| Period | Year | Month | Observations | Birds | Observations/h | Total birds/h | Raptors/h | Non-raptors/h |
|---|---|---|---|---|---|---|---|---|
| Second | 2005 | March | 41 | 50 | 4.3 | 5.3 | 0.3 | 4.9 |
| | | April | 86 | 96 | 8.1 | 9.0 | 0.0 | 9.0 |
| | | May | 54 | 69 | 5.9 | 7.6 | 0.3 | 7.3 |
| | | June | 46 | 91 | 4.2 | 8.3 | 1.1 | 7.2 |
| | | July | 25 | 47 | 2.8 | 5.3 | 3.1 | 2.1 |
| | | August | 41 | 55 | 5.0 | 6.7 | 2.9 | 3.9 |
| | | September | 43 | 46 | 4.1 | 4.4 | 1.6 | 2.8 |
| | | October | 17 | 18 | 4.1 | 4.3 | 1.7 | 2.6 |
| | | November | 26 | 43 | 2.9 | 4.9 | 0.1 | 4.8 |
| | | December | 21 | 36 | 2.4 | 4.2 | 0.0 | 4.2 |
| | 2006 | January | 27 | 45 | 4.2 | 7.0 | 0.0 | 7.0 |
| | | February | 47 | 54 | 5.9 | 6.8 | 0.1 | 6.6 |
| | | March | 58 | 68 | 7.0 | 8.2 | 0.2 | 7.9 |
| | | April | 74 | 100 | 8.5 | 11.4 | 0.7 | 10.7 |
| | | May | 64 | 75 | 6.3 | 7.4 | 0.0 | 7.4 |
| | | June | 67 | 129 | 10.7 | 20.6 | 0.2 | 20.5 |
| | | July | 32 | 36 | 4.0 | 4.5 | 0.9 | 3.6 |
| | | August | 32 | 42 | 2.7 | 3.5 | 0.4 | 3.1 |
| | | September | 34 | 40 | 4.3 | 5.0 | 0.9 | 4.1 |
| | | October | 55 | 101 | 4.6 | 8.4 | 0.8 | 7.7 |
| | | November | 21 | 28 | 3.5 | 4.7 | 0.0 | 4.7 |
| | | December | 58 | 82 | 5.8 | 8.2 | 0.6 | 7.6 |
| | 2007 | January | 20 | 34 | 3.3 | 5.7 | 0.0 | 5.7 |
| | | February | 42 | 80 | 4.2 | 8.0 | 0.0 | 8.0 |
| Third | 2009 | September | 23 | 32 | 2.9 | 4.0 | 1.4 | 2.6 |
| | | October | 20 | 37 | 2.0 | 3.8 | 0.6 | 3.2 |
| | | November | 16 | 20 | 2.0 | 2.6 | 0.6 | 1.9 |
| | | December | 10 | 11 | 1.1 | 1.3 | 0.0 | 1.3 |
| | 2010 | January | 11 | 24 | 1.4 | 3.0 | 0.1 | 2.9 |
| | | February | 8 | 10 | 1.0 | 1.3 | 0.1 | 1.1 |
| | | March | 12 | 17 | 1.9 | 2.7 | 1.1 | 1.6 |
| | | April | 12 | 19 | 1.5 | 2.4 | 1.0 | 1.4 |
| | | May | 13 | 20 | 1.6 | 2.5 | 0.6 | 1.9 |
| | | June | 29 | 46 | 3.7 | 5.9 | 1.7 | 4.2 |
| | | July | 33 | 44 | 3.7 | 4.9 | 1.3 | 3.6 |
| | | August | 16 | 163 | 2.6 | 26.4 | 4.5 | 21.9 |
| | | September | 32 | 96 | 4.0 | 12.0 | 1.4 | 10.6 |
| | | October | 11 | 24 | 1.7 | 3.7 | 0.6 | 3.0 |
| | | November | 19 | 31 | 2.4 | 3.9 | 0.1 | 3.8 |
| | | December | 19 | 25 | 2.4 | 3.1 | 0.5 | 2.6 |
| | 2011 | January | 18 | 25 | 1.8 | 2.5 | 0.7 | 1.8 |
| | | February | 24 | 24 | 3.0 | 3.0 | 0.5 | 2.5 |
| | | March | 21 | 26 | 3.2 | 4.0 | 0.9 | 3.1 |
| | | April | 31 | 35 | 3.9 | 4.4 | 0.0 | 4.4 |
| | | May | 22 | 28 | 3.1 | 3.9 | 0.3 | 3.6 |
| | | June | 36 | 53 | 4.0 | 5.9 | 1.4 | 4.4 |
| | | July | 31 | 43 | 3.1 | 4.3 | 1.0 | 3.3 |
| | | August | 28 | 53 | 3.5 | 6.6 | 2.9 | 3.8 |

## References


AEE, 2016. Asociación Empresarial Eólica. http://www.aeeolica.org (Accessed 5 May 2016).

Baisner, A.J., Andersen, J.L., Findsen, A., de Granath, S.W., Madsen, K.Ø., Desholm, M., 2010. Minimizing collision risk between migrating raptors and marine wind farms: development of a spatial planning tool. Environ. Manag. 46, 801–808.

Barrios, L., Rodriguez, A., 2004. Behavioural and environmental correlates of soaring-bird mortality at on-shore wind turbines. J. Appl. Ecol. 41, 72–81.

Bastos, R., Pinhanços, A., Santos, M., Fernandes, R.F., Vicente, J.R., Morinha, F., Honrado, J.P., Travassos, P., Barros, P., Cabral, J.A., 2016. Evaluating the regional cumulative impact of wind farms on birds: how can spatially explicit dynamic modelling improve impact assessments and monitoring? J. Appl. Ecol 53:1330–1340. http://dx.doi.org/10.1111/1365-2664.12451.

Bildstein, K., Zalles, J.L. (Eds.), 2000. Raptor Watch: A Global Directory of Raptor Migration Sites. Birdlife Conservation, London.

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

Dahl, E.L., May, R., Hoel, P.L., Bevanger, K., Pedersen, H.C., Røskaft, E., Stokke, B.G., 2013. White-tailed eagles (*Haliaeetus albicilla*) at the Smøla wind-power plant, Central Norway, lack behavioral flight responses to wind turbines. Wildl. Soc. Bull. 37, 66–74.

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

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

De Lucas, M., Ferrer, M., Bechard, M.J., 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.

Devereux, C.L., Denny, M.J.H., Whittingham, M.J., 2008. Minimal effects of wind turbines on the distribution of wintering farmland birds. J. Appl. Ecol. 45, 1689–1694.

Drewitt, A.L., Langston, H.W., 2006. Assessing the impacts of wind farms on birds. Ibis 148, 29–42.

Drewitt, A.L., Langston, H.W., 2008. Collision effects of wind-power generators and other obstacles on birds. Ann. N. Y. Acad. Sci. 1134, 233–266.

Eichhorn, M., Johst, K., Seppelt, R., Drechsler, M., 2012. Model-based estimation of collision risks of predatory birds with wind turbines. Ecol. Soc. 17:1. http://dx.doi.org/10.5751/ES-04594-170201.

Erickson, W.P., Johnson, G.D., Stricland, M.D., Young, D.P., Sernka, K.J., 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. Western Eco-Systems Technology Inc. National Wind Coordinating Committee Resource Document. http://www.west-inc.com/reports/avian_collisions.pdf (Accessed 13 October 2015).

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

Farfán, M.A., Duarte, J., Fa, J.E., Real, R. & Vargas, J.M. (in press). Testing for errors in estimating bird mortality rates at wind farms and power lines. Bird Conserv. Int. http://dx.doi.org/10.1017/S0959270916000460

Ferrer, M., de Lucas, M., Janss, G.F.E., Casado, E., Muñoz, A.R., Bechard, M.J., Calabuig, C.P., 2012. Weak relationship between risk assessment studies and recorded mortality in wind farms. J. Appl. Ecol. 49, 38–46.

Fijn, R.C., Krijgsveld, K.L., Tijsen, W., Prinsen, H.A.M., Dirksen, S., 2012. Habitat use, disturbance and collision risks for Bewick's Swans *Cygnus columbianus* wintering near a wind farm in the Netherlands. Wildfowl 62, 97–116.

García, D.A., Canavero, G., Ardenghi, F., Zambon, M., 2015. Analysis of wind farm effects on the surrounding environment: assessing population trends of breeding passerines. Renew. Energy 80, 190–196.

Gue, C.T., Walker, J.A., Mehl, K.R., Gleason, J.S., Stephens, S.E., Loesch, C.R., Reynolds, R.E., 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. Manag. 77, 1360–1371.

Hernández-Pliego, J., de Lucas, M., Muñoz, A.R., Ferrer, M., 2015. Effects of wind farms on Montagu's harrier (*Circus pygargus*) in southern Spain. Biol. Conserv. 191, 452–458.

Hill, R., du Gueschlin, P., Herring, M., McCarthy, M., Smales, I., 2011. Managing cumulative wind farm impacts on the Brolga *Grus rubicunda* in Victoria, Australia. In: May, R., Bevanger, K. (Eds.), Proceedings Conference on Wind Energy and Wildlife Impacts, 2–5 May 2011 2011. Norwegian Institute for Nature Research, Trondheim, Norway, p. 96.

Huso, M.M., 2011. An estimator of wildlife fatality from observed carcasses. Environmetrics 22 (3), 318–329.

Huso, M.M., Dalthorp, D.H., Dail, D.A., Madsen, L.J., 2015. Estimating wind-turbine caused bird and bat fatality when zero carcasses are observed. Ecol. Appl. 25 (5):1213–1225. http://dx.doi.org/10.1890/14-0764.1.

Jiménez, J.J., Muñoz, A.R., 2008. Atlas de las rapaces de Málaga (reproducción, migración e invernada). Centro de Ediciones de la Diputación Provincial de Málaga, Málaga.

Korner-Nievergelt, F., Korner-Nievergelt, P., Behr, O., Niermann, I., Brinkmann, R., Hellriegel, B., 2011. A new method to determine bird and bat fatality at wind energy turbines from carcass searches. Wildl. Biol. 17 (4), 350–363.

Korner-Nievergelt, F., Behr, O., Brinkmann, R., Etterson, M.A., Huso, M.M., Dalthorp, D., Korner-Nievergelt, P., Roth, T., Niermann, I., 2015. Mortality estimation from carcass searches using the R-package carcass-a tutorial. Wildl. Biol. 21 (1), 30–43.

Langston, R.H.W., Pullan, J.D., 2003. Wind farms and birds: an analysis of the effects of wind farms on birds, and guidance on environmental assessment criteria and site selection issues. Report T-PVS/Inf (2003) 12. BirdLife International to the Council of Europe, Bern Convention on the Conservation of European Wildlife and Natural Habitats RSPB/BirdLife in the UK. http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/BirdLife_Bern_windfarms.pdf (Accessed 2 February 2016).

Larsen, J.K., Guillemette, M., 2007. Effects of wind turbines on flight behaviour of wintering common eiders: implications for habitat use and collision risk. J. Appl. Ecol. 44, 516–622.

Leddy, K.L., Higgins, K.F., Naugle, D.E., 1999. Effects of wind turbines on upland nesting birds in Conservation Reserve Program grasslands. Wilson Bull. 111, 100–104.

Ledec, G., Rapp, K., Aiello, R., 2011. Greening the Wind: Environmental and Social Considerations for Wind Power Development. World Bank Studies, Washington.

Lekuona, J., Ursúa, C., 2007. Birds and wind farms: risk assessment and mitigation. In: De Lucas, M., Janss, G.F.E., Ferrer, M. (Eds.), Avian Mortality in Wind Power Plants of Navarra (Northern Spain). Quercus, Madrid, pp. 177–192.

Madsen, J., Boertmann, D., 2008. Animal behavioural adaptation to changing landscapes: spring-staging geese habituate to wind farms. Landsc. Ecol. 23, 1007–1011.

Mammen, U., Mammen, K., Heinrichs, N., Resetaritz, A., 2011. Red kite (*Milvus milvus*) fatalities at wind turbines – why do they occur and how they are to prevent? In: May, R., Bevanger, K. (Eds.), Proceedings Conference on Wind Energy and Wildlife Impacts, 2–5 May 2011 2011. Norwegian Institute for Nature Research, Trondheim, Norway, p. 108

Martínez-Abraín, A., Tavecchia, G., Regan, H.M., Jiménez, J., Surroca, M., 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.

Morrison, M.L., Sinclair, K., 1998. Avian Risk and Fatality Protocol. National Renewable Energy Laboratory (NREL), Golden, Colorado. http://www.nrel.gov/wind/pdfs/24997.pdf (Accessed 13 October 2015).

Muñoz, A.R., Real, R., 2013. Distribution of Bonelli's Eagle *Aquila fasciata* in southern Spain: scale may matter. Acta Ornithol. 48, 93–101.

Muñoz, A.R., Ferrer, M., de Lucas, M., Casado, E., 2011. Raptor mortality in wind farms of southern Spain: mitigation measures on a major migration bottleneck area. In: May, R., Bevanger, K. (Eds.), Proceedings Conference on Wind Energy and Wildlife Impacts, 2–5 May 2011 2011. Norwegian Institute for Nature Research, Trondheim, Norway, p. 42.

Muñoz, A.R., Jiménez-Valverde, A., Márquez, A.L., Moleón, M., Real, R., 2015. Environmental favourability as a cost-efficient tool to estimate carrying capacity. Divers. Distrib. 21, 1388–1400.

Natural England, 2010. Assessing the effects of onshore wind farms on birds. Natural England Technical Information Note TIN069, Natural England, Sheffield, UK.

Pearce-Higgins, J.W., Stephen, L., Langston, R.H.W., Bainbridge, I.P., Bullman, R., 2009. The distribution of breeding birds around upland wind farms. J. Appl. Ecol. 46, 1323–1331.

Pearce-Higgins, J.W., Stephen, L., Douse, A., Langston, R.H.W., 2012. Greater impacts of wind farms on bird populations during construction than subsequent operation: results of a multi-site and multi-species analysis. J. Appl. Ecol. 49, 386–394.

Percival, S.M., 2003. Birds and Windfarms in Ireland. A Review of Potential Issues and Impact Assessment. Ecology Consulting, Durham, UK. http://www.sustainableenergyireland.ie/uploaded files/RenewableEnergy/AssessmentMethodologyBirdsIreland.pdf (Accessed 8 March 2016).

Percival, S.M., 2005. Birds and windfarms: what are the real issues? Br. Birds 98, 194–204.

Petersen, I.K., Clausager, I., Christensen, T.J., 2004. Bird Numbers and Distribution on the Horns Rev. Offshore Wind Farm Area. Annual Status Report 2003. Report Commissioned by Elsam Engineering A/S 2003. National Environmental. Research Institute, Rønde, Denmark. http://188.64.159.37/graphics/Energiforsyning/Vedvarende_energi/Vind/havvindmoeller/vvm%20Horns%20Rev%202/Horns%20Rev/fugle/Bird_numbers_2003%2520status_report.pdf (Accessed 13 October 2015).

Ponce, C., Alonso, J.C., Argandoña, G., García-Fernández, A., Carrasco, M., 2010. Carcass removal by scavengers and search accuracy affect bird mortality estimates at power lines. Anim. Conserv. 13, 603–612.

Rees, E.C., 2012. Impacts of wind farms on swans and geese: a review. Wildfowl 62, 37–72.

Reid, T., Krüger, S., Whitfield, D.P., Amar, A., 2015. Using spatial analyses of bearded vulture movements in southern Africa to inform wind turbine placement. J. Appl. Ecol. 52, 881–892.

Sokal, R.R., Rohlf, F.J., 1981. Biometry. The Principles and Practice of Statistics in Biological Research. Freeman and Company, New York.

Stewart, G.B., Pullin, A.S., Coles, C.F., 2005. Effects of wind turbines on bird abundance. Systematic Review No. 4. Collaboration for Environmental Evidence . http://www.environmentalevidence.org/wp-content/uploads/2014/07/SR4.pdf (Accessed 13 October 2015).

Thelander, C.G., Smallwood, K.S., 2007. Birds and wind farms: risk assessment and mitigation. In: De Lucas, M., Janss, G.F.E., Ferrer, M. (Eds.), The Altamont Pass Wind Resource Area's Effects on Birds: A Case History. Quercus, Madrid, pp. 24–46.

WWEA (World Wind Energy Association), 2015. World Wind Energy Report 2014. WWEA Head Office, Bonn, Germany. http://www.wwindea.org/wwea-bulletin-special-issue-2015/ (Accessed 1 February 2016).