

## Manuscript Details

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### 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.*

Keywords *assessment collision; bird abundances; environmental impact; flight behaviour; mortality; renewable energy.*

Corresponding Author *MIGUEL ÁNGEL FARFÁN*

Corresponding Author's Institution *UNIVERSIDAD DE MÁLAGA*

Order of Authors *MIGUEL ÁNGEL FARFÁN, JESÚS DUARTE, Raimundo Real, Antonio Roman Muñoz, John Fa, JUAN MARIO VARGAS YÁÑEZ*

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## **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.

**Key-words:** assessment collision; bird abundances; environmental impact; flight behaviour; mortality; renewable energy.

## 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, Rapp & Aiello 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 1,077 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 & Rodriguez 2004; Thelander & Smallwood 2007; Drewitt & 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 & Guillemette 2007). Habitat loss or damage from the construction of wind turbines and associated infrastructure is likewise possible (Langston & 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 & Langston 2008). However, long-term studies that focus on the impact of wind farms on wildlife populations based on continuous, standardised, 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 & Guillemette 2007; Hill *et al.* 2011; Mammen *et al.* 2011; Muñoz *et al.* 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.* 2015; García *et al.* 2015). This is arguably due to a combination of lower detection rates of the smaller birds, rapid scavenger removal (Lekuona & 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 400-659 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 & 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.

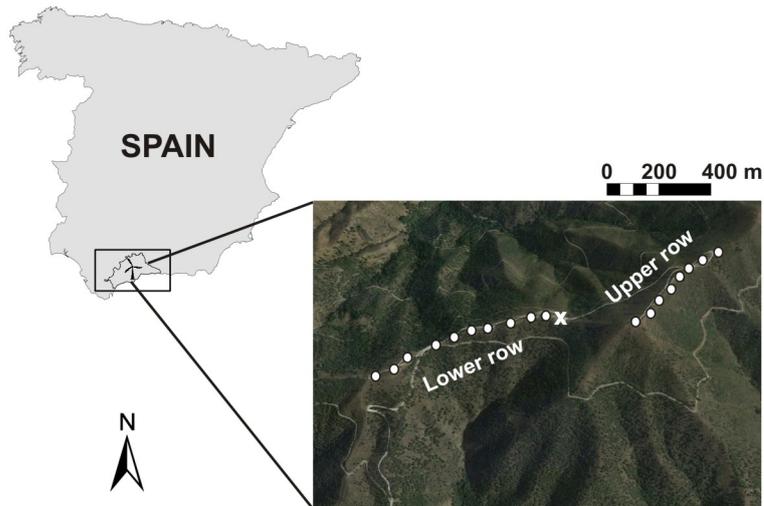


Fig 1. Location of the study area. O: wind turbine; X: geographic reference (36° 51' 18"N; 4° 46' 43"W)

## 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 hours (Period 1: 153 hours; Period 2: 209 hours; Period 3: 193 hours).

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 & 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 & Rohlf 1981).

We used the Specific Risk Index (SRI) described by Lekuona & 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 species, SRI was calculated using the following equation:

$SRI = (\text{number of birds exposed to collision} / \text{total number of individuals}) * 100$

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

### 2.2.2. Bird mortality

We searched for bird carcasses on a weekly basis for a total of 367 hours during the study period (Period 2: 186 hours; Period 3: 181 hours). We walked a 70-m radius around each wind turbine searching for dead birds. We used a protocol similar to those employed by Morrison & Sinclair (1998), De Lucas, Janss & Ferrer. (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 1,533 observations and 2,380 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,  $\chi^2 = 1.143$ ,  $df = 1$ , 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).

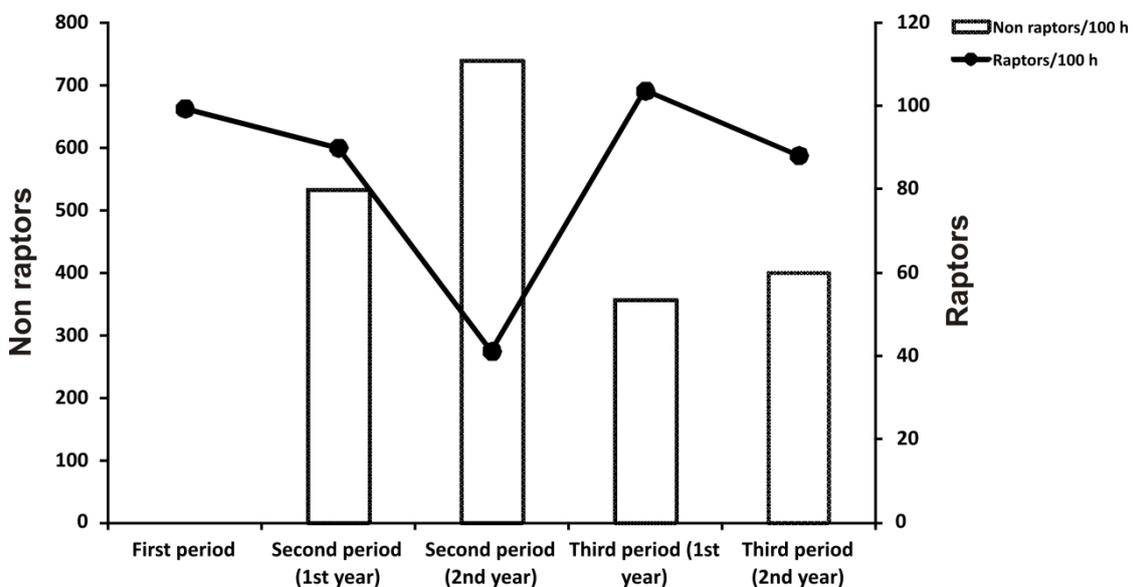


Fig. 2. Raptor and non-raptor variation abundance (individuals/h) during the study period.

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:  $\chi^2 = 65.54$ ,  $df = 1$ ,  $p < 0.01$ ) (Figure 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  $3.8 \pm 2.0$  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  $6.0 \pm 4.4$  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).

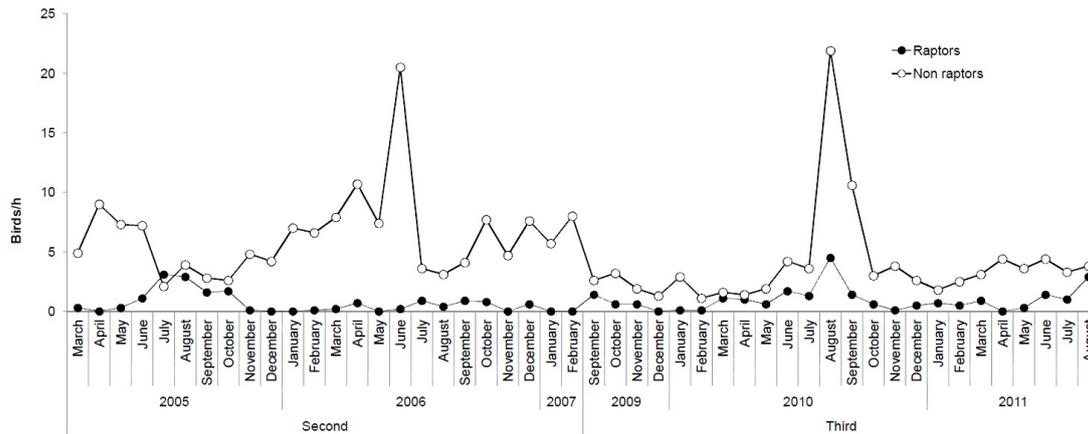


Fig. 3. Monthly flight rates (birds/h) for raptors and non-raptors during Periods 2 and 3.

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) ( $5.2 \pm 4.2$  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:  $\chi^2 = 97.152$ ;  $df = 2$ ;  $p < 0.01$ ).

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

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).

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	Non-passerines	Raptors
			<i>N</i>	<i>N</i>	<i>N</i>
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)

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 1,533 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.

## 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 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, Clausager & Christensen 2004; Stewart, Pullin & Coles 2005; Larsen & 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*), aprox. 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 Jimenez & Muñoz 2008; Muñoz & 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 & Boertmann (2008) for Pink-footed Geese (*Anser brachyrhynchus*), by Devereux, Denny & Whittingham (2008) for wintering farmland birds, and also with the idea that birds may become habituated to the presence of wind farms (Langston & Pullan 2003). Although various studies demonstrate that raptors are especially susceptible to wind turbine collisions (e.g. Barrios & Rodríguez 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, Pullin & Coles (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, Pullin & Coles 2005; Larsen & 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 & 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, Janss & Ferrer 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

“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 & 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 analyzed together to determine whether any significant impacts on birds, at the local or population level, are being addressed.

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## **APPENDIX**

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

<i>Species</i>	<i>Observations (N)</i>		<i>Observations (%)</i>		<i>Bird abundances (N)</i>		<i>Bird abundances (%)</i>	
	2nd period	3rd period	2nd period	3rd period	2nd period	3rd period	2nd period	3rd period
<b>Raptors</b>								
<i>Pernis apivorus</i>	1	2			1	25		
<i>Aquila chrysaetos</i>	1	1			1	1		
<i>Accipiter gentilis</i>	0	1			0	1		
<i>Aquila pennata</i>	4	0			5	0		
<i>Gyps fulvus</i>	2	20			2	64		
<i>Circus pygargus</i>	1	0	11.3	21.5	1	0	9.4	20.2
<i>Falco tinnunculus</i>	95	64			111	73		
<i>Circaetus gallicus</i>	4	13			7	13		
<i>Milvus migrans</i>	2	0			2	0		
<i>Accipiter nisus</i>	5	3			5	3		
<i>Aquila fasciata</i>	1	4			2	5		
<b>Passerines</b>								
<i>Lanius meridionalis</i>	0	2			0	2		
<i>Garrulus glandarius</i>	0	11			0	12		
<i>Delichon urbica</i>	12	17			22	86		
<i>Ptyonoprogne rupestris</i>	23	0			73	0		
<i>Anthus pratensis</i>	3	2			9	3		
<i>Sylvia melanocephala</i>	15	31	83.8	68.9	22	34	80.1	56.0
<i>Turdus torquatus</i>	0	1			0	1		
<i>Parus major</i>	0	3			0	3		
<i>Sturnus unicolor</i>	1	0			1	0		
<i>Galerida theklae</i>	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		
Non identified	143	27			169	47		
<b>Non-passerines</b>								
Merops apiaster	5	1			17	3		
Caprimulgus ruficollis	0	1	4.9	9.6	0	1	10.5	23.8
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
<b>TOTAL</b>	<b>1,031</b>	<b>502</b>	<b>1,465</b>	<b>915</b>

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	

2010	November	16	20	2.0	2.6	0.6	1.9
	December	10	11	1.1	1.3	0.0	1.3
	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
2011	November	19	31	2.4	3.9	0.1	3.8
	December	19	25	2.4	3.1	0.5	2.6
	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	



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

Farfán, M. A.<sup>a,b,\*</sup>, Duarte, J.<sup>b,c</sup>, Real, R.<sup>b</sup>, Muñoz, A. R.<sup>b,d</sup>, Fa, J. E.<sup>e</sup> and Vargas, J. M.<sup>b</sup>

<sup>a</sup>Biogea Consultores. Calle Navarro Ledesma 243, Portal 4, 3º C, 29010 Málaga, Spain

<sup>b</sup>Departamento de Biología Animal. Facultad de Ciencias. Universidad de Málaga. Campus de Teatinos, 29071 Málaga, Spain.

<sup>c</sup>Ofitecma, Calle Colombia 5, 29400, Ronda Málaga, Spain. E-mail: [jddofitecma@gmail.com](mailto:jddofitecma@gmail.com)

<sup>d</sup>Departamento de Botànica, Facultad de Farmacia, Universidad de Valencia, Avda. Vicente Andrés Estellés s/n, Burjassot, Valencia, Spain. E-mail: [roman@uma.es](mailto:roman@uma.es)

<sup>e</sup>Division of Biology and Conservation Ecology, School of Science and the Environment, Manchester Metropolitan University, Manchester M1 5GD, UK. E-mail: [jfa949@gmail.com](mailto:jfa949@gmail.com)

\*Correspondence author. E-mail: [mafarfanaguilar@hotmail.com](mailto:mafarfanaguilar@hotmail.com)