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What is the impact of wind farms on birds? A case study in southern Spain

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Abstract Wind farming is a relatively new form of obtaining energy that does not cause air pollution or other forms of environmental degradation associated with fossil fuel technologies. However, their use impacts on the environment, and the current rate at which they are being put into operation, combined with poor understanding of their medium- and long-term impact, is a cause of concern. Wind farms represent a new source of impact and disturbance for birds that adds to the long list of disturbance factors caused by human activity, such as power lines, radio and television towers, highways, glass windows, the practice of poisoning, illegal hunting and overexploitation. Due to the precarious situation of several bird species and their decline, any additional cause of mortality may be significant and should give rise to increased attention and research. The aim of the present work is to analyse the effect of the "Sierra de Aguas" wind farm on bird density and abundance, flight behaviour, and bird mortality. Mortality rates did not increase due to the presence of the wind turbines. The results suggest that the presence and operation of the wind turbines did not have a clearly negative effect on passerine birds present in the region where wind farm is located. However, raptors used the space around the wind farm with lower frequency than prior to its existence, which represented a displacement of the home range of these species.

Keywords Birds · Human activity · Renewable energy · Southern Spain · Wind farm

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Introduction

A basic aim throughout Europe is to reduce greenhouse gas emissions by the increased use of energy from renewable sources. As a result, wind energy and other alternative energy sources that produce "clean" energy have received strong public support (Leddy et al. 1999). This fact, together with the progressive reduction of the costs associated with wind energy production (Hansen et al. 1992), has led to a considerable proliferation in the number of wind farms around the world (Osborn et al. 2000).

Wind farms are a relatively new form of obtaining energy that does not cause air pollution and other forms of environmental degradation associated with fossil fuel technologies (Nelson and Curry 1995). However, they impact on the environment, and the current rate at which they are being put into operation, combined with poor understanding of their medium- and long-term impact, is a cause of concern. There are at least four aspects to take into account: (1) wind farms are a noise source; (2) they destroy plant cover (Larsen and Madsen 2000; Fox et al. 2006; Larsen and Guillemette 2007); (3) they have an aesthetic impact on the landscape; and (4) they have a negative effect on flying fauna, especially birds (Nelson and Curry 1995). In the latter case we can distinguish two different effects. The first concerns direct mortality due to collision with turbines, and the second consists in disturbances in the spatial use of territory caused by their presence.

Wind farms represent a new impact and disturbance source for birds (Orloff and Flannery 1992) that adds to the long list of disturbance factors caused by human activity, such as power lines (Ferrer et al. 1991; Janss and Ferrer 1998; Penteriani 1998), radio and television towers (Stahlecker 1979; Smith 1985), highways (Fajardo et al. 1998), glass windows (Klem 1990a, b), the practice of poisoning (Harmata et al. 1999; Vargas 2002), illegal hunting (Lucio and Purroy 1992; Villafuerte et al. 1998) and overexploitation (BirdLife International 2004). Nowadays, there is abundant literature on the high mortality of birds caused by man-made structures, and the impact of these structures on bird populations as well as the development of protective measures (Klem 1990a; Fajardo et al. 1998; Alonso and Alonso 1999). In the United States alone the annual number of birds killed by collisions with these elements varies between 100 million and one billion (Klem 1990b; Manville 2000). However, as the commercial production of wind energy is recent—in the United States it started at the beginning of the 1980s (American Wind Energy Association (AWEA) 1995)—the effects of wind farms on bird populations has been little studied.

The rapid development of wind farms in recent decades has generated controversy regarding the negative influence of these structures on bird conservation (Drewitt and Langston 2006). However, scientific literature on this issue is scarce. Several studies show that the negative impact of wind farms on bird populations is much less than other sources of collision (de Lucas et al. 2004, 2005). According to Erickson et al. (2001), the number of bird deaths due to collisions with turbines represent 0.01–0.02% of the total, which is far lower than impacts with other structures such as vehicles, buildings, glass windows, power lines or communication towers. On the hand, other studies report higher mortality levels and highlight raptors as being the most affected (Orloff and Flannery 1992; Barrios and Rodríguez 2004).

In any case, due to the precarious situation of several bird species and their decline—especially some raptors and other long-lived birds with low reproduction and slow maturation rates—any cause of additional mortality can be significant and should give rise to increased attention and research, particularly in cases such as wind farms where there is cumulative mortality as a consequence of multiple installations (Drewitt and Langston

2006). In this sense, monitoring programs and observing avifauna will provide better information on the causes of mortality and the factors to take into account when identifying the best location for wind farms. Since the factors that cause mortality in birds increase as the human demand for resources grows, any initiative or effort by organisations and groups involved in addressing the factors mentioned is relevant in reversing the current trend in bird mortality.

The aim of the present work is to analyse the effect of the "Sierra de Aguas" wind farm on bird density and abundance, flight behaviour and bird mortality.

Materials and methods

Study area

This work was performed in Malaga province (southern Spain) from March 2005 to February 2007 (Fig. 1). This area was chosen because of its proximity to the Strait of Gibraltar ($\sim$100 km away), which is one of the most important migrating routes in the Palaearctic (Bernis 1980; Bildstein and Zalles 2000).

The wind farm, called the "Sierra de Aguas", is located on a mountain ridge running SW to NE. It consists of 16 wind turbines evenly distributed in two continuous rows located between 815 and 940 m above sea level. The wind turbines are around 90 m apart in each row. The two rows are separated by a 500-m corridor and their total length is 1,600 m each.

Each wind turbine generates 850 KW. Thus, the total power of the wind farm is 13.6 MW. The wind turbines have three blades with variable step. They are made of

Fig. 1 Location of the study area

fibreglass and the rotors are orientated windward. Blade length is 25 m. They are white except for the ends of the blades, which are red. The tower is cylindrical, 3.3 m in diameter at the base and 44 m tall.

In the south-western row the vegetation is dominated by trees (*Pinus pinaster* and *Pinus halepensis*) due to afforestation. On the other hand, scrubland and pasture are more abundant around the north-eastern row. The most representative species in the study area are *Phlomis purpurea*, *Phlomis lychnitis*, *Quercus coccifera*, *Chamaerops humilis*, *Rosmarinus officinalis*, *Cistus albidus*, *Ulex parviflorus* and *Stipa tenacissima*.

Several breeding raptor species can be found in the area, such as griffon vulture (*Gyps fulvus*), sparrowhawk (*Accipiter nisus*), golden eagle (*Aquila chrysaetos*), Bonelli's eagle (*Hieraaetus fasciatus*), short-toed eagle (*Circaetus gallicus*) and common kestrel (*Falco tinnunculus*). According to the Red List of Andalusian Threatened Vertebrates (Junta de Andalucía 2001), golden eagle and Bonelli's eagle are classified as vulnerable. Passerines are abundant in the study area, especially thekla lark (*Galerida theklae*), chaffinch (*Fringilla coelebs*), rock bunting (*Emberiza cia*) and stonechat (*Saxicola torquata*).

Production of energy

Wind farms represent a disturbance factor for birds as well as a new collision risk. However, both aspects increase when the rotors are working. The "Sierra de Aguas" wind farm did not produce energy for 1,371 h (Table 1) during the study period, implying that the wind turbines were in motion during 92.2% of the period.

Parameters analysed

The study covered two annual periods: from March 2005 to February 2006 and from March 2006 to February 2007, and the following seasonal periods: spring (March–May), summer (June–August), autumn (September–November) and winter (December–February).

We visited the "Sierra de Aguas" wind farm on a weekly basis to analyse three different parameters as follows:

Abundance of birds and flight behaviour

The flight behaviour of birds in the proximity of wind farm (150 m high and 500 m wide on each side of the two rows of the wind turbines) was recorded by direct observation from fixed points. The birds were observed for a total of 209 h during the study period. Each observation included recording the bird species, number of birds, climatic conditions (wind direction and speed, both recorded at 9:00 hours), flight altitude (1—below blade; 2—level with the blade; 3—above the blade), flight class regarding blade (1—within blade radius; 2—outside blade radius), change of flight direction (changes in flight altitude and direction), activity of wind turbines (1—in motion; 2—still) and flight direction relative to turbine alignment (1—transversal; 2—parallel).

The data collected were used to determine the monthly number of observations and individuals, and the monthly rates of observations (number of observations/hour) and flying (number of birds/hour). In the first case, we recorded the number of observations and birds each month, whereas in the second case, we divided the number of observations and birds each month by the number of observation-hours in the corresponding month.

We used the Kruskal–Wallis test to analyse annual and seasonal differences in the number of observations and individuals, and observations and flying rates (Sokal and Rohlf 1981).

Table 1 Number of hours without production of energy in the wind farm "Sierra de Aguas" during the period of study

Year	Month	Hours without production of energy	
		Month	To origin
2005	March	69	69
	April	22	91
	May	53	144
	June	15	159
	July	23	182
	August	48	230
	September	30	260
	October	90	350
	November	64	414
	December	46	460
2006	January	56	516
	February	62	578
	March	83	661
	April	99	760
	May	36	796
	June	76	872
	July	64	936
	August	62	998
	September	25	1,023
	October	52	1,075
	November	56	1,131
	December	103	1,234
2007	January	98	1,332
	February	39	1,371

We analysed the distribution of observations according to the following:

1. Altitude. We distinguished three different altitudes: 1—below blade; 2—level with the blade; 3—above the blade.
2. Wind speed. We distinguished five different wind speeds: 1—very weak; 2—weak; 3—moderate; 4—strong; 5—very strong.
3. Combined altitude and wind speed.
4. Flight direction. We distinguished two different directions relative to wind turbine alignment: 1—transversal; 2—parallel.
5. Combined altitude and flight direction.

In all cases the χ^2 (chi-square) test was used to determine if the results obtained regarding the distribution of observations significantly differed from the values expected at random (Sokal and Rohlf 1981).

Bird density

To determine the effect of the wind farm on the density of resident birds, we selected one species and estimated its density during spring in 2005 and 2006. We chose the thekla lark

(*Galerida theklae*) because it is abundant and easy to detect. For each survey period (year), line-transect density estimation (Buckland et al. 2001) was obtained using the distance 5.0 Windows-based software package (Thomas et al. 2006), fitting the best detection model according to Akaike's information criterion (AIC) (Akaike 1973). The default analysis consisted in individuals as sighting units. These were grouped into 25-m strips, and truncated at 75–100 m (when there were no sightings beyond this distance). Each year, two transects were walked in the morning at a mean velocity of 1.5 km/h.

The Mann–Whitney *U* test (Sokal and Rohlf 1981) was used to analyse statistically significant differences between the number of individuals observed in the censuses.

Bird mortality

During the study period (from March 2005 to February 2007), we searched for birds which had been killed by colliding with the wind turbines. A total of 186 h was devoted to this task. We used a search protocol very similar to that used by other authors (Orloff and Flanery 1992; Morrison and Sinclair 1998; de Lucas et al. 2004). Thus, we checked 70 m around all the wind turbines on foot and when a carcass was found we recorded the species, sex, age, injuries, condition of plumage, date and time of find, distance and orientation to the closest wind turbine, and estimated time of death. However, we could not take into account the proportion of corpses being overlooked or removed by scavengers, because the proposed trial was not approved by the environmental authorities.

Observations of raptor abundance and flight behaviour were compared with data included in an unpublished report about this group of birds for the period November 2000–October 2001, which were used as baselines prior to construction of the wind farm. We used the G-test of independence (Sokal and Rohlf 1981) to analyse the differences in the abundance of the common kestrel in comparison to other raptor species prior and after the construction of the wind farm.

Results

Abundance of birds and flight behaviour

In the study period, we recorded 1,031 observations and 1,465 individuals in the proximity of the wind farm (Table 2). The most abundant birds were Passerines and about eight out of every ten observations and individuals sighted were species in this group, whereas the remaining 20% were evenly distributed between raptors and non passerines.

Without taking into account non-identified passerines, the most abundant species were thekla lark (26.2% of individuals recorded), rock bunting (10.2%), common kestrel (7.6%), stonechat (6.2%), swift sp. (5.3%), goldfinch (5.1%) and crag martin (5.0%).

The monthly number of observations and individuals is shown in Table 3. No statistical differences were detected in the annual and seasonal number of observations (annual: Kruskal–Wallis test, $\chi^2 = 1.143$, $df = 1$, nonsignificant; seasonal: Kruskal–Wallis test, $\chi^2 = 9.199$, $df = 7$, nonsignificant) and individuals (annual: Kruskal–Wallis test, $\chi^2 = 0.368$, $df = 1$, nonsignificant; seasonal: Kruskal–Wallis test, $\chi^2 = 6.513$, $df = 7$, nonsignificant).

The monthly observation rate was not constant over the study period. It fluctuated between a minimum value of 2.4 observations/hour in December 2005 and a maximum value of 10.7 observations/hour in June 2006 (Table 3), with a mean monthly value of

Table 2 Number of observations and individuals recorded in the wind farm throughout period of study

Species	No. of observations	% Observations	No. of individuals	% Individuals
Raptors				
Honey buzzard	1	11.3	1	9.4
Griffon vulture	2		2	
Short-toed eagle	4		7	
Sparrow hawk	5		5	
Booted eagle	4		5	
Common kestrel	95		111	
Bonelli's eagle	1		2	
Golden eagle	1		1	
Montagu's harrier	1		1	
Black kite	2		2	
Passerines				
Crag martin	23	83.8	73	80.1
Meadow pipit	3		9	
Black redstart	2		2	
Spotless starling	1		1	
Thekla lark	348		384	
Linnet	32		66	
Melodious warbler	2		2	
Thrush sp.	1		3	
Red-rumped swallow	2		2	
House martin	12		22	
Nightingale	1		1	
Stonechat	68		91	
Dartford warbler	15		16	
Sardinian warbler	15		22	
Spotted flycatcher	2		2	
Chaffinch	58		72	
Goldfinch	9		75	
Crossbill	12		12	
Rock bunting	115		150	
Non identified	143		169	
Non passerines				
Alpine swift	1	4.9	2	10.5
Hoopoe	1		1	
Woodpigeon	1		1	
Bee-eater	5		17	
Swift sp.	19		77	
Red-legged partridge	24		56	
Total	1,031		1,465	

Table 3 Monthly abundance of observations and individuals and monthly variation of the observation and flying rates

Year	Month	Observations	Individuals	Observations/h	Total birds/h	Raptors/h	Non raptors/h
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	2.8	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

4.9 ± 2.0 observations/hour. In general, the observation rates were higher in the second year than in the first, although no statistically significant differences were found (Kruskal–Wallis test, $\chi^2 = 0.653$, $df = 1$, nonsignificant). The highest observation rates occurred in spring, but there were no statistically significant seasonal differences (Kruskal–Wallis test, $\chi^2 = 9.653$, $df = 7$, nonsignificant).

The total monthly flying rate showed considerable variations too and varied between a maximum value of 20.6 birds/h in June 2006 and a minimum value of 3.5 birds/hour in August of the same year (Table 3) with a mean monthly value of 7.0 ± 3.5 birds/h. The highest total flying rates occurred during the second year in spring although no statistical differences were detected (annual: Kruskal–Wallis test, $\chi^2 = 1.080$, $df = 1$, nonsignificant; seasonal: Kruskal–Wallis test, $\chi^2 = 8.200$, $df = 7$, nonsignificant).

Annual flying rate of raptors prior to the construction of the wind farm was 1.1 raptors/hour. This rate diminished slightly during the first year after the construction of the wind farm (0.93 raptors/h; Kruskal–Wallis test previous study vs first year of wind farm, $\chi^2 = 0.429$, $df = 1$, $P = 0.513$) and more sharply and significantly during the second year (0.39 raptors/h; Kruskal–Wallis test previous study vs second year of wind farm: $\chi^2 = 3.857$, $df = 1$, $P < 0.05$). During the two years of existence of the wind farm raptors contributed very little to total flying rate values. More specifically, the maximum value for this group was 3.1 raptors/hour in July 2005, with a mean monthly value of 0.7 ± 0.9 raptors/h. The highest values were detected in summer and the lowest in winter (Table 3) but, despite this, there were no statistically significant seasonal differences (Kruskal–Wallis test, $\chi^2 = 12.463$, $df = 7$, nonsignificant).

The monthly flying rates of nonraptors fluctuated between 20.5 birds/h in June 2006 and 2.1 birds/h in July 2005, with a monthly mean value of 6.4 ± 3.8 birds/hour. The lowest flying rates occurred during the first year in spring-summer (Table 3), although the differences were not statistically significant (annual: Kruskal–Wallis test, $\chi^2 = 2.803$, $df = 1$, nonsignificant; seasonal: Kruskal–Wallis test, $\chi^2 = 10.667$, $df = 7$, nonsignificant).

Table 4 shows the distribution of the observations grouped by raptors, passerines and nonpasserines according to altitude. In all cases the most frequent observations occurred below the blades (~80%). The second-most frequent observations involved raptors, although at lower percentages, and took place at the level of the blades (12.1%). These results differ from those found prior to the existence of the wind farm, when the most frequent observations for raptors occurred at the level of the blades (61.2%). For passerines and nonpasserines the proportions of observations at the level of the blades and above blades was very similar. We found statistically significant differences between the distribution of observations according to altitude versus the values expected at random (raptors: $\chi^2 = 128.34$; $df = 2$; $P < 0.01$; passerines: $\chi^2 = 959.47$; $df = 2$; $P < 0.01$; nonpasserines: $\chi^2 = 46.71$; $df = 2$; $P < 0.01$).

Most observations of raptors occurred in strong winds (43.1%) and there were fewer in very weak winds (34.5%). However, the situation was the reverse in passerines and nonpasserines. Thus, observations were more frequent in very weak winds, 66.8 and 66.7, respectively, and less frequent in strong winds, 17.9 and 13.9%, respectively (Table 5). In all cases, there were fewer observations when there was a very strong wind. In all three bird groups the distribution of the observations according to wind speed significantly differed from the values expected at random (raptors: $\chi^2 = 73.05$; $df = 4$; $P < 0.01$; passerines: $\chi^2 = 1{,}248.25$; $df = 4$; $P < 0.01$; nonpasserines: $\chi^2 = 70.67$; $df = 4$; $P < 0.01$). Prior to the construction of the wind farm flight rate was reported to be related to wind speed only in winter.

Table 4 Distribution of the observations according to altitude. 1—below blades; 2—same level that blades; 3—beyond blades

	Raptors			Passerines			Non passerines		
	1	2	3	1	2	3	1	2	3
N	96	14	6	717	85	62	40	5	6
%	82.8	12.1	5.2	83.0	9.8	7.2	78.4	9.8	11.8

Table 5 Distribution of the observations according to wind speed. 1—very weak; 2—weak; 3—moderate; 4—strong; 5—very strong

	Raptors					Passerines					Non passerines				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
N	40	15	6	50	5	577	81	16	155	35	34	4	4	7	2
%	34.5	12.9	5.2	43.1	4.3	66.8	9.4	1.9	17.9	4.1	66.7	7.8	7.8	13.7	3.9

Table 6 Distributions of the observations according to altitude and wind speed. 1—below blades; 2—same level that blades; 3—beyond blades

Altitude	Wind speed	Raptors		Passerines		Non passerines	
		N	%	*N*	%	*N*	%
1	Very weak	33	28.4	470	54.4	23	45.1
	Weak	11	9.5	67	7.8	4	7.8
	Moderate	6	5.2	15	1.7	4	7.8
	Strong	41	35.3	137	15.9	7	13.7
	Very strong	5	4.3	28	3.2	2	3.9
2	Very weak	5	4.3	61	7.1	5	9.8
	Weak	3	2.6	6	0.7	0	0.0
	Moderate	0	0.0	1	0.1	0	0.0
	Strong	6	5.2	10	1.2	0	0.0
	Very strong	0	0.0	7	0.8	0	0.0
3	Very weak	2	1.7	46	5.3	6	11.8
	Weak	1	0.9	8	0.9	0	0.0
	Moderate	0	0.0	0	0.0	0	0.0
	Strong	3	2.6	8	0.9	0	0.0
	Very strong	0	0.0	0	0.0	0	0.0

Independently of wind speed, the most frequent observations occurred below the blades (Table 6); 82.8% for raptors, 83.0% for passerines and 78.4% for nonpasserines. In all three cases there were no statistically significant differences in the distribution of the observations versus the values expected at random (raptors: $\chi^2 = 3.38$; $df = 15$; nonsignificant; passerines: $\chi^2 = 13.33$; $df = 7$; nonsignificant; nonpasserines: $\chi^2 = 7.01$; $df = 7$; nonsignificant).

When we analyzed the distribution of the observations relative to flight direction (transversal and parallel), statistically significant differences were found ($\chi^2 = 46.52$; $df = 1$; $P < 0.01$). The most frequent observations occurred in the transversal direction relative to the wind turbines (60.6%) (Table 7). This tendency is mainly due to passerines, as the most frequent observations for this group occurred in the transversal direction (66.9%) and the differences were statistically significant versus the values expected at random ($\chi^2 = 98.69$; $df = 1$; $P < 0.01$). However, for raptors and nonpasserines, the most

Table 7 Distribution of the observations according to altitude and flight direction regarding alignments of wind turbines. 1—below blades; 2—same level that blades; 3—beyond blades

Altitude	Direction	Raptors		Passerins		Non passerines	
		N	%	*N*	%	*N*	%
1	Transversal	18	15.5	500	57.9	17	33.3
	Parallel	78	67.2	217	25.1	23	45.1
2	Transversal	4	3.4	46	5.3	1	2.0
	Parallel	10	8.6	39	4.5	4	7.8
3	Transversal	4	3.4	32	3.7	3	5.9
	Parallel	2	1.7	30	3.5	3	5.9

numerous observations occurred parallel to wind turbine alignment (77.6% and 58.8%, respectively), although statistically significant selection of flight direction was found for the first group only (raptors: $\chi^2 = 35.31$; $df = 1$; $P < 0.01$; nonpasserines: $\chi^2 = 1.59$; $df = 1$; nonsignificant). In contrast, prior to the building of the wind farm 64.5% of raptor flights were reported to occur in transversal direction.

Although most frequent raptor and nonpasserines flights occurred both parallel to the wind turbines and below the blades (Table 7), differences were not significant (raptors: $\chi^2 = 7.80$; $df = 5$; nonsignificant; nonpasserines: $\chi^2 = 1.15$; $df = 5$; nonsignificant). For passerines, the most frequent observations were recorded in the transversal direction and below the blades (57.9%). The differences detected between the observed values and those expected at random were statistically significant ($\chi^2 = 15.42$; $df = 5$; $P < 0.01$).

During the study period, we recorded only seven observations where birds avoided crossing the wind turbine rows. In all cases, these were passerines. In the same period, we recorded 51 observations in the transversal direction and at the same altitude as blades. Only 27.5% of these occurred within the blade radius. Therefore, and taking into account that we recorded 1,031 observations during the 2-year study period, the observations with a high risk of collision represented a very small percentage (1.4%), that is, about one in every hundred.

When we analyze the results for raptors only, the percentage of observations with a high risk of collision is very similar to that obtained for all birds. Thus, we recorded 116 observations of raptors and only two occurred in the transversal direction and at the same altitude as the blades (1.7%).

The particular case of raptors

The number of raptors recorded decreased 38.2 and 71.7%, respectively, during the first and second year after the construction of the wind farm (previous study vs first year of wind farm: $\chi^2 = 13.67$, $df = 1$, $P < 0.01$; previous study vs second year of wind farm: $\chi^2 = 30.46$, $df = 1$, $P < 0.01$). Differences in the number of raptors between first and second year of wind farm operation were statistically significant too (first year of wind farm vs second year of wind farm: $\chi^2 = 18.99$, $df = 1$, $P < 0.01$).

When we exclude the common kestrel from the reckoning, the number of raptors observed during the first and second year of the wind farm decreased more strongly, 86.4% and 88.3, respectively, with respect to the previous report (previous study vs first year of wind farm: $\chi^2 = 67.70$, $df = 1$, $P < 0.01$; previous study vs second year of wind farm: $\chi^2 = 72.00$, $df = 1$, $P < 0.01$). The first and second year the number of raptors remained similarly low (first year of wind farm vs second year of wind farm: $\chi^2 = 0.15$, $df = 1$, nonsignificant).

Before the construction of the wind farm the common kestrel was the most frequent raptor observed. Out of 152 raptors observed, 49 individuals (32.2%) belonged to this species. In the present study the common kestrel was the most frequent raptor observed too, but the proportion of this species with respect to the total number of raptors registered was higher than that reported in the previous study. To be exact, 85.1 and 75.1% of the raptors observed were common kestrels in the first and second year, respectively. Number of common kestrel observed increased significantly during first year of the wind farm (80 individuals; previous study vs first year of wind farm: $\chi^2 = 7.45$, $df = 1$, $P < 0.01$). On the contrary, the second year of the wind farm the number of common kestrel decreased significantly with respect to the previous report (32 individuals; previous study vs second year of wind farm: $\chi^2 = 4.05$, $df = 1$, $P < 0.05$). The seasonal distribution of the

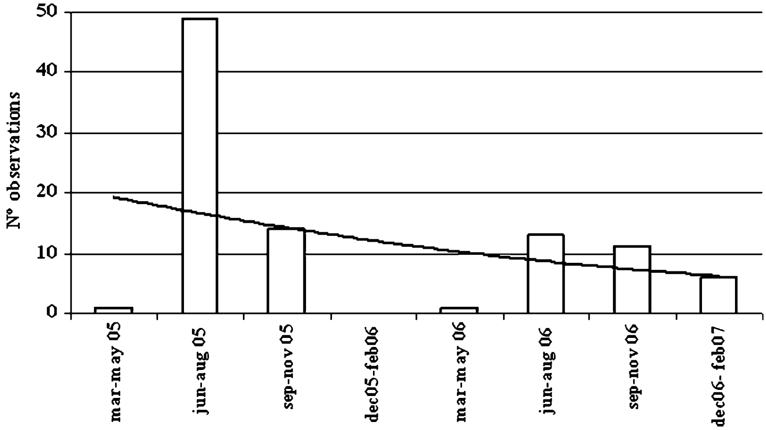

Fig. 2 Distribution of observations of common kestrel (*Falco tinnunculus*) in the wind farm "Sierra de Aguas" along period of study

observations of common kestrel during the study period showed a decreasing trend (Fig. 2). Differences between both years were statistically significant (first year of wind farm vs second year of wind farm: $\chi^2 = 21.63$, $df = 1$, $P < 0.01$). Nevertheless, and despite its constant presence, mainly during the first year of the wind farm, there were very few observations with a high risk of collision. Only 17.9% of the observations of this species occurred in the transversal direction and 82.4% of these occurred across the corridor between the two rows. In only three cases, common kestrels passed through the rows at the same altitude as the blades, and in one of them the kestrels flew outside blade radius.

Differences in the abundance of the common kestrel in comparison to other raptor species between before and after construction of wind farm were statistically significant (previous study vs first year of wind farm: independence *G*-test, $\chi^2 = 65.09$, $df = 1$, $P < 0.001$; previous study vs second year of wind farm: independence G-test, $\chi^2 = 22.01$, $df = 1$, $P < 0.001$).

Bird density

The results of the censuses of thekla lark in each year of the study period demonstrated 7.43 individuals/10 ha and 7.30 individuals/10 ha, respectively (Table 8). The densities recorded in spring 2005 are slightly higher than these obtained in spring 2006. However, no statistically significant differences were detected (Mann–Whitney $U_4 = 0.500$; nonsignificant).

Bird mortality

During the entire study period (24 months), we found the remains of one bird only: some feathers of an adult male common kestrel. There were obvious signs that it had been eaten by a mammal. In addition, we found carnivore excrement next to the feathers. The remains were located near a wind turbine and we think that its death was due to collision with a wind turbine. However, we can be certain of nothing in this respect. If we assume that collision was the cause of death, then the mortality rate in the wind farm would be 0.03 birds/turbine/year.

Table 8 Densities of thecla lark (*Galerida theklae*) in the wind farm "Sierra de Aguas" along 2 years of study

Year	Density (individuals/10 ha)	AIC	LC	UC	CV
2005	7.43	20.24	0.252	2.187	0.502
2006	7.30	10.37	0.288	1.849	0.408

AIC: Akaike's information criterion. *LC* and *UC*: Confidence intervals. *CV*: coefficient of variation

The low number of dead birds prevented us from comparing different areas in the wind farm or establishing a chronological pattern between collisions and species phenology.

Discussion

The effects of a wind farm on birds depend on a wide variety of factors such as the characteristics and location of the wind farm, topography, habitat of the surrounding land, and species present (Percival 2000; Barrios and Rodríguez 2004; de Lucas et al. 2004, 2008; Hoover and Morrison 2005). Based on the results of the present study, the presence and operation of wind turbines have a clearly negative effect on the raptors present in the region. The effect is different on the common kestrel, which decline in number during the second year of operation, than on the other raptor species, which decline sharply the first year and remain in low numbers during the second one.

In general, most research, shows that a negligible number of birds are disturbed by wind farms (de Lucas et al. 2004, 2005; Walker et al. 2005; Madders and Whitfield 2006 and references therein). Only our results obtained for Passerines are in accordance with that assertion. The monthly number of Passerine observations and individuals does not significantly differ by year and season. Similarly, neither did the observation and flying rates show significant variations over the study period. We did not observe passerine birds avoiding flying close to the wind farm. In the case of the thekla lark, the densities in the wind farm were similar to those detected in other habitats and regions within its range in the Iberian Peninsula (Díaz 2003), although in the second year of the study period the values recorded were slightly lower than those of the first year.

There is some evidence in the scientific literature that the longer the period the turbines are in operation, the greater the decrease in bird abundance (Stewart et al. 2004). In contrast, Smallwood and Thelander (2004) observed increasing raptor presence at a wind farm over the long term. This fact suggests that any earlier displacement effect no longer occurs and that the birds have probably become used to the wind farms. In our case, only the common kestrel decreased significantly during the two years of farm operation, while the other raptor and Passerine species remained steady. However, 2 years is a very short period to obtain accurate data on the effects of wind farms on bird abundance. Like Madders and Whitfield (2006), we think that post-construction impact studies should be conducted over a longer period.

We verified that the most frequent observations, independently of wind speed, occur below the blades and, therefore, outside their radius. Nevertheless, for raptors we observed an important change in this aspect probably associated to the presence of wind turbines. The fact is that the most frequent observations for this group in the post-construction period occur below the blades while in the previous study occurred at the level of the blades. This fact shows that birds detect the presence of wind turbines and regulate its fly to the new conditions (de Lucas et al. 2007). Thus, the observations with a risk of collision and collision rates are very few. Specifically, the mortality rate in the "Sierra de Aguas" wind farm is 0.03 birds/turbine/year. This result is in agreement with most studies on collisions caused by wind turbines, which have recorded low levels of mortality (Percival 2000; Erickson et al. 2001; de Lucas et al. 2004). However, there are some other issues to address in this respect. First, in some cases, as in this study, mortality rates may be underestimated because the adjustments due to corpses being overlooked or removed by scavengers cannot be made (Langston and Pullan 2003).

Second, the percentage of dead birds resulting from collisions with wind turbines is much smaller than that due to other human structures, although we have to take into account that, currently, there are far fewer wind farms than these other disturbance factors caused by human activity. Such low levels of additional mortality may in fact be significant for certain species, such as raptors, with low reproduction and slow maturation rates, particularly in situations where cumulative mortality occurs due to the considerable proliferation in the number of wind farms.

Third, although the mortality rate per turbine was low, overall collision rates may be very high when the number of wind turbines involved is large (Orloff and Flannery 1992).

Fourth, the low levels of mortality caused by wind turbines reported by most studies on collisions may reflect the fact that wind farms are located to avoid areas where bird concentrations are high (Drewitt and Langston 2006). Thus, when wind farms are located in areas used by birds for hunting, roosting or breeding, the mortality rates increase. This is the case reported by Hunt (1999) for golden eagle in the Altamont Pass where a minimum number of 75 individuals are killed annually. This is why positioning new wind farms in locations with low densities of birds is the best way to minimize mortality rates due to collisions (Erickson et al. 2001; de Lucas et al. 2004).

Fifth, the low levels of mortality caused by wind turbines in the present study can be due, at least partly, to the decline in the number of raptors flying around the wind farm. Presence of wind farm did not cause an increase in raptor mortality rate because raptors used the space around the wind farm with lower frequency. This fact represents a loss of habitat for these species.

As Devereux et al. (2008), the results of the present study show that the "Sierra de Aguas" wind farm does not act as a barrier to passerines (Table 7). However, this is less evident in the case of raptors and nonpasserines. Thus, the most numerous observations for both groups occur in the direction parallel to wind turbine alignment. Furthermore, in the case of raptors the change is obvious because in the previous period the most frequent observations occurred in transversal direction. According to Drewitt and Langston (2006), this may be due to the short distance between wind turbines (90 m). In any case, the potential barrier effect may have been lessened due to the rows being short (Dirksen et al. 1998) and due to the corridor between them. Longer wind turbine rows could effectively block a flight line used between hunting areas or hunting and nesting areas. The barrier effect could also increase in areas where several wind farms cumulatively interact to create an extensive barrier. In both cases, there is an increase in energy expenditure when birds have to fly further to avoid wind turbines and due to potential disruptions of foraging, roosting and breeding areas. In any case, as Drewitt and Langston (2006) suggest additional research before and after the construction of wind farms is needed to better understand the effects of such structures on bird populations.

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