Effects of wind farms on Montagu's harrier (*Circus pygargus*) in southern Spain

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Abstract

To study the potential impact of wind turbines and associated structures on Montagu's harriers *Circus pygargus*, we located 111 nests over five years (18 – 28 nests per year) and compared their distances to several features (natural and anthropogenic) between wind farm pre- and post-construction periods using a before-after (BA) study design. In addition, we deployed an impact gradient (IG) study design to examine the potential impact of turbines on Montagu's harrier nest locations. We analysed abundance and density of nests and colonies through the study period. We also fitted a predictive model of nest occurrence using distance-to-feature variables and habitat as predictors. Lastly, Montagu's harrier fatalities from collision with wind turbines were estimated. No differences were detected between pre- and post-construction periods in nest or colony abundances. We found that harriers nested closer to the locations of wind turbines and power lines after wind farm construction, although distance to closest track did not change. We detected a higher spatial aggregation of Montagu's harrier nests after wind farms were installed, when the distribution of nests was mostly explained by habitat and distance to the closest track. Distance to wind turbine was apparently not influential. Fatality through collision was relatively uncommon during the study period. Our findings demonstrate that the construction, operation and maintenance of wind farms did not seem to adversely affect Montagu's harrier nesting decisions in our study area. However, we encourage further studies including reproductive parameters and foraging strategies of Montagu's harrier to provide a complete investigation of potential impacts of wind farms on this species.

Key-words: BA design, IG design, bird collision, avoidance distance, disturbance, Tarifa.

Introduction

Numerous studies have focused on wind farm impacts on wildlife due to the spectacular growth in capturing wind energy as means to obtain 'clean' energy around the world in last decades (Smallwood and Thelander, 2005; Everaert and Stienen, 2007). One of the most studied impact of wind farms is bird mortality caused by collision with turbine blades (De Lucas et al., 2008; Drewitt and Langston, 2008; Marques et al., 2014). These deaths represent 0.01 – 0.02 % of annual avian mortality rates, and so lower than due to other human activities, such as electrocution at power lines (Calvert et al., 2013; Sovacool, 2013; Erickson et al., 2014). However, some discrepancy has arisen because of the high variation in indices of mortality caused by collisions with blades regarding to species or locations (Stewart et al., 2007), being raptors among the most affected species (Barrios and Rodríguez, 2004; Hoover and Morrison, 2005; Kuvlesky et al., 2007; Loss et al., 2013), independent of their abundance in the potentially affected area (Orloff and Flannery, 1992; Thelander et al., 2003; Drewitt and Langston, 2006; Hötker et al., 2006; De Lucas et al., 2008; Smallwood et al., 2009; Ferrer et al., 2012; Zimmerling et al., 2013; Erickson et al., 2014; Everaert, 2014).

Wind farms may also act as sources of disturbance for birds, such that the vicinity of wind farm infrastructures may be avoided (Langston and Pullan, 2003), causing the displacement of local fauna from the surroundings of wind farms, and consequently may reduce their reproduction and/or survival rates (De Lucas et al., 2004; Kuvlesky et al., 2007; Larsen and Guillemette, 2007). Despite awareness of such indirect effects, they have been rarely evaluated because of, on the one hand, the difficulty in their detection and, on the other hand, the shortage of standardized protocols that complicates comparison between studies (Garvin et al., 2011; Hale et al., 2014). Anderson et al. (1999) outlined potential study designs to encourage common standards across studies investigating wind farm impacts on birds. The Before-After design (BA) evaluates an impact of a target event by comparing conditions before and after the target event appeared using the same protocols in the same study area (Anderson et al., 1999). This approach usually entails difficulties for research on wind farm impacts because it requires repeated measures across several years before and after the installation of a wind farm, and these requirements are unusually met (Gove et al., 2013). The Impact-Gradient (IG) design quantifies the impact of a target event by measuring specific biological traits across a distance gradient from the target event location (Anderson et al., 1999).

The Montagu's harrier is a migratory medium-sized raptor that breeds in small colonies widespread in the Palearctic (Cramp and Simmons, 1980). Montagu's harrier has been declining globally in recent decades primarily due to agricultural intensification, especially in Western Europe (BirdLife International, 2015). In Spain, this species broadly shows a high spatial coincidence between its breeding distribution and wind farms (Tellería, 2009) but, as far as we know, there is an absence of studies examining wind farm impacts on Montagu's harrier. Evaluations of wind farm impacts on a closely related species, the hen harrier *Circus cyaneus*, have reported effects of small-scale displacement of foraging birds from around wind turbines (Johnson et al., 2000; Madders and Whitfield, 2006; Whitfield and Madders, 2006a). Hen harriers typically forage flying close to the ground and below the sweep of turbine blades (Whitfield and Madders, 2006b), and so collision victims are rarely found, even when foraging activity may be high (Smallwood and Thelander, 2005; Whitfield and Madders, 2006a; Smallwood and Karas, 2008; Garvin et al., 2011). However, most studies have involved foraging hen harriers, and turbines near breeding locations may incur a greater risk of collision, through acrobatic display flights that occur higher above the ground early in the breeding season around prospective breeding sites. Montagu's harrier has a pre-breeding display similar to the hen harrier.

We used a long term monitoring data set of a Montagu's harrier breeding population to evaluate its persistence and distribution during a time when several wind farms were installed in the same area of southern Spain. We conducted a BA study to analyse: (A) abundance and density of nests and colonies; and (B) nesting habitat selection through the study period. We also carried out an IG study to quantify any wind turbine impact on Montagu's harrier nest location. In addition, we developed a multivariate model to examine the spatial variables that best explained nest locations after wind farm construction. Lastly, we also estimated the number and timing of Montagu's harriers killed by collision with turbine blades.

Methodology

Study area and wind farms

The study was conducted in Tarifa (Cadiz, Andalusia, southern Spain), close to the Strait of Gibraltar. This area is considered the main migratory passage for western Palearctic bird species between European breeding areas and African wintering quarters (Bernis, 1980). The hinterland of the Strait of Gibraltar is also considered an area with major potential for wind power development in Spain due to the strong winds that constantly lash the region (IDAE). Since 1998, 22 wind farms have been installed in the study area with their associated structures of tracks and power lines (see Table 1). A total of 342 wind turbines are arranged in North to South oriented rows within the study area (Figure 1). The area is dominated by extensive crops alternated with some grazing patches; scrubland and woodland are mostly restricted to mountain ridges. The area is predominantly flat without steep slopes, situated 10 – 150 m above sea level (a.s.l.), with some hills in the near vicinity that do not exceed 430 m a.s.l.

Study species

The Montagu's harrier is a ground-nesting species that traditionally breeds in lowland heaths, dunes, hay-meadows, and steppes. However, habitat loss and land-use changes derived from agricultural intensification in recent decades has caused an increase in Montagu's harriers breeding in arable crops (Arroyo et al., 2004). It has been estimated that 70-90% of breeding pairs in western Europe breed in agricultural habitats since the 1990s, with cereal crops being the most used nesting habitat (Cramp and Simmons, 1980). Several conservation problems of the Montagu's harrier have been described, with the overlap between breeding season and cereal harvesting one of the major causes of mortality due to the high rate of nest destruction (Arroyo et al., 2002). The breeding season of Montagu's harrier in southern Spain predominantly extends from late March to the beginning of June.

Study design

The study was carried out during Montagu's harrier breeding seasons in two periods regarding wind farm construction in the study area: pre-construction period (years 1995 and 2002) and post-construction period (years 2008, 2009, and 2010). The first wind farm of the study area was already installed by 2002 (see Table 1), although this year was considered belonging to pre-construction period in order to increase the sample size. We did this only after confirming that there were not any statistical differences (Mann-Whitney tests, $p > 0.07$) between years 1995 and 2002 in distances from Montagu's harrier nest to closest elements of that wind farm (turbines, power lines, and tracks) , or future elements in the case of year 1995 because it was not installed yet.

The study area was visited every study year during the pre-laying period to detect potential Montagu's harrier breeders. If no birds were seen, those areas were considered not occupied. All areas were visited again at least once during the nestling and post-fledging periods, to ensure that no nests had gone undetected. Observations were made with 10 x 42 binoculars and 20-60 x 80 telescopes during twenty minutes repeated every two kilometres along the abundant roads and tracks that crossed the study area. A nest location of a breeding pair was determined when a female brought nest material and/or when a male provisioned with food his mate or chicks, and was registered using hand-held GPS. We distinguished three categories of habitat in which nests were found: cereal crops (mostly wheat), hay crops (mixture of herbaceous plants cropped for livestock feeding) and others (non-cereal, fallow or pastures).

Nest and colony abundances and densities

Nests were included in a single colony when the distance to the closest conspecific nest was lower than 250 m, which is the most conservative distance which adults were registered hunting according to García & Arroyo (2005). Abundances were calculated as the number of nests and colonies detected each year within the study area. Nest density was calculated by dividing the number of nests detected by the area suitable for nesting each year in the study area. We considered areas suitable for nesting to be areas of non-irrigated crops and pastures, which Montagu's harrier pairs use to nest, and we excluded areas occupied by irrigated crops, water streams, woodland or scrubland, and human-made structures within the study area. We estimated the reduction suffered by the area suitable for nesting due to wind farm installation each year by subtracting those areas occupied by wind turbines, power lines and tracks from the total area suitable for nesting within the study area using Geographic Information Systems (GIS). We compared nest abundance, density, and distance to the closest conspecific nest between pre- and post-construction period using the BA analyses.

Nesting habitat selection

We entered the location of each nest (and its associated habitat) into the GIS, then we calculated the distance from nest to the closest different elements we anticipated may affect their location: water streams, woodland or scrubland, buildings (isolated constructions), villages, roads (paved ways), tracks (unpaved ways), wind turbines and power lines (or future tracks, wind turbines and power lines in year 1995). We obtained two topographical characteristics (altitude above sea level and slope) of nest locations from a 10 m-resolution DEM of Andalusia (Agriculture Department, Junta de Andalucía, 2010-2011).

We conducted the BA analysis to compare distance from nests to the closest elements of wind farms and associated structures (wind turbines, power lines, and tracks) between pre- and post-construction periods. We performed the IG analysis to calculate the avoidance distance from nest to the closest wind turbine, power line, and track in the post-construction period. The avoidance distance was considered as the median distance from nests to each of these structures, that is the distance at which 50 % of nests were excluded from wind farms and associated structures in the post-construction period (adapted from Larsen and Madsen, 2000).

We compared locations of nest and random points in order to reveal the spatial variables explaining nest location after wind farm construction. Using GIS, we generated the same number of random points within the study area as for the number of nests detected in each year of the post-construction period. Because of the clumped spatial distribution of nests, first we generated random points in the same number of colonies detected each year and used them as a centre of simulated colonies whose circular area was the mean area occupied by real colonies (49 ha, n = 14). Then, the "true" random points used in analysis were generated inside such simulated colonies. All distance variables measured for nest locations were also obtained for these random points (see the beginning of this section). Habitat of the random points was recorded by visiting their spatial coordinates obtained from the GIS and asking farmers what they cultivated there in the corresponding year. We obtained such habitat information for 48 of the total of 74 random points, discarding from the analysis those random points for which we could not obtain habitat information.

All spatial analysis and distance measurements were performed using ArcGIS 9.3 (ESRI, Redlands, USA) and aerial photographs of the study area, which are available from the regional government (http://www.juntadeandalucia.es/medioambiente).

Fatality collisions with turbines

Mortality data was recorded at every wind turbine in a daily basis during the breeding, dispersal and migratory periods of the Montagu's harrier (March–September) after wind farms were installed in the study area. The trained observers were evenly distributed throughout the area covered by the wind farms every day from dawn to dusk, thoroughly searching an area of 50 m on both sides along wind turbine strings in fixed routes on foot (Morrison and Sinclair, 1998). No carcass disappearance experiments were conducted because observers were looking for mid- and large-sized bird carcasses that have a long persistence in the region (De Lucas et al., 2012). Data gathered consisted of age, sex, distance to the closest wind turbine, and date (for more details about carcass searches see Ferrer et al., 2012).

Statistical methods

We used one-way ANOVA and Mann-Whitney tests to compare variables normally and non-normally distributed under BA design. Some variables were transformed (logarithmically or square-rooted) to accord to a normal distribution for parametric statistical assumptions. A generalized linear model (GLM) was fitted to a binary response variable (0 = "random point", 1 = "nest") to model the probability of Montagu's harrier nest occurrence regarding the distances to several elements and habitat. We used a binomial distribution of errors and a logit link function. We included the distances to several closest elements (see *nesting habitat selection* section) as continuous predictors and habitat as a categorical predictor with three levels (see above). The model was fitted following a backward-stepwise procedure, removing one-by-one non-significant variables until all remaining variables were significant. To assess the predictive success of the final model we used receiver operating characteristics (ROC) plots, which depict on the y-axis sensitivity (true positive rate of the model confusion matrix) against 1 – specificity (true negative rate) on the x-axis for all possible thresholds (Fielding and Bell, 1997). The threshold acts as a limit above and below which the responses are considered as one or the other alternative of the binomial model. Then, the area under the curve (AUC) was obtained as a measure of the model accuracy. AUC ranges from 0.5, corresponding with the ROC plot diagonal of a random performance, and 1.0, which represents the perfect fitted model. So, the greater AUC value, the higher explicative ability of the model.

Statistical analyses were conducted with STATISTICA version 8 and a level of 0.05 was used to evaluate significance of results. All tests were two-tailed.

Results

Nest and colony abundances and densities

A total of 111 nests of Montagu's harriers were located within the study area (Figure 1). We did not find any statistical differences in nest abundance (one-way ANOVA: $F_{1,3} = 3.89$, $p = 0.14$), colony abundance ($F_{1,3} = 2.14$, $p = 0.24$) or the number of nests per colony ($F_{1,3} = 1.81$, $p = 0.19$) between pre- and post-construction periods (Table 2).

The area suitable for nesting did not decrease significantly from pre to post-construction period ($F_{1,3}$ = -9.03, p = 0.07; mean ± standard deviation: $area_{pre}$ = 59.41 ± 0.14 km^2, $area_{post}$ = 58.51 ± 0.01 km^2). Nest density did not show statistical differences between the two study periods ($F_{1,3}$ = 2.63, p = 0.11; $density_{pre}$ = 0.31 ± 0.01 nests/km^2, $density_{post}$ = 0.42 ± 0.07 nests/km^2). Distance to the closest conspecific nest decreased significantly from pre to post-construction periods ($F_{1,109}$ = 13.54, p < 0.001; $distance_{pre}$ = 253 ± 315 m, $distance_{post}$ = 181 ± 560 m) (Figure 2).

Nesting habitat selection

We found statistical differences between the two periods in the distances from nests to the closest power line (Z = 5.04, p < 0.001; mean ± standard deviation: $distance_{pre}$ = 1471 ± 1053 m, $distance_{post}$ = 580 ± 337 m) and to the closest wind turbine ($F_{1,109}$ = 23.69, p < 0.001; $distance_{pre}$ = 1621 ± 869 m, $distance_{post}$ = 893 ± 546 m). However, we did not find any statistical differences between pre and post-construction periods in the distance from nests to the closest track ($F_{1,109}$ = 0.10, p = 0.75; $distance_{pre}$ = 404 ± 265 m, $distance_{post}$ = 417 ± 196 m). The IG model estimated the avoidance distance for wind turbines at 655 m (first and third quartiles: 385 – 1414 m, range 122 – 2000 m), for power lines at 657 m (235 – 860 m, ranged 4 – 1156 m), and for tracks at 426 m (260 – 547 m, range 73 – 936 m) in the post-construction period (n = 74).

We built the GLM with data from 74 nests detected in the post-construction period, and 48 random points (N = 122). The backward-stepwise fitting procedure resulted in discarding every distance and topographic variable included in the original set apart from habitat and the distance to the closest track. There was no significant relationship with distance to wind turbine. The model showed that the probability of nest occurrence increased significantly according to hay presence and significantly decreased with the presence of cereals and other less abundant habitats (mainly pastures). Additionally, the probability of nest occurrence increased significantly with distance to the closest track (Table 3). The model explained 42.94% of the deviance and classified correctly 79.03% of the points (72.92% of random points and 85.13% of nest). ROC plots showed high accuracy of nest/random point classification by the proposed model, with an AUC value of 0.91 (Figure 3).

Fatality collisions with wind turbines

A total of seven Montagu's harrier carcasses were found during the post-construction period: four birds in 2008, and three birds in 2010 (Figure 1). Thus, the mean mortality rate was 0.007 ± 0.006 birds/turbine/year. Carcass decomposition limited data collection of sex and age. Only four carcasses could be sexed, two were males and two were females. Three carcasses were aged as adult and two as fledged young. Regarding date, three carcasses were detected in August and the other four carcasses were detected in April, June, July and September, respectively. Carcasses were found at 45.8 ± 59.6 m as the mean distance (± standard deviation) from the closest wind turbine. The low number of carcasses prevented any statistical analysis.

Discussion

Our results suggested that nesting decisions of Montagu's harriers was not adversely affected by the construction, operation and maintenance of wind farms, although these structures have been repeatedly considered as a disturbance source for birds (Kuvlesky et al., 2007; Smallwood and Thelander, 2004). Hötker et al. (2006) pointed out that any negative effect on bird breeding populations has yet to be verified, in agreement with our results.

Nest and colony abundances and densities

Nest and colony abundances and nest density remained stable throughout the study period. Our results are concordant with several studies that reported no negative effects of wind farms on bird populations (De Lucas et al., 2005; Douglas et al., 2011; Hale et al., 2014; Hatchett et al., 2013), although other studies did show important negative impacts (Larsen and Guillemette, 2007; Leddy et al., 1999; Pearce-Higgins et al., 2009). Raptor abundances normally decreased during and after the construction of wind farms compared to the initial situation (Garvin et al., 2011). Stewart et al. (2007) proposed that the longer the period of wind turbine operation, the greater the decline in bird abundance due to lack of habituation to wind farms (although see Madsen and Boertmann, 2008). On the contrary, nest abundance increased, although not significantly, since wind turbines were built in our study area. Drewitt & Langston (2006) opined that the apparent absence of wind farm displacement impacts on birds concluded by several studies may be due to the high philopatry and longevity of study individuals returning to former breeding sites. Montagu's harrier is considered as having relatively low breeding philopatry (Arroyo et al., 2004), so this hypothesis can be discarded as an explanation of our findings. Thus, the relatively stable density of pairs over time in our study would in large part be due to a high turnover with new recruits establishing as breeders in the study area, and this would not support the existence of disturbances caused by wind farms that were overridden by strong breeding site fidelity.

Nevertheless, while wind farm installation did not seem to affect nest abundance and density, a change in spatial distribution of nests took place. Breeding pairs tended to nest closer together after wind farms were installed (see Figure 1). The desertion of the most distant colonies in the west and southwest of the study area before wind farm installation and the establishment and aggregation of colonies in the north of the study area after wind farm installation resulted in the observed reduction of distances between conspecific nests. The south-western colony disappeared during the pre-construction period, so at least for this colony we do know that the installation of a wind farm in its surroundings was not the cause of its desertion by breeding pairs.

Nesting habitat selection

BA analysis of distances from nests to closest wind turbine and power line differed between pre- and post-construction periods, both showing higher values in the pre-construction period. Breeding pairs located their nests closer to wind turbines and power lines when all wind farms were installed in the study area than when only one wind farm was present. On the one hand, this result may simply be due to chance, or that more powerful influences (distribution of preferred nesting habitat) were at play. On the other hand, does support the idea that Montagu's harriers were not avoiding the surroundings of wind turbines to nest, contrary to results of previous studies (e.g. Pearce-Higgins et al., 2009). However, the distance from nest to closest track did not vary through the study period despite the greater length of tracks installed after wind farm construction. This suggest that tracks could have some effect on Montagu's harrier decisions on nest location, and this may explain why nest sites were more concentrated at the north part of the study area after wind farms installation, where wind farm (and associated track) density was lowest.

The IG model showed higher avoidance distances for wind turbines in comparison to other studies on the closely related hen harrier (Madders and Whitfield, 2006; Whitfield and Madders, 2006a; Pearce-Higgins et al., 2009), although those studies estimated avoidance distances from bird flight activity, mainly foraging, rather than nest location. Therefore, we probably overestimated the real avoidance distance for wind turbines of Montagu's harriers as they might forage closer to these structures than where they locate nests. Anyhow, observed avoidance distances for wind farms, especially for wind turbines and power lines (on average up to 650 m), were high and could suggest some effect on harrier nesting decisions. However, reduced nesting densities of Montagu's harriers in our study (< 0.5 nest/km^2), and extensively of raptors as top predator of terrestrial ecosystems (Newton, 1979), seem more plausible to explain the results than an avoidance behaviour for these structures of nesting harriers. Notably since our BA analysis found that harriers tended to nest slightly closer to turbine locations after their installation (BA being usually more powerful as an investigative tool than IG: Anderson et al., 1999) and the distance to closest turbine was not an important predictor defining nest locations. Our IG analysis, moreover, could not account for the availability of suitable habitat with varying distance to turbines and other wind farm features: the availability of one habitat (hay fields) appeared to be a major factor in nest site selection according to additional analyses. It is also possible that fundamental preferences for suitable locations of turbines and nests differed between wind farm developers and Montagu's harriers, respectively, at a scale that we could not attribute. For example, developers likely prefer turbine locations where wind strengths are higher but nesting harriers likely prefer more sheltered locations where vegetation growth is lusher, and so taller. Overall, our study does show that developers' selection of turbine locations did not apparently interfere with nest site choices of Montagu's harriers, even though some suitable harrier nesting areas were within a few hundred metres of turbines. The IG results, thanks to the wider temporal context provided by our additional BA studies do not necessarily indicate, as could be interpreted on face value, that nesting harriers 'avoid' turbines within the derived range of values. Our study thereby provides an instructive example of the potential danger in placing too much emphasis on simplistic and singular post-construction analyses. Nevertheless, our study was restricted to nesting decisions and potential changes in breeding numbers: further studies on foraging behaviours and home ranges of breeding Montagu's harriers would, therefore, be useful in the environs of operating wind farms.

The GLM fitted to the binary response variable (random points/nests) was relatively robust. Habitat and distance to closest track were the only variables with significant effects on nest occurrence after wind farm constructions. The high predictive ability of habitat included in the model suggests that this species primarily considers a preferred habitat to locate nests rather than the distances to other features which may act as sources of disturbance. The model highlighted a preference for nesting in hay crops and avoidance of cereal crops, in disagreement with previously stated preference of cereal crops for nesting (Cramp and Simmons, 1980). However, it has been reported elsewhere that in areas where hay fields are available they are used in greater proportion than expected (Barros and Benítez, 1995). Thus, the negative effect of cereal crops on the probability of nest occurrence may be explained by this preference in Montagu's harrier nesting habitat selection in our study area. The third type of habitat (mainly pastures) also had a negative effect on nest location. Montagu's harrier breeding pairs tend to nest in areas dominated by plants characterized by fast growth in height that act as a defence against predators by hiding nests (Limiñana et al., 2006). However, pastures were often heavily grazed by livestock in our study area, restricting growth of graminoid and herbaceous plants. Consequently, pastures would not reach sufficient height to protect Montagu's harrier nests and so breeding pairs should avoid this habitat, as suggested by our model. The distance from nest to closest track arose as an important predictor with a negative effect on the probability of nest occurrence. It has been demonstrated that noise and vibrations from tracks and roads are important negative effects on raptors and other birds (Benítez-López et al., 2010; Martínez-Abraín et al., 2010). As a ground-nesting species, the Montagu's harrier can be specially affected by vibrations caused by vehicle users of tracks. This may explain why the distance from nest to closest tracks remained constant over the study period, contrary to what we found with wind turbines and power lines, and the probability of nest occurrence increase with that distance (see BA results). Although agricultural habitat changes were not detected at greater spatial scale (province of Cadiz, www.juntadeandalucia.es/agriculturaypesca/portal/servicios/estadisticas/agrarias/superficies-y-producciones.html), we cannot reject that some habitat changes would have happen in our study area that, in conjunction with the proliferation of tracks associated to wind farms, would have caused the observed displacement and aggregation of nesting Montagu's harrier throughout the study period.

Fatality collisions with wind turbines

The mortality rate reported per wind turbine and year in our study agreed with avian collision rates recorded in the literature, that show a wide variation from 0.01 to 23 birds/turbine/year (Drewitt and Langston, 2006). Fatality rate we obtained was relatively low (0.007 bird/turbine/year), like most assessment of wind farm impacts on birds (De Lucas et al., 2008). A weakness of our results is that they lacked any measure of searching efficiency due to the vegetation height during some periods of the year (Smallwood, 2013). Nonetheless, we were confident that the trained observers had experience and time to account for variation in vegetation height; and the time interval between searching events was only one day, increasing detection probability.

The Montagu's harrier is characterized by high aerial agility and manoeuvrability, conferring lower risk to collision with wind turbines than larger raptors (Brown et al., 1992; Lucas et al., 2012). Hen harrier, a closely related species to Montagu's harrier, tends to fly at low altitudes, with most aerial activity occurring less than 20 m above the ground (Whitfield and Madders, 2006b). Montagu's harrier has very similar flight behaviour. The heights of the turbine blades in our study ranged between 27 and 65 m from the ground to the highest point, except one wind farm whose turbines had blades with a lowest sweep only 15 m high. Thus, flight behaviour of harriers typically avoids collisions with blades and this could be the reason for the low mortality rate we found. We did not find any concentration of collision victims at the beginning of the breeding season when pre-breeding birds will have been conducting elaborate aerial displays higher above the ground (rather casualties tended to occur towards the end of the breeding season). This suggests that such displays may not carry a risk of collision greater than other forms of flight behaviour.

Conclusion

Our results suggest that wind farms did not cause adverse negative effects on nesting decisions of Montagu's harriers in our study area, contrary to what has been described for other bird species. The abundance and densities of Montagu's harrier nests remained constant through the study period although a change in nest spatial distribution occurred, from being more widespread before wind farm construction to being more aggregated after construction. We could detect no population-wide consequence of this apparent increased aggregation, however. Breeding pairs seemed to decide where to build their nest mostly on suitable vegetation availability instead of distances from potential disturbance sources, notably wind turbines. Only distance to tracks seemed to be influential in nest location decisions of breeding pairs, presumably because of vibrations caused by vehicular use of tracks. Habitat changes through the study period within the study area might be the main driver of nest aggregation, although birds tend to choose nest sites at a particular distance from tracks. Nevertheless, we encourage further studies of reproductive parameters and foraging behaviour of Montagu's harriers with the aim to provide supplementary research that we could not address and examine further our findings of no negative effect of wind farms and associated structures on this species.

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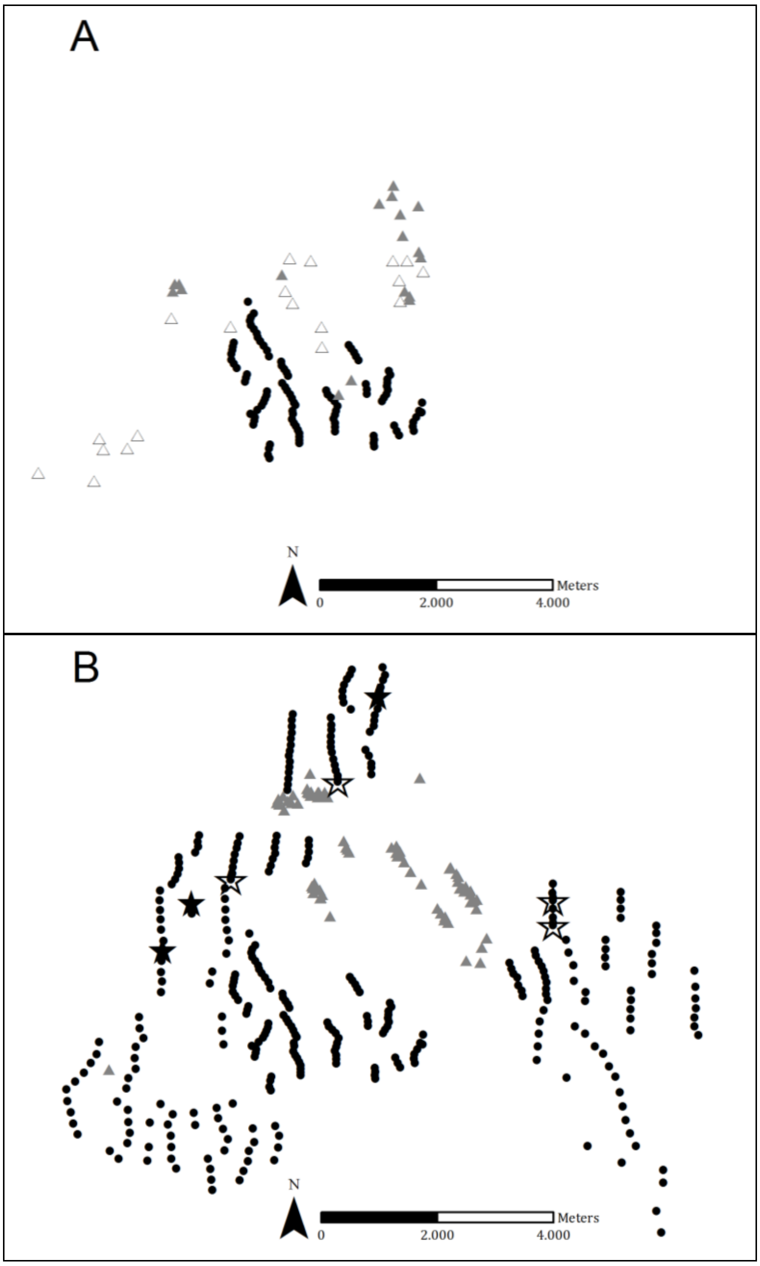

Figure 1: Spatial distribution of wind farms (circles), Montagu's harrier nests (triangles), and bird carcasses (stars) in the study area during the pre-construction period (panel A) and during the post-construction period (panel B). In panel A, open and grey triangles represent Montagu's harrier nest locations detected in years 1995 and 2002, respectively. In panel B, white stars represent the closest wind turbine from Montagu's harrier carcass locations. Because we did not obtain the spatial coordinates of three of the seven carcasses, only the wind farm where they were detected, we represent the wind turbine situated in a central point within those wind farms with a black star.

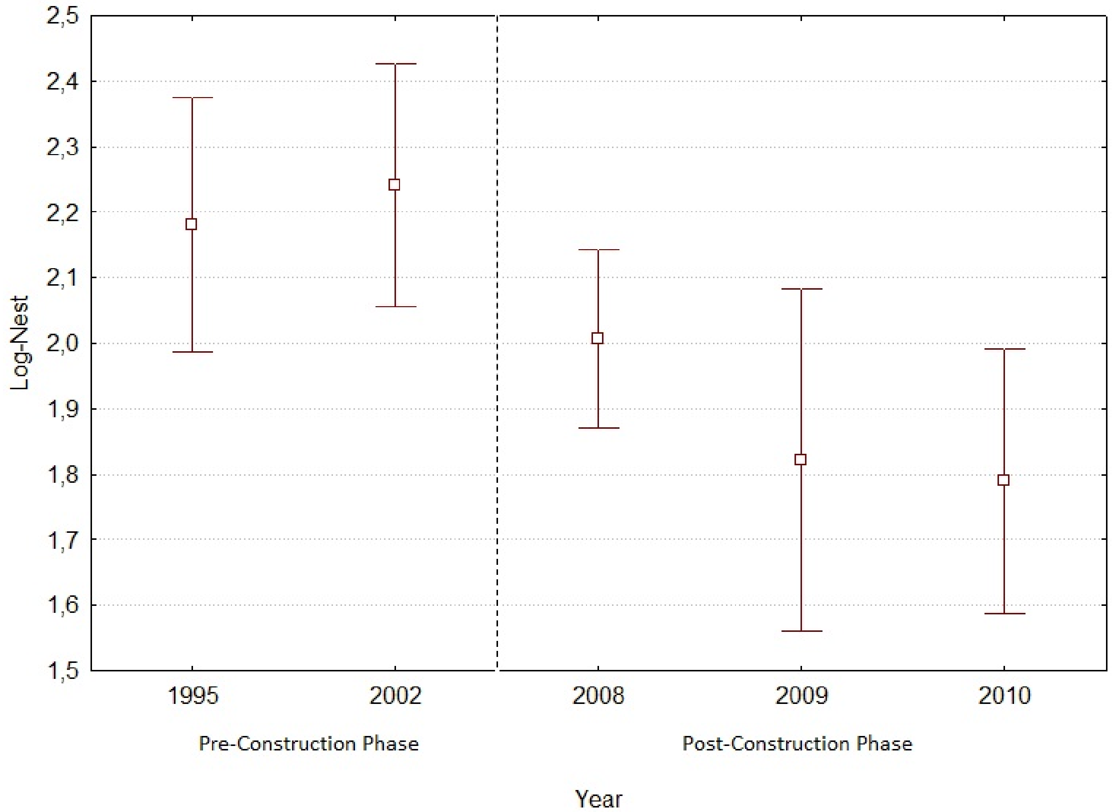

Figure 2. Distance from nest to closest conspecific nest throughout the study period. Mean distances and standard deviation per year were plotted because of the greater clarity provided. The dashed line separates the two defined periods of the study.

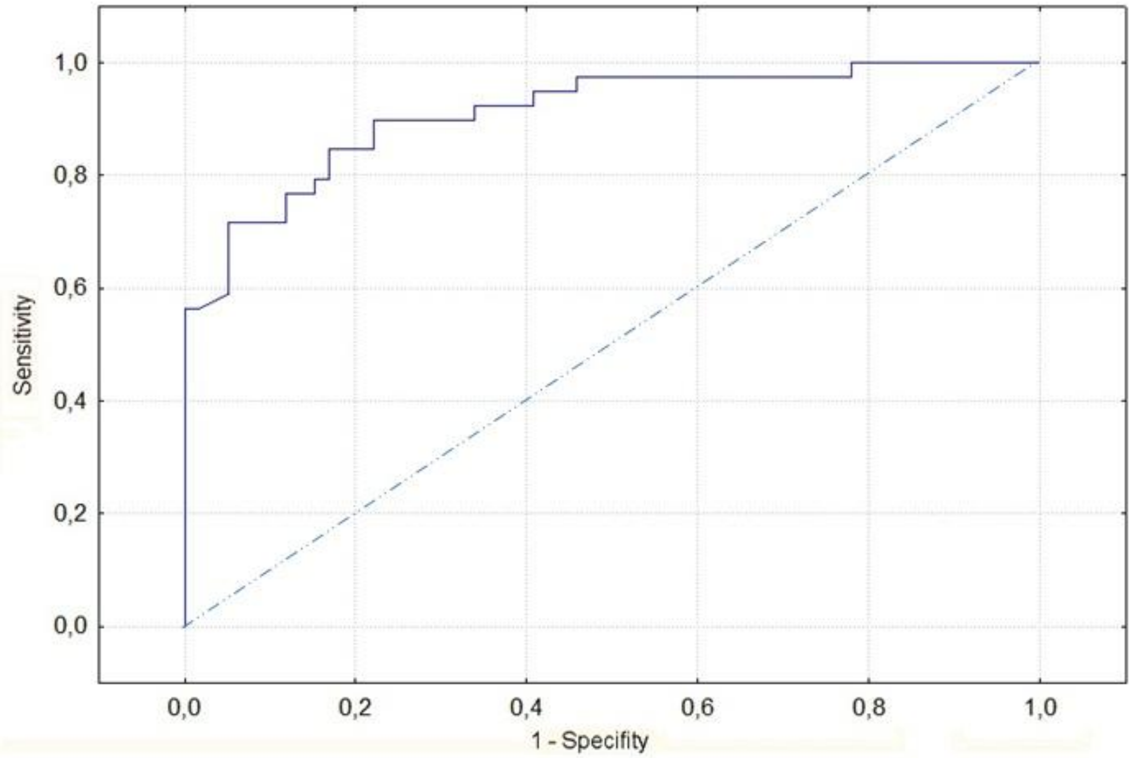

Figure 3. ROC plot derived from the fitted binomial GLM. The solid line represents the values of sensitivity and 1-specificity for all possible threshold of the proposed model. The dotted line represents the values of a random performance model, which are not able to discriminate between the two alternatives of the logistic model.

Table 1. Wind farms installed in the study area along the study period. We specified information about year of operating starting, number of wind turbines, power per wind turbine, hub height, and the diameter of the rotor of each wind farm.

Wind farm	Year	Nº turbines	Power turbine (kW)	Hub height (m)	Rotor diameter (m)
WF 1	1998	100	300	30	30
WF 2	2005	11	2000	67-100	87
WF 3	2005	17	800	50-60	59
WF 4	2005	30	800	50-60	59
WF 5	2005	20	800	50-60	56
WF 6	2005	28	1670	70-80	80
WF 7	2005	15	800	50-60	59
WF 8	2005	6	1670	60-80	74
WF 9	2005	16	800	50-60	56
WF 10	2006	4	1500	80-95	72
WF 11	2007	10	2000	95-125	90
WF 12	2007	10	2000	67-100	87
WF 13	2007	7	1800/2000	80-105/95-125	90
WF 14	2007	4	1800/2000	80-105/95-125	90
WF 15	2007	6	2000	60-100	80
WF 16	2007	8	2000	67-100	87
WF 17	2007	6	2000	67-100	87
WF 18	2007	10	2000	95-125	90
WF 19	2007	10	2000	65	70.6
WF 20	2007	8	1800/2000	80-105/95-125	90
WF 21	2007	10	2000	65	70.6
WF 22	2008	6	2000	60-100	80

Table 2. Nest and colony abundances and average number of nests per colony during the study period.

Pre-Construction period

Number of Nests		Number of Colonies		Average Number of Nests/Colony	
1995	2002	1995	2002	1995	2002
19	18	6	5	3.1	3.6

Post-Construction period

Number of Nests			Number of Colonies			Average Number of Nests/Colony		
2008	2009	2010	2008	2009	2010	2008	2009	2010
28	20	26	5	4	5	5.6	5.0	5.2

Table 3. Parameters of the fitted binomial GLM. The intercept included the effect of cereal plots within habitat variable. Sample size = 122 points.

	β	Standard Error	Wald Statistic	p-value
Intercept	-1.38	0.58	5.68	0.02
Distance-Track	0.003	0.001	6.52	0.01
Non-cereal plots	-1.82	0.47	15.16	<0.001
Hay plots	2.21	0.38	34.69	<0.001

Null Deviance: 163.54 with 121 degrees of freedom.

Residual Deviance: 93.31 with 118 degrees of freedom.