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Aves y parques eólicos: efectos e interacciones

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A mis padres,
a Fran, mi esposo,
a mis sobrinas, mis amores,
a Maia y a Celta, mis perris.

"... mire vuestra merced, respondió Sancho,
que aquellos que allí se parecen no son gigantes,
sino molinos de viento,
y lo que en ellos parecen brazos son las aspas,
que, volteadas del viento,
hacen andar la piedra del molino."

Don Quijote (Miguel de Cervantes)

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Introducción

Aves y parques eólicos: efectos e interacciones

Introducción

Biología de la conservación

Desde mediados del siglo XXI la preocupación por la conservación de la biodiversidad ha pasado de ser una actitud minoritaria, a ser compartida por un gran número de ciudadanos, como queda reflejado en el incremento en el número de asociaciones no gubernamentales, gubernamentales y revistas científicas cuya temática central es la Biología de la Conservación. Esto conlleva un cambio radical en la imagen que se tiene del mundo y de los seres humanos. La visión dominante de un futuro cada vez mejor ha sido frenada por la crisis de la biodiversidad, generada en gran medida por la actitud humana (Soulé, 1985, Meffe & Carroll, 1997)

White (1967) postula que la crisis ambiental que padecemos, de origen claramente occidental, se hunde en nuestra forma de entender y estar en el mundo. Los seres humanos forman parte de la naturaleza, y no puede entenderse que la naturaleza alcance su sentido sólo cuándo es utilizada por los hombres. La naturaleza aún bajo condiciones no alteradas por las acciones humanas, no permanece fija en el tiempo, sino que es influenciada por procesos ecológicos y evolutivos. Es más que probable que aquellos cambios en la diversidad biológica que ocurran más rápida o más extensamente debidos a los impactos de las acciones antrópicas afecten de manera negativa al hábitat humano.

Así la Biología de la Conservación tendría dos objetivos: el primero, la investigación de los efectos de las actividades humanas sobre los ecosistemas; y el segundo el desarrollo de aproximaciones prácticas para disminuir los efectos adversos de las acciones humanas, del cual ha surgido la Biología Aplicada. Dentro del segundo objetivo aparecen las infraestructuras construidas por el hombre, tales como los tendidos eléctricos de las que se han obtenido avances muy significativos para reducir sus impactos sobre las poblaciones de aves (Bevanger, 1994, Janss, 2001). Con estos antecedentes la presente memoria, de clara finalidad aplicada, pretende incrementar y mejorar los conocimientos sobre las interacciones entre la fauna (las aves y los micromamíferos) y parques eólicos, así como el potencial impacto de los parques eólicos sobre la fauna.

Energía eólica

El precursor de los actuales aerogeneradores es la aeroturbina de Lacourt (1892), máquina de cuatro palas de 25 metros de diámetro capaz de desarrollar entre 5 y 25 kW. Pero es durante la crisis del petróleo de 1973 cuando la energía eólica se ve impulsada como fuente energética para la generación de electricidad. En España, fue el INTA (Instituto Nacional de Técnica Aeroespacial) a principios de los 80, el que identificó las zonas de mayor potencial eólico (Díaz, 1993), destacando Tarifa donde se instaló el primer aerogenerador experimental (Marín, 2004).

A partir de 1990 la potencia instalada ha ido aumentando exponencialmente, llegando en el año 2000 a 2.292 MW, que era 13 veces más de la potencia prevista para dicho año por el Plan de Ahorro y Eficiencia Energética. Según los objetivos del Plan de Energías Renovables (PER), en el año 2010 la potencia eólica instalada alcanzará los 20.155 MW y la generación eólica será de 40.996 GWh (Ceña, 2006). El 1 de Enero de 2006 la potencia eólica era de 10.028 MW, lo que ha permitido a España ocupar el segundo puesto mundial en potencia instalada, por detrás de Alemania.

El número total de parques eólicos en España asciende a 535, incluyendo ampliaciones y parques experimentales. En relación con las Comunidades Autónomas, aunque Andalucía, Cataluña y País Vasco han tenido un importante crecimiento, siguen siendo Galicia, Castilla La Mancha y Castilla y León, las regiones con una mayor potencia eólica instalada (IDEA 2006) (Tabla 1). Cantabria, Extremadura y la Comunidad de Madrid siguen sin tener ningún parque eólico (Migoya et al., 2007).

Tabla 1. Relación de potencia instalada y relativa por comunidades autónomas

Comunidades	Nº parques	Potencia (MW)	Potencia relativa (%)
Galicia	112	2.603,08	22,41
Castilla La Mancha	74	2.311,46	19,90
Castilla y León	104	2.119,61	18,25
Aragón	64	1.548,64	13,33
Navarra	35	916,81	7,89
Andalucía	42	609,51	5,25
La Rioja	13	436,62	3,76
C. Valenciana	10	299,49	2,58
Cataluña	11	225,87	1,94
Asturias	8	198,86	1,71
País Vasco	6	144,27	1,24
Canarias	46	129,49	1,11
Murcia	7	67,72	0,58
Baleares	3	3,65	0,03
TOTAL	535	11.615,08	100,00

Los aerogeneradores constan de tres partes fundamentales: la torre, la barquilla que es el conjunto situado encima de la torre donde se genera la electricidad, y el rotor con las palas. Un aerogenerador tipo tiene tres palas situadas en el eje horizontal, una torre tubular, una orientación activa frente al viento (barlovento). Su vida media ronda los 20 años.

La altura de los aerogeneradores ha ido aumentando con el tiempo, puesto que va asociada a un mayor diámetro del rotor, que implica una mayor potencia. Actualmente los aerogeneradores instalados tienen una altura total de alrededor de 120 m, con 40-60 m de diámetro de rotor y su potencia unitaria es de entre 1500 y 2000 kW, frente a los antiguos aerogeneradores de 55 KW con

15 m de diámetro y 50 m de altura total. El prototipo terrestre más potente en la actualidad tiene una torre de 80 m y una potencia de 2,5 MW.

La producción de electricidad por los aerogeneradores empieza a partir de los 4,5 m/s de velocidad del viento (16 km/h), llegando a la potencia nominal (producción máxima) a los 15 m/s., manteniéndose constante hasta los 25 m/s (90 Km/h). A más velocidad la máquina se para por razones de seguridad, puesto que pueden romperse las palas.

Interacciones entre fauna y parques eólicos

La obtención de electricidad a partir de una fuente inagotable como es el viento, parece ser una contribución óptima a la solución del problema del cambio climático debido a las emisiones de gases de efecto invernadero. Sin embargo, de una visión más profunda resulta una historia más complicada. Se ha demostrado que los parques eólicos pueden tener distintos efectos adversos sobre la flora y fauna, centrándose la mayoría de los estudio en la mortalidad de aves y murciélagos y en la pérdida de hábitat para la avifauna (de Lucas et al., eds, 2007).

La pérdida indirecta de hábitat se debe a las molestias que se generan durante la construcción del parque eólicos y durante su fase de operaciones, provocando que la fauna evite esa zona. Así, Pedersen y Poulsen (1991) detectaron un efecto vacío sobre las avefrías *Vanellus vanellus*, y el chorlito grande *Charadrius haiticula* puesto que evitaban utilizar la zona del parque eólico. Asimismo, Larsen y Madsen (2000) comprobaron que la densidad de ánsares piquicortos *Anser brachyrhynchus* era menor en el entorno del parque eólico, y este efecto era más pronunciado en aquellos parques con aerogeneradores agrupados que en aquellos que eran lineales. La predicción de estas molestias requiere un enfoque semejante a la predicción de la pérdida de hábitat, ampliamente estudiada (Goss-Custard et al., 1994, Gill, 2007).

La pérdida directa de hábitat es considerada de escasa importancia, puesto que el espacio que ocupa el parque eólico se restringe a la base de los aerogeneradores, los caminos de mantenimiento y la línea de evacuación (Percival, 2000). No obstante, requieren una atención especial aquellos emplazamientos que pueden afectar a vegetación natural en general y flora amenazada en particular. Las excepciones incluyen la construcción de los parques eólicos en turberas o en sistemas dunares. Asimismo, los movimientos de tierra necesarios para la construcción de los caminos de acceso y servicio, así como las plataformas de los aerogeneradores, pueden no ser admisibles en zonas muy accidentadas.

Las molestias durante la fase de operaciones y la mortalidad por colisión son procesos antagonistas y espacialmente excluyentes (si un ave no está en la zona del parque eólico no presenta riesgo de colisión). Sin embargo la relación entre estos dos procesos puede no ser estable en el tiempo (Band et al., 2007).

La mortalidad de aves por colisión con las palas de los aerogeneradores fue el primer efecto de los parques eólicos que se investigó (Orloff & Flannery, 1992). La mayoría de los estudios sobre colisión de aves en parques eólicos han obtenido niveles relativamente bajos de mortalidad (Erickson et al., 2001). Estos bajos niveles de mortalidad pueden ser significativos en especies de larga vida con baja productividad y lenta maduración, especialmente cuando se trata de especies con problemas de conservación (Drewitt & Langston, 2006). Los grupos de especies afectadas son muy diversos, y trata aves marinas, acuáticas, rapaces, passeriformes, etc. (de Lucas et al., eds, 2007). Otro grupo de vertebrados del que también se han registrado colisiones con los aerogeneradores, es el de los murciélagos (Keely et al., 2000, Arnett, 2005, Jain et al., 2007).

El riesgo de colisión de las aves depende de factores relacionados con la especie, el número, el comportamiento, las condiciones climáticas, la orografía y la propia naturaleza del parque eólico (Drewitt & Langston, 2006). Las aves grandes con poca maniobrabilidad tienen generalmente un mayor riesgo de colisión con estructuras (Brown, 1992, Janss, 2000), como el buitre leonado *Gyps fulvus* en los parques eólicos (Barrios & Rodríguez, 2004, Lekuona & Ursúa 2007, de Lucas et al. submit). Las condiciones climatológicas especialmente las que reducen la visibilidad (p.e. niebla) aumentan el riesgo de colisión (Erickson et al., 2001). Las luces de seguridad aérea presentes en los aerogeneradores pueden aumentar el riesgo de colisión al atraer y desorientar a las aves (Hill, 1990, Winkelman, 1990, Thelander et al., 2003), aconsejándose el uso de pocas luces blancas intermitentes de baja intensidad (Hüppop et al., 2006).

Es necesario considerar también las infraestructuras asociadas a los parques eólicos como son los tendidos eléctricos de evacuación y los caminos de acceso y servicio. La red de evacuación interna del parques suele ser subterránea y centralizarse en una subestación. De la subestación eléctrica parte una línea de evacuación de electricidad, normalmente de mayor voltaje que la red interna, que permita su conexión a la red de transporte. Estas líneas deben ir provistas de dispositivos protectores de aves en caso de que atraviesan áreas con avifauna sensible a la mortalidad en tendidos eléctricos (Janss, 2001).

Esta tesis

Esta tesis analiza las interacciones entre las aves y micromamíferos con los parques eólicos, con el objetivo de obtener conclusiones aplicables a la evaluación y a la reducción de los riesgos que entrañan las instalaciones eólicas sobre la avifauna.

Los datos para la elaboración de esta tesis ha sido recogidos en dos zonas muy distintas: Malpica (en la provincia de La Coruña, noroeste de la Península Ibérica) y Campo de Gibraltar (en la provincia de Cádiz, sur de la Península Ibérica). Ambas zonas han sido pioneras en el desarrollo de la energía eólica. A nivel de avifauna, Malpica es esencial para las aves migrantes en casos de fuertes tormentas atlánticas, y el Campo de Gibraltar es una de las rutas más importantes de migración de aves del Paleártico (Bernis, 1980, Finlayson, 1992).

La estructura de esta tesis consta de cinco capítulos. En el **capítulo 1** se estudia el impacto de un parque eólico sobre las poblaciones de paseriformes comparando con dos zonas control, y el comportamiento de vuelo de las aves planeadoras en el parque eólico en la proximidad de los aerogeneradores. En el **capítulo 2** se utiliza un diseño BACI (Before After Control and Impact, en inglés) para analizar el impacto del parque eólico sobre las aves, y un diseño IG (Impact Gradient, en inglés) para los micromamíferos. En el **capítulo 3** se analiza la mortalidad detectada durante 10 años en dos parques eólicos, identificándose el riesgo de colisión de ciertas especies corregido por su abundancia. Además, se utiliza el análisis de tiempos de fallos para caracterizar la distribución de la mortalidad de aves en el parque eólico. El **capítulo 4** considera una población nidificante de aguilucho cenizo *Circus pygargus* en Tarifa antes y después de la instalación de un parque eólico, analizando la densidad de nidos y la distancia a los aerogeneradores. En el **capítulo 5** se analizan las trayectorias del viento en una la simulación en un túnel de viento y se compara con las rutas de vuelo observadas en el campo. Las aves planeadoras utilizan el viento como principal fuerza motriz en sus desplazamientos, recorriendo largas distancias con un mínimo gasto energético. La hipótesis de partida es que las trayectorias de vuelo de aves planeadoras serán muy similares a las trayectorias de viento obtenidas en la simulación. En nuestro caso, se analizaron las trayectorias de vuelo de buitres leonados (*Gyps fulvus*) en una zona de un parque eólico.

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Capítulo 1

**The effects of a wind farm on birds in a migration point:
The Strait of Gibraltar**

Referencia: De Lucas, M., Janss, G. and Ferrer, M. 2004 The effects of a wind farm on birds in a migration point: the Strait of Gibraltar. *Biodiversity and Conservation* 13(2): 395-407.

Resumen

La mortalidad de aves por colisión con las palas de los aerogeneradores es conocida como uno de los principales efectos adversos de los parques eólicos, pero hasta la actualidad, el presente estudio de dos parques eólicos en el sur de España es el primero en considerar la mortalidad registrada durante 10 años. La abundancia de las aves se comparó con los registros de mortalidad por colisión para identificar el riesgo de mortalidad especie-específico. Los análisis de tiempos de fallos incorporaron los datos de mortalidad censurados, en los que el tiempo de ocurrencia del evento (en nuestro caso, la colisión) no es conocido, y se utilizaron para testar la hipótesis nula de homogeneidad en la distribución de la mortalidad de las aves según distintos factores. La mortalidad y la abundancia de las aves varían de forma muy marcada entre las estaciones del año, no siendo la mortalidad mayor en la época de mayor abundancia. Este resultado es contrario a la frecuente asunción en los estudios de parques eólicos, de que la mortalidad aumenta con la abundancia de las aves. La probabilidad de colisión depende de las especies (el buitre leonado es la víctima más frecuente), la altura de los aerogeneradores (los más altos), y la altura sobre el nivel del mar (lo más alto). Factores especie-específicos y topográficos están implicados en la mortalidad por colisión, pero no hay evidencias de una asociación entre la probabilidad de colisión y el tipo de aerogenerador (tubular o celosía) o la posición del aerogenerador en la fila. Sugerimos que el problema de la colisión sería mejor entendido con estudios sobre el comportamiento de vuelos de las aves en los parques eólicos.

Palabras claves: comportamiento de vuelo, impacto de estructuras humanas en aves, aerogenerador, parque eólico, España.

Abstract

The interaction between birds and wind turbines is an important factor to consider when a wind farm will be constructed. A wind farm and two control areas were studied in Tarifa (Andalusia Province, S Spain, 30STF590000 – 30STE610950). Variables were studied along linear transects in each area and observations of flight were also recorded from fixed points in the wind farm. The main purpose of our research was to determine the impact and the degree of flight behavioural change in birds' flights resulting from a wind farm. Soaring birds can detect the presence of the turbines because they changed their flight direction when they flew near the turbines and their abundance did not seem to be affected. This is also supported by the low amount of dead birds we found in the whole study period in the wind farm area. More studies will be necessary after and before the construction of wind farms to assess changes in passerine populations. Windfarms do not appear to be more detrimental to birds than other man-made structures.

Keywords: flight behaviour, impact on birds of human structures, turbine, wind farm, Spain.

Introduction

During the last century, bird populations have been affected by different kinds of disturbances and impacts due to man-made structures such as highways (Fajardo et al., 1998), power lines (Ferrer et al., 1991, Janss and Ferrer, 1998, Penteriani, 1998), radio/television towers (Stahlecker, 1979, Smith, 1985, Nelson and Curry, 1995), wind farms (Orloff and Flannery, 1992), glass windows (Klem, 1990a, b), and due to human activities such as poisoning (Harmata et al., 1999) and illegal shooting (Villafuerte et al., 1998). The increasing mortality of birds by human structures has generated an important literature evaluating the impact of these elements on bird populations and developing the application of protective measures (Klem, 1990b, Fajardo et al., 1998, Alonso et al., 1999). Nevertheless, the impact of wind farms on birds is one of the less studied impacts and the scientific literature on this topic is scarce.

Wind farms are a relatively new method of obtaining "clean" energy by avoiding air pollution and other forms of environmental degradation associated with fossil fuel technologies (Nelson and Curry, 1995) and have received strong public support as an alternative energy source (Leddy et al., 1999). Moreover, wind farms have shown a spectacular growth because they have reduced the costs of energy production. This phenomenon has resulted in a proliferation of wind farms around the world (Germany, Holland, Spain, United States, etc) (Osborn et al., 2000). In Spain, there are now a lot of wind farms already working or under construction, especially in those areas subject to strong winds such as Cádiz, Castilla-La Mancha, Castilla-León, Cataluña, Galicia, Navarra and The Canary Islands.

Nevertheless, there are three special concerns that arise with respect to the development of wind farms. They represent a source of noise, they have an aesthetic impact on landscapes and they might represent a supplemental negative impact on bird populations (Nelson and Curry, 1995).

Wind turbine farms in landscapes have given rise to much controversy relating to bird conservation issues in many European countries (Larsen and Madsen, 2000). Wind turbines seem to add an obstacle for bird movements and research has shown that birds fly into the rotor blades (Morrison and Sinclair, 1998). Although some studies have recorded bird collisions with rotor blades (Orloff and Flannery, 1992, Barrios, 1995, Musters et al., 1996, Hunt, 1999), other studies gave evidence that birds could detect the presence of wind turbines and generally avoid them (Nelson and Curry, 1995, Osborn et al., 1998) .

The scarce information on the possible interactions between birds and wind turbines has shown that: (1) waterfowl and raptors seem to be the groups with the highest risk of collision, not directly related to their abundance (Orloff and Flannery, 1993, Osborn et al., 1998), (2) familiarity with turbines, leading to a decrease in wariness may be an important factor contributing to increased mortality (Orloff and Flannery, 1993), (3) dark nights increase mortality of waders (Dirksen et al., 1998), (4) passerine species appear to be at greatest risk of colliding during spring and autumn migrations (Higgins et al., 1996, Osborn et al., 1998) and (5) there is evidence that waterfowl, wading bird and

raptor densities near turbines are lower (Leddy et al., 1999). Moreover, birds avoid flying in areas with wind turbines and their flight patterns are deferred when wind turbines are rotating or not rotating (Osborn et al., 1998). However, up to now population-level effects have not yet been demonstrated to reject the further development of wind power.

The main purposes of our research were to determine (1) the possible impacts of wind turbines on both the local, breeding and migratory bird population in one of the most important migration points between Europe and Africa, the Strait of Gibraltar in the south of Spain, and (2) the degree of flight behavioural change in birds resulting from the presence of a wind farm.

Study area

The study was conducted in Tarifa (Andalusia Province, south of Spain, 30STF590000 – 30STE610950) from July 1994 to September 1995 (Figure 1). This area was chosen because of the impressive abundance of birds crossing the Strait of Gibraltar, one of the most important migrating routes of the Palearctic (Bernis, 1980, Finlayson, 1992, Bildstein, 2000).

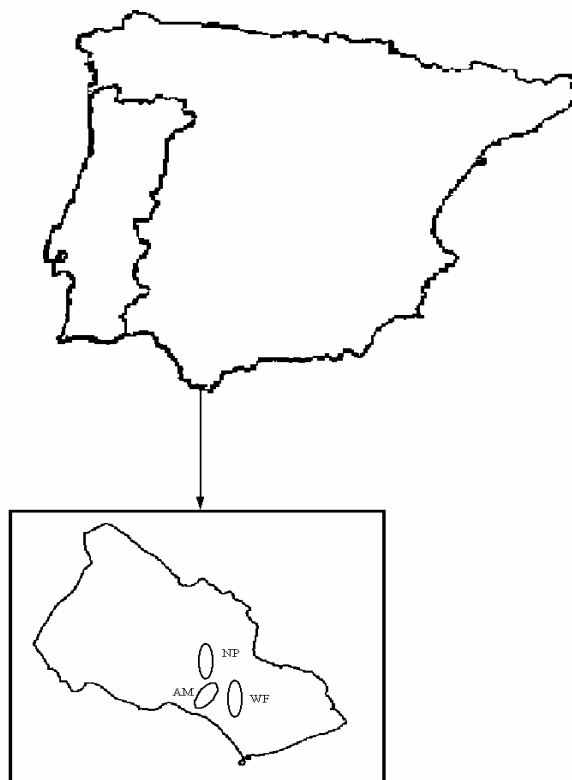


Figure 1. The three study areas in Tarifa, near the Strait of Gibraltar (Andalusia Region, southern Spain, 30STF590000 – 30STE610950). WF = wind farm area. AM = expansion area of the existing wind farm. NP = protected natural area.

In this area, breeding species such as white storks *Ciconia ciconia*, griffon vultures *Gyps fulvus*, common kestrels *Falco tinnunculus*, bonelli's eagles *Hieraaetus fasciatus*, black kites *Milvus migrans*, peregrine falcons *Falco peregrinus*, and short-toed eagles *Circaetus gallicus* can be found. Passerines were abundant in the study area, the most abundant of which were stonechat *Saxicola torquata*, black-eared wheatear *Oenanthe hispanica*, dartford warbler *Sylvia undata*, blue rock thrush *Monticola solitarius*, thekla lark *Galerida theklae*, and wren *Troglodytes troglodytes*. Blanco and González (1992) had classified all of these species like not vulnerable in Spain, except for the white stork, bonelli's eagle and peregrine falcon.

The study was carried out in the Eólica del Estrecho windplant. This windfarm is situated over a mountain ridge, which ranges in elevation from 550-650 m above sea level. The ridge is orientated North and South. The wind farm consisted of 66 wind turbines AE-20 MADE and 20/150 Ecotècnia. The model AE-20 MADE has a 21 m tall tubular steel tower and its rotor is 20 m in diameter. The model 20/150 Ecotècnia has a 24 m tall tubular tower and its rotor is 20 m in diameter. Rotors are orientated windward, and have three blades. The total power of the wind farm was 10 MW. The turbine strings were located in two sections, a North Ridge (turbines 1 to 34) and a South Ridge (turbines 35 to 66). Both sections were aligned in a single row on the mountain ridge. Within strings, wind turbines were separated by between 60 and 90 m. From now on, we will refer to this area as the WF Area (Windfarm).

Two adjacent mountain ridges without turbines were included in this study to be used as a reference for the wind farm. One ridge had an East-West orientation (AM Area, which is planned for expansion of the existing wind farm) and the other one had the same orientation as the wind farm ridge (NP Area: protected natural area with limited access).

The flora on the three study areas was very similar and characterised by brushwood and few trees (*Quercus suber*, *Q. rotundifolia*). The vegetation cover was different among the three study areas: in WF Area zones without vegetation were predominated whereas in AM and NP areas zones with dense brushwood and trees were predominated.

Study design

We studied several variables concerning bird population investigating differences between the wind farm mountain ridge and the two controls ridges. Variables were studied along a linear transect with a fixed length in each area. Observations of flight behaviour were also recorded from several fixed observation points in the WF Area (see for similar approach Morrison, 1998). Variables recorded were (1) abundance of passerines and soaring birds (birds / m), (2) breeding abundance (nº of nests / m) and productivity of passerines, (3) flight behaviour in the windfarm of soaring birds, and (4) bird mortality due to collision in the wind farm.

Abundance of birds

The abundance of passerines and soaring birds (griffon vultures, black kites, white storks, common kestrels and short-toed eagles) was registered while walking linear transects in each area (total 228 visits). Transects of fixed length were defined in the three study areas: WF Area 2,780 m., AM Area 1,110 m. and NP Area 2,960 m. Although transects were of a fixed length, they were not monitored entirely during each count. A total of 576 hr was dedicated to monitoring the transect areas. For each observation of a bird group, we recorded the bird species, number of birds, climatic conditions (temperature, wind velocity and wind direction), change of flight direction (changes in flight altitude and flight direction between bird was entering and leaving the survey area), activity of the turbines, the period of the year, and the length of the survey section in meters.

We defined the breeding period as the period from March to mid-July. The post-breeding migration period was defined as the period from when the birds begin to cross the Strait of Gibraltar (mid-July) until the end of migration (mid-October) (Finlayson, 1992). The winter period was defined as the remaining period, which is from mid-October to the beginning of March.

Breeding abundance and productivity of passerines

The breeding abundance of passerines was registered while walking linear-transects in each area. For each passerine group seen, we recorded the species, sex, age and the number of birds. We used the number of passerines divided by metres of transect as breeding abundance measure.

To estimate the reproductive output of breeding passerines in both the windfarm and control areas, we searched for nests during the breeding period. Linear-transect methods were used to detect the nests (Eberhardt, 1978). The length of linear-transects was defined in the three study areas as in before variables. When we observed a nest of a passerine we recorded the species, the number of eggs and/or chicks (productivity) and the location (vegetation, substrate) where the nest was located. Number of fledged chicks was used as productivity measure of each nest.

Flight behaviour of soaring birds

Flight behaviour in the proximity of wind turbines (150 meters height max. and 100 meters width max.) was recorded by direct observation and by video cameras (total observation; 435 hrs). The flight behaviour of soaring birds was recorded from fixed points. In this case the same variables as those mentioned for abundance of birds were recorded. Three anemometer towers located in the wind farm measured climatic conditions (temperature, wind velocity and wind direction). These variables were recorded at midday.

Flight behaviour was expressed by flight altitude and flight direction. Flight altitude and flight direction were calculated by direct observations. Changes in these variables were related to the

presence and functioning of turbines. An index of flight direction change was created using the bird's flight direction while entering and leaving the survey area. We calculated the angular distance between initial flight direction and final flight direction in values from 0° (no direction change) to 180° (maximum direction change) (see also Batschelet, 1981). An angular distance less than 90° between initial and final flight direction was considered as a large deviation from the original flight direction. The change in flight height was calculated by subtracting the final flight height to initial flight height.

Bird mortality

From July 1994 to September 1995 we searched for dead birds resulting from collisions with turbines by checking 50 m. around all turbines on foot (Orloff and Flannery, 1992, Morrison and Sinclair, 1998). The search frequency was at least once a week by experienced observers (Ferrer et al., 1991, Janss and Ferrer, 1998). When a carcass was found, data such as species, age, sex, distance to the closest turbine, kind of injuries and estimated time of the death were recorded (Orloff and Flannery, 1992, Morrison and Sinclair, 1998). When a carcass was found, it was taken away to avoid double counting during following surveys.

Statistical methods

We used non-parametric statistics for those variables that did not correspond to a normal distribution. We used the Kruskal-Wallis Test to compare the abundance of birds between areas. When statistical differences appeared, post-hoc comparisons were made with Mann-Whitney U-Test. Analysis of Chi-Squared (goodness of fit) was used to determine whether flight direction change was related to the functioning of the wind turbines. Analysis of Spearman Correlation was used to determine whether flight direction change was related to flight height change. We used an alpha value of $P = 0.05$. SPSS 10.0 software statistical package was used to perform all statistical procedures.

Results

Abundance of birds

A total of 18,831 birds were recorded in the three study area transects during 576 hrs. of observation. A total of 62,227 birds were recorded from fixed observation points in the WF area only during 1917 hrs of observation. The flying rate (n° birds / hour of observation) of the most abundant species in WF Area were of 20.7 individuals for the white stork, 5.2 for the black kite, 2.8 for the griffon vulture and 1.5 for the swift (*Apus apus*).

No significant differences between abundance of soaring birds and study areas were detected (Kruskal-Wallis Test, $X^2 = 0.978$, $df = 2$, $p = 0.613$), recording 30.17 birds / km in the WF Area, 12.85 birds / km in the NP area and 11.55 birds / km in the AM area (Table 1).

Table 1. Results of passerine bird counts mean (birds / km) along one transect per study areas within periods.

Study periods	WF Area	NP Area	AM Area
Total	8.5 (0.36 – 81.65)	69.0 (0.00 – 552.78)	23.0 (0.45 – 584.54)
Breeding	5.35 (0.36 – 30)	28.25 (4.09 – 182.23)	14.2 (0.45 – 141.67)
Post-Breeding	15.78 (0.36 – 81.65)	36.44 (2.5 – 126.11)	82.24 (2.72 – 584.54)
Wintering	8.76 (0.36 – 42.86)	156.46 (0.00 – 552.78)	9.37 (0.91 – 35.22)

We detected significant differences between passerine abundance in study areas (Kruskal-Wallis Test, $X^2 = 15.334$, $df = 2$, $p < 0.0001$). Post-hoc analysis indicated significant differences in passerine abundance between Area WF (8.5 birds / km) and NP Area (69.0 birds / km) (Mann-Whitney Test, $Z = -3.778$, $p < 0.0001$), and between AM Area (23.0 birds / km) and NP Area (Mann-Whitney Test, $Z = -2.382$, $p = 0.017$). In both cases, passerines were more abundant in NP Area than in the other areas.

These differences in passerine abundance between areas existed during the breeding period (Kruskal-Wallis Test, $X^2 = 10.057$, $df = 2$, $p = 0.007$), but not during the post-breeding (Kruskal-Wallis Test, $X^2 = 2.904$, $df = 2$, $p = 0.234$) and winter (Kruskal-Wallis Test, $X^2 = 3.264$, $df = 2$, $p = 0.196$) periods.

When we analyzed bird's species individually, no statistical differences between study areas were found in the abundance of griffon vultures (Kruskal-Wallis Test, $X^2 = 0.353$, $df = 2$, $p = 0.838$), short-toed eagles (Kruskal-Wallis Test, $X^2 = 1.922$, $df = 2$, $p = 0.383$), black kites (Kruskal-Wallis Test, $X^2 = 1.782$, $df = 2$, $p = 0.410$) and white storks (Kruskal-Wallis Test, $X^2 = 2.724$, $df = 2$, $p = 0.256$). Only the abundance of common kestrels showed significant differences between the three study areas (Kruskal-Wallis Test, $X^2 = 10.832$, $df = 2$, $p = 0.004$). Common kestrels were less abundant in the AM Area than in the WF (Mann-Whitney Test, $Z = -2.933$, $p = 0.003$) and NP (Mann-Whitney Test, $Z = -2.450$, $p = 0.014$) Areas (Table 2).

Table 2. Results of bird count (birds / km) along one transect per study area for several soaring species.

Species	WF Area	NP Area	AM Area
Griffon vulture <i>Gyps fulvus</i>	8.88 (0.36 – 125.91)	5.23 (0.36 – 11.67)	11.41 (0.36 – 85.91)
Short-toed eagle <i>Circus gallicus</i>	0.92 (0.00 – 16.11)	0.72 (0.34 – 1.12)	0.70 (0.00 – 3.34)
Common kestrel <i>Falco tinnunculus</i>	0.60 (0.00 – 1.67)	0.62 (0.56 – 1.12)	0.58 (0.36 – 2.78)
White stork <i>Ciconia ciconia</i>	0.18 (0.00 – 2.50)	0.27 (0.01 – 0.95)	0.19 (0.00 – 0.78)
Black kite <i>Milvus migrans</i>	25.94 (0.00 – 1111.12)	34.43 (1.12 – 277.78)	14.4 (0.56 – 73.89)

Breeding abundance and productivity of passerines

In the WF Area more species (45%) nested in soil without vegetation or between cracks in rocks (*Anthus campestris*, *Galerida theklae*, *Monticola solitarius*, *Oenanthe hispanica*), while in the others areas, the species predominantly nested in dense bushes (66%; *Parus caeruleus*, *Phylloscopus collybita*, *Certhia brachydactyla*, *Emberiza cia*).

Statistical differences in abundance of passerine's nests between study areas were detected (Kruskal-Wallis Test, $X^2 = 12.225$, $df = 2$, $p = 0.002$). In the NP Area (0.0045 ± 0.0019 nests/m), the passerine nests resulted more abundant than in WF (0.0014 ± 0.0015 nests/m; Mann-Whitney Test, $Z = -3.328$, $p = 0.001$) and AM areas (0.0023 ± 0.0019 nests/m; Mann-Whitney Test, $Z = -2.831$, $p = 0.005$) (Table 3).

Table 3. Abundance of passerine bird nests (nests / km²) per study area for several species.

Species	WF Area	NP Area	AM Area
Tawny pipit <i>Anthus campestris</i>	0.36	0.00	0.00
Short-toed treecreeper <i>Certhia brachydactyla</i>	0.00	0.00	0.90
Great spotted woodpecker <i>Dendrocopos major</i>	0.36	0.00	0.00
Rock bunting <i>Emberiza cia</i>	0.00	0.33	1.80
Thekla lark <i>Galerida theklae</i>	0.72	0.00	0.00
Blue rock thrush <i>Monticola solitarius</i>	0.36	0.00	2.70
Black-eared wheatear <i>Oenanthe hispanica</i>	2.51	0.67	1.80
Blue tit <i>Parus caeruleus</i>	0.36	0.00	0.90
Chiffchaff <i>Phylloscopus collybita</i>	0.00	0.00	0.90
Stonechat <i>Saxicola torquata</i>	1.80	0.00	1.80
Dartford warbler <i>Sylvia undata</i>	0.72	0.33	7.20
Sardinian warbler <i>Sylvia melanocephala</i>	0.72	0.00	0.00
Wren <i>Troglodytes troglodytes</i>	1.80	0.00	2.70
Blackbird <i>Turdus merula</i>	0.36	0.00	0.00

When comparing the breeding abundance between the study areas, we observed significant differences (Kruskal-Wallis Test, $X^2 = 48.688$, $df = 2$, $p < 0.0001$). Breeding abundance was higher in AM Area (1.24 ± 2.44 birds/km) than WF Area (0.62 ± 0.44 ; Mann-Whitney Test, $Z = -6.379$, $p < 0.0001$) and than NP Area (1.00 ± 1.81 ; Mann-Whitney Test, $Z = -3.569$, $p < 0.0001$).

Significant differences in the productivity between the study areas were also observed (Kruskal-Wallis Test, $X^2 = 7.995$, $df = 2$, $p = 0.018$): WF (0.027 ± 0.047 chicks/m; Mann-Whitney Test, $Z = -1.862$, $p = 0.063$) and AM (0.022 ± 0.023 chicks/m; Mann-Whitney Test, $Z = -2.873$, $p = 0.004$) areas showed higher reproductive output than NP (0.003 ± 0.004 chicks/m).

Flight behaviour of soaring birds

We observed 16,225 birds from fixed points in the WF Area (435 hrs, 944 registers). Of those, 71.8% showed changes in flight direction. When a change in flight direction was detected, 28.5% showed a large change ($<90^\circ$ angle).

When we analysed the relationship between flight direction change (177.88 ± 106.58) and flight height change (46.11 ± 58.82), no significant relationship was observed (Spearman Correlation Test, $r_s = 0.032$, $N = 176$, $p = 0.669$). When comparing the flight direction change between functioning (182.58 ± 105.95) and non-functioning turbines (175.27 ± 109.80), we observed a significant difference (Fisher Exact Test, $p = 0.016$). More flight direction changes were detected (82.41 %) when turbines were functioning than when turbines were non-functioning (15.38 %).

Flight height in the WF Area during the post-breeding period was significantly higher than during the other study periods (Kruskal-Wallis Test, $X^2 = 76.113$, $df = 2$, $p < 0.0001$). This difference was also detected in the NP Area (Kruskal-Wallis Test, $X^2 = 12.092$, $df = 2$, $p = 0.002$), but not in the AM Area (Kruskal-Wallis Test, $X^2 = 1.635$, $df = 2$, $p = 0.441$) (Table 4).

Table 4. Mean flight heights (in meters) of soaring birds in the three study areas and within three study periods.

Study periods	WF Area	NP Area	AM Area
Breeding period	57.24 (-75.00 – 1000.00)	45.62 (0.00 – 100.00)	68.20 (0.00 – 500)
Post-breeding period	110.02 (-200.00 – 1300.00)	100.94 (-6.00 – 500.00)	79.00 (-50.00 – 600.00)
Winter period	58.90 (-50.00 – 500.00)	37.14 (0.00 – 150.00)	60.07 (-10.00 – 350)

In the post-breeding migration period the flight heights of griffon vulture were higher than in the other study periods, both in the WF (58.3 ± 65.3 m); Kruskal-Wallis Test, $X^2 = 52.866$, $df = 2$, $p < 0.0001$) and in the NP (32.3077 ± 41.1104 m; Mann-Whitney Test, $Z = -3.362$, $p = 0.001$) areas.

Flight heights of white stork in post-breeding period differed significantly between study areas (Kruskal-Wallis Test, $X^2 = 18.883$, $df = 2$, $p < 0.0001$). Flight heights in WF Area (162.08 ± 204.65 m) was lower than in the AM (420.00 ± 238.92 m; Mann-Whitney Test, $Z = -3.698$, $p < 0.0001$) and NP (500.00 ± 397.64 ; Mann-Whitney Test, $Z = -2.742$, $p = 0.006$) areas.

Within the WF Area, except for white storks (22.7 ± 22.6 m), all soaring birds significantly increased their flight heights when crossing lines of the turbines: griffon vultures (21.4 ± 57.7 m; Wilcoxon Test, $Z = -14.016$, $p < 0.0001$), short-toed eagles (3.8 ± 65.3 m; Wilcoxon Test, $Z = -3.981$, $p < 0.0001$), black kite (-0.6 ± 15.6 m; Wilcoxon Test, $Z = -3.539$, $p < 0.0001$) and common kestrels (12.1 ± 37.2 m; Wilcoxon Test, $Z = -1.74$, $p = 0.08$).

Bird mortality

During the whole study period (14 months) only two bird carcasses were found: a young female griffon vulture and an adult male short-toed eagle. They were found under two different towers. This represented a mortality rate of 0.03 birds/turbine/year.

Discussion

Our work has clearly demonstrated that birds can detect the presence of turbines and turbines of different size do not represent a significant problem for bird populations. Soaring birds appeared to detect and to avoid the presence of the turbines better when they were functioning based on changes in their flight direction. Bird abundance was not affected by the presence of turbines. Our observations are supported by the low numbers of dead birds found during the whole study period in the wind farm. Although we did not conduct any experiments of scavenger removal of dead birds, the number of dead birds found in our two visit/week was well below the average found in other studies of power lines using similar methodology (Janss and Ferrer, 1998). Bird mortality attributed to turbine collisions was smaller than that detected by Hunt (1999) and Osborn et al. (2000). Raptors appeared to be accustomed to the presence of turbines and many of the birds flew close to turbines (Orloff and Flannery, 1993). Our results support the conclusion of Nelson and Curry (1995) that mortality of birds associated with the wind farm is not an important factor and avian collisions with turbines are infrequent. In Erickson et al. (2001), turbines constituted 0.01-0.02 % of the avian collisions, and were much lower than other sources of collision mortality such as vehicles, buildings, windows, high-tension lines and communication towers. No passerine mortality data were used in this study because it would be necessary to study the predatory actions on small bird carcasses. More studies are necessary about passerine mortality to know this factor would be considered in the future wind farms.

No statistical differences in the abundance of soaring birds among the three study areas were detected, except for common kestrels. Our data could represent a further element supporting the idea that soaring birds get accustomed to the presence of turbines (Orloff and Flannery, 1993). The difference found for common kestrels might be related to differences in vegetation structure. This species prefers open areas such as at the AM Area (Cramp and Simmons, 1982).

In contrast, the abundance of passerines in NP Area was higher than in the others areas. Passerine nest abundance was higher in the WF and NP areas than in AM Area, probably due to differences in vegetation structure and habitat differences between the areas, being more dense in the NP Area. Leddy et al. (1999) supported the hypothesis of those areas without turbines support higher densities of grassland birds than areas near the turbines. Osborn et al. (1998) presented the same results and suggested that passerines, waterfowl and raptors avoid flying near turbines. Also Larsen and Madsen (2000) detected that wind farms caused a habitat loss equivalent to 4% of the total field area around the turbines for pink-footed geese (*Anser brachyrhynchus*).

Our data showed that passerines had higher productivity near than far from the turbines while Leddy et al. (1999) detected a linear positive relationship between breeding bird density and transect distance from turbines. The umbrella effect of passerine predators (such as booted eagle *Hieraetus pennatus*) in the turbine area about passerine productivity in wind farm area could be suggested (Fleishman et al., 2001, Suter et al., 2002). However, our work has not explained this result because there were several variables we did not study, such as habitat differences, vegetation structure, vegetation cover, number of singing males, which may have influenced our results. More studies are necessary about passerines comparing data before and after the construction wind farms to explain these differences.

Our study has shown that 71.2% of soaring birds changed their flight direction when detecting the turbines on the top of the mountain. Dirksen et al. (1998) detected that only 9% of the birds crossed the turbine line by passing between the turbines, whereas 18% turned away from the turbines. Dirksen et al. (1998) also showed that birds changed their flight direction more when the turbines were functioning than when they were stopped. They also concluded that turbine lines might act as flight path barriers. Griffon vultures, short-toed eagles, black kites and common kestrel flight heights differed between entering and leaving the wind farm, perhaps in efforts to avoid turbines.

Conservation applications

The results of our study may have important implications for the future development of wind farms. Birds detected the presence of functioning turbines and apparently avoided them changing their flight direction or increasing their flight height. Because of this, the mortality in this wind farm was practically nil and much less than that reported by Osborn et al. (2000). However Hunt (1999) reported important mortality for young golden eagles that used the area of the wind farm as a hunting ground. The low risk of the windfarm studied in our case might be related to the fact that the area is used basically as a flight route and passageway, but not as a feeding, roosting or breeding area, which would induce lower flight heights (nearest nest of Bonelli's Eagle *Hieraetus fasciatus* is 4 km., out of Nearest Neighbour Distance (NND) (Penteriani et al. in press)).

There are some other issues related to wind farms that are necessary to consider. First, wind farms are associated with power lines, a more important cause of avian mortality (Janss et al., 1999), especially because of the extent of the power line network. Erickson et al. (2001) estimated that 750.000 to 1 million birds were killed annually by collisions with power lines in The Netherlands, and from 130 to 174 million birds per year in United States. Ferrer et al. (1991) estimated that 400 raptors per year along 100 km of power lines within and around Doñana National Park, in Southwestern Spain. Collision with power lines was considered an important cause of death for some species of birds (Janss and Ferrer, 1998). When the wind farm is in a preconstruction phase, effects of associated power lines must be studied to reduce their effect on birds.

Secondly, although birds can detect turbines, long lines of turbines have a potential barrier effect (Dirksen et al., 1998). Shorter turbine rows could reduce this effect, allowing birds to avoid them more easily. If the area is a passageway for migrating birds, the rows of turbines could have this potential barrier effect in the migratory trajectories. Shorter turbines rows may mitigate the barrier effect and more research about it is needed.

In all cases, additional research before and after the construction of wind farms are needed to better understand what changes to bird populations installing a wind farm might cause. It is imperative that new wind power development should be placed in locations of relatively low risk to birds, and that existing wind developments assess negative impacts on birds (Morrison and Sinclair, 1998). Specific locations should be evaluated *a priori* when a wind farm is planned.

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Capítulo 2

**A bird and small mammal BACI and IG design studies in
a wind farm in Malpica (Spain)**

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Resumen

Los parques eólicos han experimentado un espectacular crecimiento en los últimos 10 años. Este estudio es el primero en el que se han considerado las relaciones entre los parques eólicos con las aves y los micromamíferos. Para el estudio de la comunidad de aves se utilizó un diseño BACI (Antes-Después Área Control e Impacto, siglas en inglés), considerando como zona de impacto el parque eólico y como zona control una adyacente, tanto antes como después de la instalación del parque eólico. Para el estudio de los micromamíferos se utilizó un diseño IG (Gradiente de Impacto, siglas en inglés), considerándose distintas distancias desde las turbinas para medir las variables. La hipótesis nula era el no impacto del parque eólico sobre la comunidad de aves y la de micromamíferos. Las instalaciones eólicas no parecen tener una clara afección sobre las poblaciones de aves y micromamíferos. La altura de vuelo de las aves nidificantes y de las no nidificantes no mostraron una tendencia clara. Las poblaciones de micromamíferos sufrieron grandes variaciones en su número debido a factores intrínsecos. Se recomienda la realización de estudios a largo plazo para eliminar problemas debidos a la influencia humana en la abundancia de las distintas poblaciones.

Palabras claves: diseño BACI, diseño IG, aves, parque eólico, micromamíferos.

Abstract

Wind farms have shown a spectacular growth during the last ten years. As far as we know, this study is the first where the relationship between wind power and birds and small mammals has been considered. BACI (Before-After Control Impact) study design to birds and IG (Impact Gradient) study design to small mammals to test the null hypothesis of no impact of a wind farm were used. In the BACI model Windfarm Area and a Reference Area were considered. Distance from turbines was considered in the IG model. Windfarm installations did not clearly affect bird and small mammal populations. Flight height of nesting and no nesting birds did not show a clear tendency. Small mammals populations suffered high variations in numbers through times by intrinsic population factors. There are many practical problems of detection of human influence on abundances of populations so sampling in the long run can be suggested.

Keywords: BACI design, IG design, birds, windfarm, small mammals.

Introduction

Wind farms are a relative new form to obtain "clean" energy by avoiding air pollution and other forms of environmental degradation associated with fossil fuel technologies (Nelson and Curry 1995) and have received strong public support as an alternative energy source (Leddy et al. 1999). Moreover, wind farms have shown a spectacular growth because they have reduced the costs of energy production and produced a clean energy. This phenomenon has generated a proliferation of wind farms around the world (Germany, Spain, United States, etc) (Osborn et al. 2000).

Most of studies about possible effects of wind power on wildlife animals have been focused on birds, specifically on avian activity, habitat use and bird mortality (Winkelman 1990; Orloff and Flannery 1992; Musters et al. 1996; Howell 1997; Dirksen et al. 1998; Morrison and Sinclair 1998, Strickland et al. 1998, Thelander and Rugge 1998, Osborn et al. 2000; Erickson et al. 2001; de Lucas et al. 2004). None have studied the effects of wind power on small mammal communities.

The Before-After Control Impact (BACI) design has been called the "optimal impact study design" (Anderson et al. 1999). The aim of BACI studies is to compare environmental variables before and after a human activity (e.g. the construction of the windfarm) and between the area presumably affected by the development and a control area (Stewart-Oaten 1986; Guillemette et al. 1998). Use of reference areas increases the reliability of conclusions concerning quantification of impact (Underwood 1994).

We used bird abundance to assess the impact of a construction of a wind farm. Changes in the abundance of organisms is a good impact indicator, but abundance vary naturally through time, so any change observed in an assessment area between the pre- and post- impact periods could conceivably be unrelated to the treatment. In the analysis of impact the percentage of biological indicators that are significantly different (positive and negative) when tested at a given level of significance (Page et al. 1993; Stekoll et al. 1993) is used to determine the direction and magnitude of the impact. In this study rodents were also studied using an Impact-Gradient Design (IG). This study design is used for impact quantification in relatively small assessment areas on homogeneous environments. The analysis was based on the relationship between the impact indicator and distance of rodent captures from the wind turbines.

We tested the null hypothesis of no effect of a wind farm on birds and small mammals in Malpica (A Coruña, Spain). We used a BACI design to analyse (1) the possible impacts of the wind farm on nesting and no nesting bird communities, (2) flight behavioural of both nesting and no nesting birds resulting from the presence of a wind farm; and we used a IG design to analyse the possible impacts of the wind farm on rodents.

Study area

The study area was conducted in Malpica (A Coruña), in the northwestern Spain (Figure 1) from June 1995 to June 1997. In this part of Spain high density of migrating and shore birds can be observed. Here, the shore birds arrive when the weather is bad. This area was swept away by strongest winds from Atlantic storm (Natural 1995a, b; Alonso 2002).

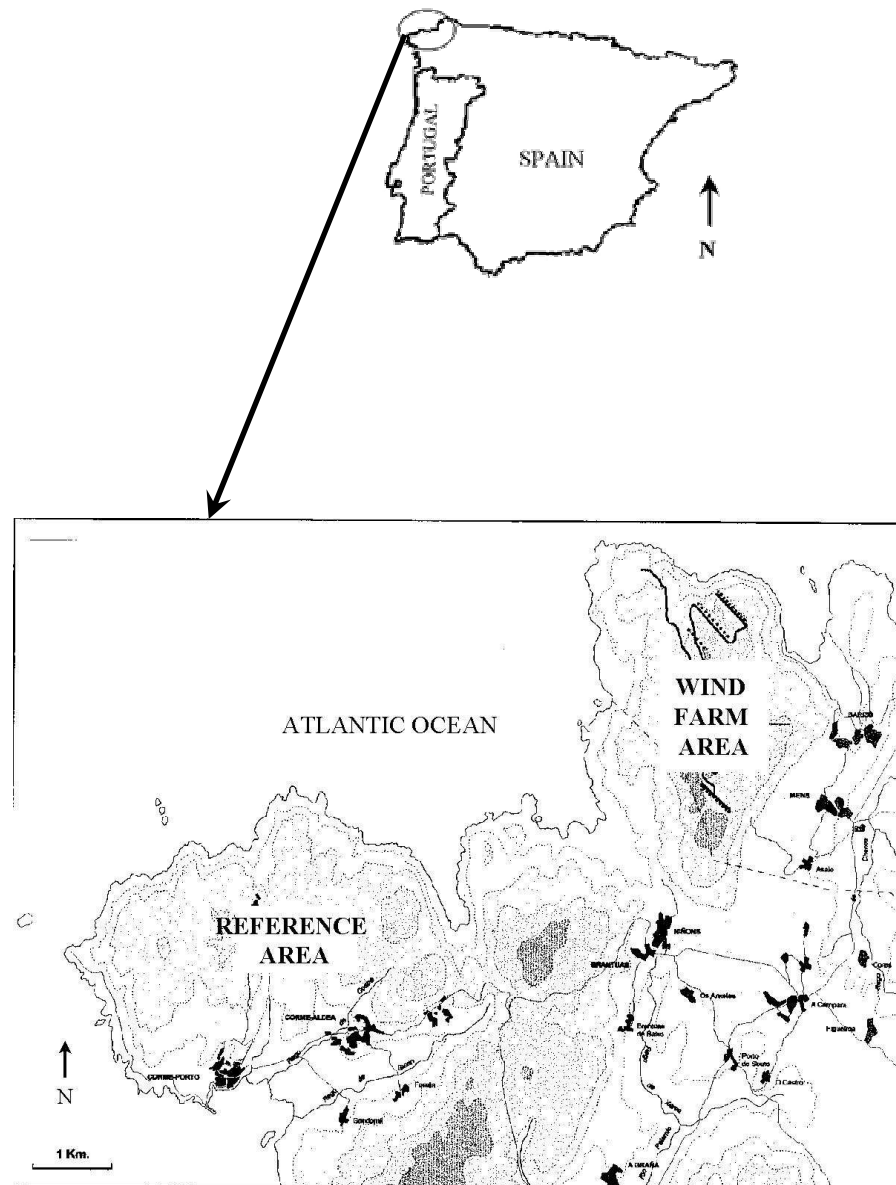


Figure 1. Map of the study areas in Malpica (Galicia Region, northwestern Spain).

In this area 73 breeding passerine and raptor species can be found (see Table 1 and 3). Only Montagu's Harriers was classified like vulnerable in Spain by the Red Book (Blanco and González, 1992). Colonies of breeding Yellow-legged Gulls *Larus cachinnans* were distributed along the coastline (Natural 1995a).

Small mammals community were composed by Western Hedgehog *Erinaceus europaeus*, Iberian Mole *Talpa occidentalis*, Common Shrew *Sorex araneus*, Pygmy Shrew *S. minutus*, Wood Mouse *Apodemus sylvaticus*, Miller's Water Shrew *Neomys anomalus*, Greater White-toothed Shrew *Crocidura russula*, and Lesser White-toothed Shrew *C. suaveolens* (Natural, 1995b). Blanco and González (1992) had classified Iberian Mole like insufficient acquaintance.

The study was carried out in the Malpica Windfarm. This windfarm was 150-200 m. above sea level and 160-200 m. far from the coast. The wind farm consisted of 67 wind turbines Ecotècnia 28/225. This model has a tubular steel tower of 32 m and its rotor is 20 m in diameter. Rotor was orientated windward, and have three blades. The total power of wind farm was 15 MW. The turbines strings were aligned in 7 rows and they were orientated from North-West to South-East. Within strings, wind turbines were separated between 60 and 90 m. From now on, we will refer to this area as the WF Area (Windfarm).

A near area without turbines was included in this study to be used as a reference area. This area and WF Area were separated by 6 km. The reference area was 100-150 m. a.s.l. and 150-170 m. far from the coast. From now on, we will refer to this area as the R Area (Reference).

The flora's species on both study areas were very similar, consisting in bush of *Ulex* sp. and small wood of Southern Blue-gum *Eucaliptus globulus* and Maritime pine *Pinus pinaster* (Rivas-Martínez 1987). Some area were cut by farmers, then grazing land and heather proliferated. Also, in R Area some fields were sowed with corn *Zea mays* and wheat *Triticum* sp.

Methodology

The study was carried out through three years (1995, 1996 and 1997), during the second fortnight of June. BACI and IG models were used for this study. Three periods were defined: pre-construction (June 1995), construction (June 1996) and post-construction (June 1997) of the wind farm.

We studied several variables concerning birds analysing for differences among study areas and study periods. Variables were recorded along fixed length transects in both areas. We also studied several variables concerning small mammals comparing study periods in WF Area only. Three groups of variables were recorded in this comparative study: 1) specific composition (number of species present), relative abundance (IKA: n° birds/km) and density (birds/km²) of nesting and no nesting birds; 2) flight behavioural of nesting and no nesting birds (direction and flight height); and 3) specific composition (number of species present) and abundance of small mammals in WF Area.

We distinguish between nesting birds and no nesting birds based in the following criteria: 1) nesting birds were all passerine birds (except corvids) which were in the study areas during reproductive period; 2) nesting birds were all those bird species whose breed in the study areas were known; and 3) nesting birds were all those bird species whose reproductive requirements were in the study areas.

Avian mortality was not studied because the windfarm had been operating as full potential only for a few months.

Composition, abundance and density of birds

The abundance, density and composition of bird's communities in both study areas were detected by transect method (Tellería 1986). In each study area, we selected a census' transect and recorded all visual contact with birds or flocks of birds walking to constant velocity. Both transects were circular and measured 2.6 km. over the 3 year study (the second fortnight of June). A total of 32 hours was dedicated to monitoring transects per year. In all cases, the census were executed at the first hours in the morning or at dusk.

When we observed a bird, several variables such as date, hour, species, number of birds, sex, age, climatic conditions (wind velocity and wind direction), habitat where birds were (rocks, bushes, trees and grazing land) and distance to transect were recorded. With this data, an index of avian abundance per km. (IKA) and an avian density per km² in each study area were calculated (Ferry and Frochot 1958).

Flight behaviour of birds

Flight behaviour was recorded by direct observation from linear-transects by foot in each area (as above). When we observed birds the same variables as those mentioned for avian abundance and composition were recorded. Anemometer towers located in the wind farm measured climatic conditions (wind velocity and wind direction). These data were used in R Area too due to the proximity of both areas and their similar morphology characteristics.

Flight behaviour was described by flight altitude, flight direction, kind of flight and singing (if bird was singing or not). Flight altitude and flight direction were calculated by direct observations.

Composition and abundance of small mammals

The specific composition was detected with "capture – marked – recapture" model using live trap with bait (Orrock et al. 2000). The traps measured 28 x 10 x 7 cm. Traps were checked twice at day: in the morning and in the afternoon, every 10 study days per study period. When a small mammal was captured, several variables such as species, sex and reproductive condition were recorded. The captured small mammals were marked by cutting a lock.

The relative abundance was detected with footprint searches on specific gadgets. Therefore we used PVC tubes with 29 cm long and 7 cm in diameter with a white paper with a mixture of charcoal and oil inside. The small mammal's footprints were imprinted in these white papers when passing through the oil mixture.

The traps and tubes were distributed alternated and separated by 20 m along 4 line transects covering WF Area (Figure 2). The same points were used in all the study period. They were classified in four categories: less than 40 m to the turbines, between 40 and 80 m to the turbines, between 80 and 120 m to the turbines and more than 120 m to the turbines. The line transects were placed from the North to the South. Also, to each point several variables about landscape were recorded such as kind of morphological features and vegetation (rocks, bushes, pines and grassland), vegetation cover (open, middle and dense) and homogeneity of landscape (uniform and edge).

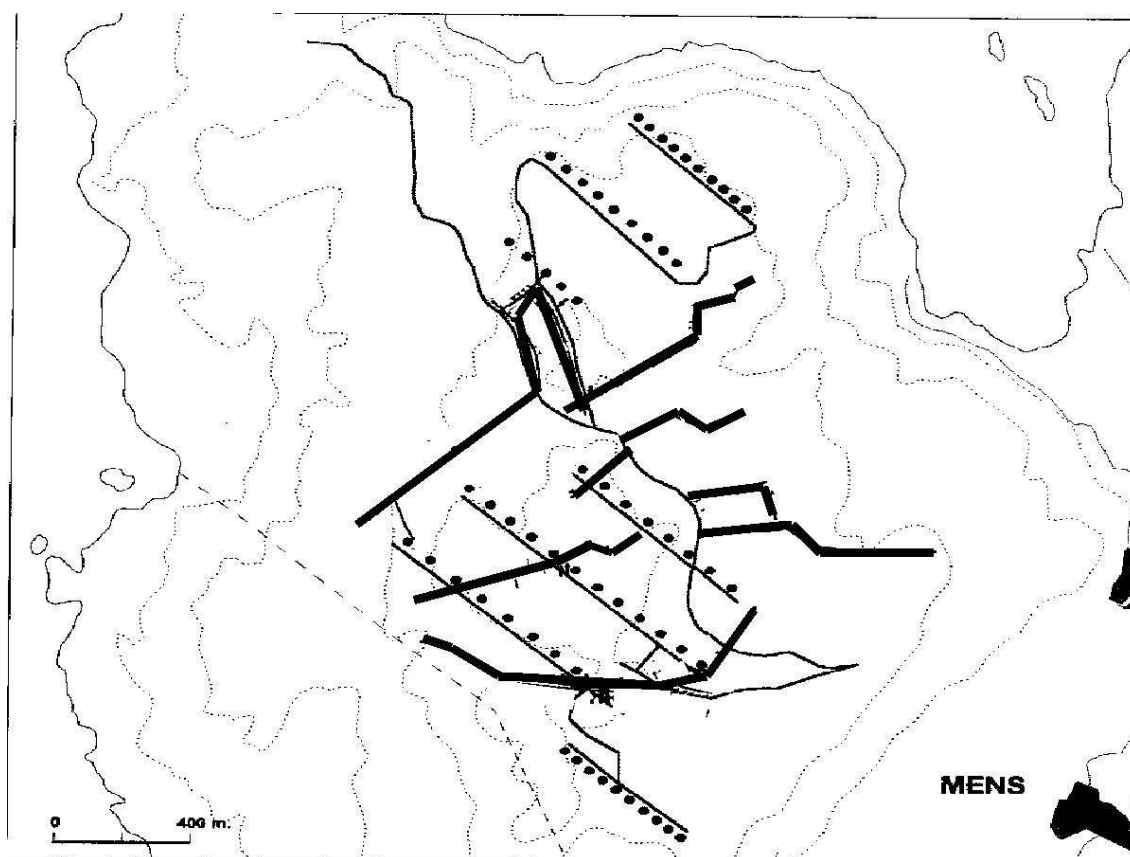


Figure 2. Map of the transects (dark lines) used to distributed all traps and tubes covering all WF Area.

An index of captures in each study year was calculated dividing the number of captured small mammals by study days and by number of active traps.

Statistical methods

Avian density (birds / km²) according to distance of bird observation to the transect were calculated by DISTANCE 4.0 Beta 6 program (Thomas et al. 2002).

We used non-parametric statistics for those variables that were not normally distributed. We used the Wilcoxon Test to compare the IKA index of birds (birds / km) between areas. Kruskal-Wallis Test were used to compare the flight height between areas. When statistical differences appeared, post-hoc comparisons were made with Mann-Whitney U-Test. Analysis of Chi-Squared (goodness of fit) was used to analyse the predominated flight direction of birds between study area.

Kolmogorov-Smirnov Test was used to test normal distribution of bird's density. We used two ways ANOVA to analyse the density of birds through study periods and study areas.

Small-mammals are mainly caught one at each time in small traps. So, each capture can be recorded as an independent observation. Two forward stepwise logistic regression procedure were used to create the models of captures and signals, because this multivariate statistical technique permits the prediction of binary attributes such as presence/absence.

We used an alfa value of $P = 0.05$. SPSS 10.0 software statistical package was used to perform all statistical analyses.

Results

Composition, avian abundance and avian density

1) Nesting birds

A total of 2,121 birds from 21 different species in the two study areas in all study period (total observation 32 hrs) were recorded. In 1995, 614 birds from 12 species were observed. In 1996, 833 birds from 16 species were observed. In 1997, 669 birds from 18 species were recorded (Table 1). Four species through study period were only detected in R Area: Fan-tailed Warbler, Cirl Bunting, Blackcap and Spectacled Warbler, and only one in WF Area: Greenfinch.

When comparing the IKA index of each species between study areas significant differences were observed only in 1996 (Table 2).

No significant differences were detected in IKA index between study periods neither in WF Area (Kruskal-Wallis Test, $X^2 = 1.027$, $df = 2$, $P = 0.599$), nor in R Area (Kruskal-Wallis Test, $X^2 = 0.106$, $df = 2$, $P = 0.948$).

No significant differences in bird's density were detected between both study areas among study years (two-way ANOVA, $F_{5,30} = 0.794$, $P = 0.565$).

Table 1. Abundance (numbers of birds / Km) of nesting bird species in the two study areas and in all study period.

Nesting species	Wind farm area			Reference area		
	1995	1996	1997	1995	1996	1997
<i>Alauda arvensis</i> (Skylark)	1.54	1.46	1.99	0.34	0.19	0.00
<i>Anthus trivialis</i> (Tree Pipit)	0.00	0.31	0.13	0.05	0.22	0.13
<i>Carduelis cannabina</i> (Linnet)	3.03	5.58	6.92	7.60	3.49	8.91
<i>Carduelis carduelis</i> (Goldfinch)	1.32	0.81	1.41	0.87	1.96	0.83
<i>Carduelis chloris</i> (Greenfinch)	0.81	1.31	1.35	0.77	0.83	0.51
<i>Cisticola juncidis</i> (Fan-tailed Warbler)	0.00	0.00	0.00	0.00	0.32	0.06
<i>Emberiza cirius</i> (Cirl Bunting)	0.00	0.00	0.00	0.00	0.00	0.06
<i>Erithacus rubecula</i> (Robin)	0.04	0.00	0.06	0.00	0.13	0.13
<i>Fringilla coelebs</i> (Chaffinch)	0.04	0.00	0.00	0.00	0.00	0.00
<i>Hyppolais polyglota</i> (Melodious Warbler)	0.00	0.04	0.00	0.00	0.13	0.00
<i>Lullula arborea</i> (Woodlark)	0.00	0.00	0.13	0.00	0.03	0.00
<i>Muscicapa striata</i> (Spotted Flycatcher)	0.21	0.00	0.00	0.05	0.00	0.00
<i>Parus ater</i> (Coal Tit)	0.00	0.23	0.00	0.29	0.26	0.06
<i>Parus major</i> (Great Tit)	0.00	0.00	0.06	0.00	0.00	0.26
<i>Prunella modularis</i> (Dunnock)	0.47	0.58	2.12	0.77	1.28	1.99
<i>Saxicola torquata</i> (Stonechat)	2.74	2.77	4.68	1.83	1.57	2.95
<i>Sylvia atricapilla</i> (Blackcap)	0.00	0.00	0.00	0.00	0.00	0.13
<i>Sylvia conspicillata</i> (Spectacled Warbler)	0.00	0.00	0.00	0.00	0.35	0.06
<i>Sylvia undata</i> (Dartford Warbler)	0.00	1.96	2.63	2.12	0.64	1.03
<i>Troglodytes troglodytes</i> (Wren)	0.34	0.73	1.35	0.29	0.22	0.64
<i>Turdus merula</i> (Blackbird)	0.26	0.27	0.96	0.53	1.70	1.35
Total	10.94	16.04	23.97	15.48	13.33	19.23
Birds / Km	256/23.4	417/26	374/15.6	322/20.8	416/31.2	300/15.6

Table 2. IKA index of nesting species between study areas and study periods were analysed with Wilcoxon Test.

Years	Areas	Mean	s.d.	n	Z	P
1995 (pre)	WF	0.332	0.216	24	0.302	0.763
	R	0.349	0.168			
1996 (const)	WF	0.337	0.225	32	-2.348	0.019
	R	0.462	0.131			
1997 (post)	WF	0.375	0.502	36	-1.168	0.243
	R	0.305	0.364			

2) No nesting birds

A total of 672 birds from 18 different species were recorded in the two study areas in the whole study period (total observation 32 hrs) (Table 3). Five species were only detected in WF Area (Raven,

House Martin, Yellowhammer, Swallow and Black Redstart) and Jackdaw, Nightingale and Pied Wagtail only in R Area.

Table 3. Abundance (numbers of birds / Km) of no nesting bird species in the two study areas and in all study period.

No nesting species	Wind farm area			Reference area		
	1995	1996	1997	1995	1996	1997
<i>Apus apus</i> (Swift)	0.00	0.08	0.00	0.14	0.38	0.32
<i>Buteo buteo</i> (Buzzard)	0.26	0.27	0.06	0.24	0.06	0.06
<i>Columba palumbus</i> (Woodpigeon)	0.00	0.12	0.13	0.34	0.10	0.13
<i>Corvus corax</i> (Raven)	0.04	0.00	0.00	0.00	0.00	0.00
<i>Corvus corone corone</i> (Carrion Crow)	0.00	0.04	0.45	1.06	1.12	1.22
<i>Corvus monedula</i> (Jackdaw)	0.00	0.00	0.00	0.05	0.00	0.00
<i>Delichon urbica</i> (House Martin)	0.00	0.04	0.00	0.00	0.00	0.00
<i>Dendrocopos major</i> (Great Spotted Woodpecker)	0.09	0.04	0.00	0.00	0.06	0.06
<i>Emberiza citrinella</i> (Yellowhammer)	0.30	0.00	0.00	0.00	0.00	0.00
<i>Falco tinnunculus</i> (Common Kestrel)	0.13	0.04	0.06	0.05	0.00	0.00
<i>Hirundo rustica</i> (Swallow)	0.00	0.00	0.13	0.00	0.00	0.00
<i>Larus cachinnans</i> (Yellow-legged Gull)	2.52	2.54	0.77	7.16	2.85	1.99
<i>Luscinia megarhynchos</i> (Nightingale)	0.00	0.00	0.00	0.05	0.00	0.00
<i>Motacilla alba</i> (Pied Wagtail)	0.00	0.00	0.00	0.05	0.00	0.00
<i>Phoenicurus ochruros</i> (Black Redstart)	0.00	0.00	0.13	0.00	0.00	0.00
<i>Picus viridis</i> (Green Woodpecker)	0.00	0.12	0.13	0.05	0.10	0.00
<i>Streptopelia turtur</i> (Turtle Dove)	0.00	0.08	0.00	0.10	0.77	0.83
<i>Sturnus unicolor</i> (Spotless Starling)	0.00	0.00	0.06	0.00	0.00	0.06
Total	3.59	3.35	3.33	9.23	5.45	5.58
Birds / Km	84/23.4	87/26	52/15.6	192/20.8	170/31.2	87/15.6

When comparing the IKA index of each species between study areas no significant differences were detected (Table 4).

Table 4. IKA index of no nesting species between study areas were analysed with Wilcoxon Test.

Years	Areas	Mean	s.d.	n	Z	P
1995 (pre)	WF	0.239	0.310	18	-1.025	0.305
	R	0.406	0.280			
1996 (const)	WF	0.552	0.285	20	-1.022	0.307
	R	0.433	0.324			
1997 (post)	WF	0.334	0.265	32	0.000	1.000
	R	0.327	0.267			

No significant differences in IKA index were detected between study years neither in WF Area (Kruskal-Wallis Test, $X^2 = 0.187$, $df = 2$, $P = 0.911$) nor in R Area (Kruskal-Wallis Test, $X^2 = 0.4296$, $df = 2$, $P = 0.808$).

Significant differences in bird's density were detected (two-way ANOVA, $F_{5,32} = 3.501$, $P = 0.016$) between both study areas ($F = 6.045$, $P = 0.022$) among study years ($F = 3.779$, $P = 0.037$). This variable showed higher values during 1995 in R Area.

Flight behaviour of birds

1) Nesting birds

Only in 1996 significant differences were detected (WF Area rank = 376.74, R Area rank = 457.36; Mann-Whitney Test; $Z = -5.576$; $n = 833$; $P < 0.0001$) when the height flight of birds between study areas were analysed. Nesting birds flew higher in R Area than in WF Area.

Significant differences in flight height were detected between study periods in R Area (Kruskal-Wallis Test, $X^2 = 53.056$, $df = 2$, $P < 0.0001$). Birds flew higher in 1996 (rank = 591.53) than 1995 (rank = 477.94; Mann-Whitney Test, $Z = -5.831$, $P < 0.0001$) and 1997 (rank = 464.23; Mann-Whitney Test, $Z = -6.253$, $P < 0.0001$). In WF Area flight height between study periods were not statistically different (Kruskal-Wallis Test, $X^2 = 5.426$, $df = 2$, $P = 0.066$).

2) No nesting birds

Only in 1996 significant differences were detected when the flight height of birds between study areas were analysed (WF Area rank = 168.09, R Area rank = 108.99; Mann-Whitney Test, $Z = -6.092$, $n = 257$, $P < 0.0001$). Nesting birds flew higher in WF Area than in R Area.

Significant differences in flight height were detected between study periods in R Area (Kruskal-Wallis Test, $X^2 = 13.809$, $df = 2$, $P = 0.001$). Birds flew higher in 1995 (rank = 217.56) than 1996 (rank = 251.06; Mann-Whitney Test, $Z = -2.642$, $P = 0.008$) and than 1997 (rank = 190.50; Mann-Whitney Test, $Z = -1.901$, $P = 0.057$). Also in WF Area significant differences in flight height were detected between study periods (Kruskal-Wallis Test, $X^2 = 64.036$, $df = 2$, $P < 0.0001$). Birds flew higher in 1996 (rank = 154.58) than 1995 (rank = 89.62; Mann-Whitney Test, $Z = -6.584$, $P < 0.0001$) and 1997 (rank = 76.91; Mann-Whitney Test, $Z = -6.965$, $P < 0.0001$).

In 1995 (northern directions = 54, eastern directions = 4, southern directions = 14 and western directions = 9; expected ratio 25% in each direction; $X^2 = 77.469$, $df = 3$, $P < 0.0001$), and 1996 Northern flight direction predominated when flight direction were analysed in WF Area.

Statistical differences R Area in 1995 were detected. However in WF Area no predominated flight direction were detected ($X^2 = 2.586$, $df = 3$, $P = 0.460$) in 1995.

In 1996 in R Area predominated northern flight direction was detected (northern directions = 39, eastern directions = 11, southern directions = 13 and western directions = 19; expected ratio 25 % in each direction; $X^2 = 23.951$, $df = 3$, $P < 0.0001$), but not in WF Area ($X^2 = 3.895$, $df = 3$, $P = 0.273$).

In 1997 predominated eastern flight direction were detected in R Area (northern directions = 12, eastern directions = 18, southern directions = 3 and western directions = 7; expected ratio 25% in each direction; $X^2 = 12.6$, $df = 3$, $P = 0.006$). In WF Area flight directions not were statistical differences ($X^2 = 2.048$, $df = 3$, $P = 0.563$).

Small mammals

Through the day, no small mammals were captured. In 1995, total capture effort was 897 traps-night and 936 tubes. Index of captures was 0.0025 small mammals per study day and number of traps-night ($n = 13$). All were Wood Mouse *Apodemus sylvaticus* and there were placed all in bushes. In middle vegetation cover 69.2% of total captures were situated, and in uniform landscapes the same percentage were found. 53.85% of captures were situated in the second category of distance (40-80 m). The index of small mammal signs was 0.003 signs of small mammals per study day and number of tubes ($n = 18$). 38.9% of these were placed in grassland, 66.7% in open vegetation cover, 72.2% in edge landscape and 50% were in the second category of distance.

In 1996, total capture effort was 886 traps-night and 1842 tubes. Index of captures was 0.001 small mammals per study day and number of traps ($n = 7$). All of these were identified as Wood Mouse *Apodemus sylvaticus*. The 57% of these were placed in rocks, the 57% were in middle vegetation cover, 71.4% were in edge landscape and 71.4% were in the second category of distance. The index of small mammal signs was 0.0005 signs of small mammals per study day and number of tubes ($n = 24$). The 57% of these were placed in grassland, 71.4 % were in dense vegetation cover, 71.4% were in edge landscape and 66.7% were in the third category of distance.

In 1997, total capture effort was 728 traps-night and 1442 tubes. Index of captures was 0.012 small mammals per study day and number of traps ($n = 59$). One small mammals was Greater White-toothed Shrew *Crocidura russula* and the others were Wood Mouse *Apodemus sylvaticus*. 51.2% of these were in grassland, 44.2% were in middle vegetation cover, 51.2% were in edge landscape and 33.9% were in the second category of distance. The index of small mammals signs was 0.016 signs of small mammals per study day and number of tubes ($n = 118$). The 49.5% of these were in bushes, 58% were in middle vegetation cover, 84.12% were in edge landscape and 38.13% were in the second category of distance.

The logistic regression model quantified the linear combination of independent variables best discriminating between presence/absence of captures in traps only study year variable entered the model ($B = -0.191$, $Wald = 6.1$, $df = 1$, $P = 0.014$) and distance from turbines variable did not ($B = -0.201$, $Wald = 2.727$, $df = 1$, $P = 0.099$). Only study year entered into the logistic regression model in

quantifying track signs in tubes ($B = 1.022$, Wald = 55.865, $df = 1$, $P < 0.0001$). This variable, in traps and tubes analysis, showed higher values in 1997.

Discussion

Windfarm installations did not clearly affect bird and small mammal populations, so the presence of turbines seemed not to be a significant problem for these populations. Avian abundance and avian density in breeding does not differ by study years (pre windfarm, windfarm installation and post windfarm) and between areas (R and WF). Avian density in no breeding birds show a light tendency to decrease with time. In contrast, Lucas et al. (2004) detected more abundance of passerines in a control area than the others (another control and windfarm areas). Leddy et al. (1999) supported the hypothesis of those areas without turbines support higher densities of grassland birds than areas near the turbines, and also Larsen and Madsen (2000) detected that wind farms caused a habitat loss equivalent to 4% of the total field area around the turbines for pink-footed geese (*Anser brachyrhynchus*).

Flight height of nesting and no nesting birds did not show a clear tendency. No nesting birds flew higher in 1996 in WF Area. This effect could be related to the machines and personal working in the construction of the windfarm. However, this effect did not appear in flight height of nesting birds. In Lucas et al. (2004) soaring birds we detected a significantly higher flight height in WF Area than in the others control areas.

Flight of nesting birds had not been considered because their flight was local distances and between bushes (Rodewald and Yahner 2001). In no nesting birds the predominated flight direction in R Area suggest that birds flew mainly in one direction (South – North), while in WF Area birds did not have a clear flight direction, changing often their direction of flight. Lucas et al. (2004) detected that 71.2% of soaring birds changed their flight direction when detecting the turbines on the top of the mountain, and Dirksen et al. (1998) also showed that birds changed their flight direction more often when the turbines were operating than when they were not. So turbine lines might act as flight path barriers.

Small-mammals populations suffered high variations in numbers through times by several factors (Snyder 1978). The higher index of captures and signs in 1997 could be assumed to 1) several factors affecting populations, 2) change in vegetation variables with the construction of windfarm (open landscape, less bushes) and 3) umbrella effects of small-mammals predators (Chase et al. 2000).

There was a spatial distribution on small-mammals captures. The strip of distance more used was 40 to 80 meters in all study years. Because an increase of captures near turbines is expected through study years, the second hypothesis can not supported. The impact of the construction of turbines specially could be only in the immediate vicinity of the wind park. This contradicts findings of Guillemette and Larsen (2002) that the wind park did not influence the distribution of eiders because their experiments conducted at a small spatial scale (around the wind park) showed that wind

turbines did not have a negative influence on the distribution and the abundance of small-flock common eiders when correcting food availability. The third hypothesis has not been out but avian community have not changed through study years.

In conclusion, our results do not support an important effect of the windfarm on birds and small-mammals populations. The BACI design we had used was criticised by Hurlbert (1984) on the basis that the control site would need to be very similar to the impact site in order to come up with a sound conclusion. Therefore our study areas (Reference and Windfarm) were chosen to be very similar in characteristic of landscape, vegetation and altitude.

Management applications

Our study may have important implications for the future development of wind farms. Bird and small-mammals populations might not affected by the presence of turbines. Soaring birds detected the turbines and change their flight direction and small-mammals seems not to be affected by the new constructed windfarm. These results could not be extrapolated to other areas with different avian community and sampling in the long run can be suggested.

Attention to the intricate relationship that may exist between the presence/absence of disturbance and the probability of collisions with turbines. Therefore, absence of disturbance may increase the probability of collisions (Guillemette and Larsen 2002). We did not study mortality because in the after period the windfarm had been operating as full potential only for a few months.

There are many practical problems of detection of human influence on abundances of populations, but two are paramount in designing sampling programs. First is the large temporal variance of many populations, so that their abundances are very "noisy". Second, many populations show a marked lack of concordance in their temporal trajectories from one place to another. This results in considerable statistical interaction between changes in mean abundance from time to time and differences from place to place (Underwood 1994).

Any difference in abundance between the impact and the control sites could be explained by a priori differences in the two sites and that no causal relationship of presence/absence of an impact could be derived from this design (Hurlbert 1984). So postdevelopment experiences should be considered a complement to BACI studies rather than an alternative (Guillemette and Larsen 2002).

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Capítulo 3

**Long-term study of bird fatalities in wind farms in
southern Spain**

Resumen

La mortalidad de aves por colisión con las palas de los aerogeneradores es conocida como uno de los principales efectos adversos de los parques eólicos, pero hasta la actualidad, el presente estudio de dos parques eólicos en el sur de España es el primero en considerar la mortalidad registrada durante 10 años. La abundancia de las aves se comparó con los registros de mortalidad por colisión para identificar el riesgo de mortalidad especie-específico. Los análisis de tiempos de fallos incorporaron los datos de mortalidad censurados, en los que el tiempo de ocurrencia del evento (en nuestro caso, la colisión) no es conocido, y se utilizaron para testar la hipótesis nula de homogeneidad en la distribución de la mortalidad de las aves según distintos factores. La mortalidad y la abundancia de las aves varían de forma muy marcada entre las estaciones del año, no siendo la mortalidad mayor en la época de mayor abundancia. Este resultado es contrario a la frecuente asunción en los estudios de parques eólicos, de que la mortalidad aumenta con la abundancia de las aves. La probabilidad de colisión depende de las especies (el buitre leonado es la víctima más frecuente), la altura de los aerogeneradores (los más altos), y la altura sobre el nivel del mar (lo más alto). Factores especie-específicos y topográficos están implicados en la mortalidad por colisión, pero no hay evidencias de una asociación entre la probabilidad de colisión y el tipo de aerogenerador (tubular o celosía) o la posición del aerogenerador en la fila. Sugerimos que el problema de la colisión sería mejor entendido con estudios sobre el comportamiento de vuelos de las aves en los parques eólicos.

Palabras claves: abundancia de aves, datos censurados, riesgo de colisión, análisis de tiempo de fallos, *Gyps fulvus*, energía eólica, Tarifa.

Abstract

Avian mortality through collision with moving rotor blades is well-known as one of the main adverse impacts of wind farms, but as far as we know, this study of two wind farms in southern Spain is the first where 10 years of mortality records have been considered. Bird abundance was compared with collision fatality records to identify species-specific death risk. Failure time analysis incorporated censored mortality data in which the time of event occurrence (collision) was not known and was used to test null hypotheses of homogeneity in avian mortality distribution according to several factors. Bird mortality and bird abundance varied markedly among seasons, but mortality was not highest in the season with highest bird abundance: this result called into question a frequent assumption of wind farm studies, that collision mortality should increase with bird abundance. Bird collision probability depended on species (griffon vulture being the most frequent victim), turbine height (taller) and elevation above sea level (higher), implicating species-specific and topographic factors in collision mortality, but there was no evidence of an association between collision probability and turbine type (tubular or lattice) or the position of a turbine in a row. We suggest that the problem of collision could be better understood with more studies of bird flight behaviour around wind farms.

Keywords: bird abundance, censored data, collision risk, failure time analysis, *Gyps fulvus*, wind energy, Tarifa.

Introduction

The use of wind as a renewable energy source has been increasing in many countries. Despite the obvious benefit of wind turbines as a clean energy source, it is known that wind farms can potentially have adverse effects on birds, notably fatality through collision with rotating turbine rotor blades (e.g. Langston & Pullan 2003). At the current level of development, wind turbines have been estimated to comprise less than 0.01% of the total annual avian mortality from human-caused sources in the USA (Erickson *et al.* 2002). Although such analyses do not acknowledge that some bird species may potentially be affected more by wind turbines than other anthropogenic mortality sources, at least one study has concluded that wind turbines, when properly planned, should have minimal impact in comparison with other factors (Fielding, Whitfield & McLeod 2006). Nevertheless, the potential for wind farms to cause problems for bird populations should not be underestimated (Hunt 2002), so the coexistence of birds and wind farms would be enhanced by a more detailed approach to this conservation issue and a greater understanding of the factors involved in influencing collision fatality (Barrios & Rodríguez 2004).

A major difficulty in assessing the mortality impact of wind farms on bird populations is the apparent paucity of available information from long-term studies at operational wind farms. Despite the existence of numerous studies in the “grey” literature (Orloff and Flannery 1992, 1993; Hunt *et al.* 1995; Howell 1997; Hunt 1998; Morrison *et al.* 1998; Erickson *et al.* 2001; Kerlinger 2002), relatively little material on wind farm impacts has been published in the scientific literature (Musters, Noordervliet & Terkeus 1996; Osborn *et al.* 2000; Johnson *et al.* 2002, 2004; Barrios & Rodríguez 2004; Chamberlain *et al.* 2006). Furthermore, study methods vary greatly, as do their results, and more than one year of data may be needed to obtain robust estimates of fatality rates (Smallwood & Thelander 2004) yet long-term studies are extremely rare. Here we present the first attempt by a single study to examine long-term avian fatalities in wind farms. We analyse ten-year sampling of bird fatalities at two windfarms in Tarifa (Cadiz, Spain) in relation to bird abundance, and test several factors which have been hypothesised to be associated with bird mortality.

Materials and methods

Study area

The study wind farms, called Energía Eólica del Estrecho and PESUR, were located in Tarifa, Campo de Gibraltar area, Andalusia region, south of Spain (30STF590000 – 30STE610950) (see also Barrios & Rodríguez 2004). In Spain, Andalusia was the pioneer region installing turbines and involved the municipality of Tarifa, since the Strait of Gibraltar is one of the four areas in Spain with the greatest potential for producing wind energy (IDAE 1996).

The study area at Tarifa consists of a series of mountain ranges (maximum altitude 820 m a.s.l.) running north – south and reaching the northern shore of the Strait of Gibraltar. The vegetation was

characterised by brushwood and scattered trees (*Quercus suber*, *Q. rotundifolia*) on the mountain ridges, and pasture land used for cattle grazing predominating in the lower areas. Easterly winds prevailed.

Energía Eólica del Estrecho wind farm is situated along Sierra de Enmedio mountain ridge (550-650 m a.s.l.) (Fig. 1). During our study it contained 66 wind turbines of two models and all rotors were oriented windward (Table 1). Two new rows of turbines were constructed in 1998 and were not included in our study. Hereafter we will refer to this area as the EEE wind farm.

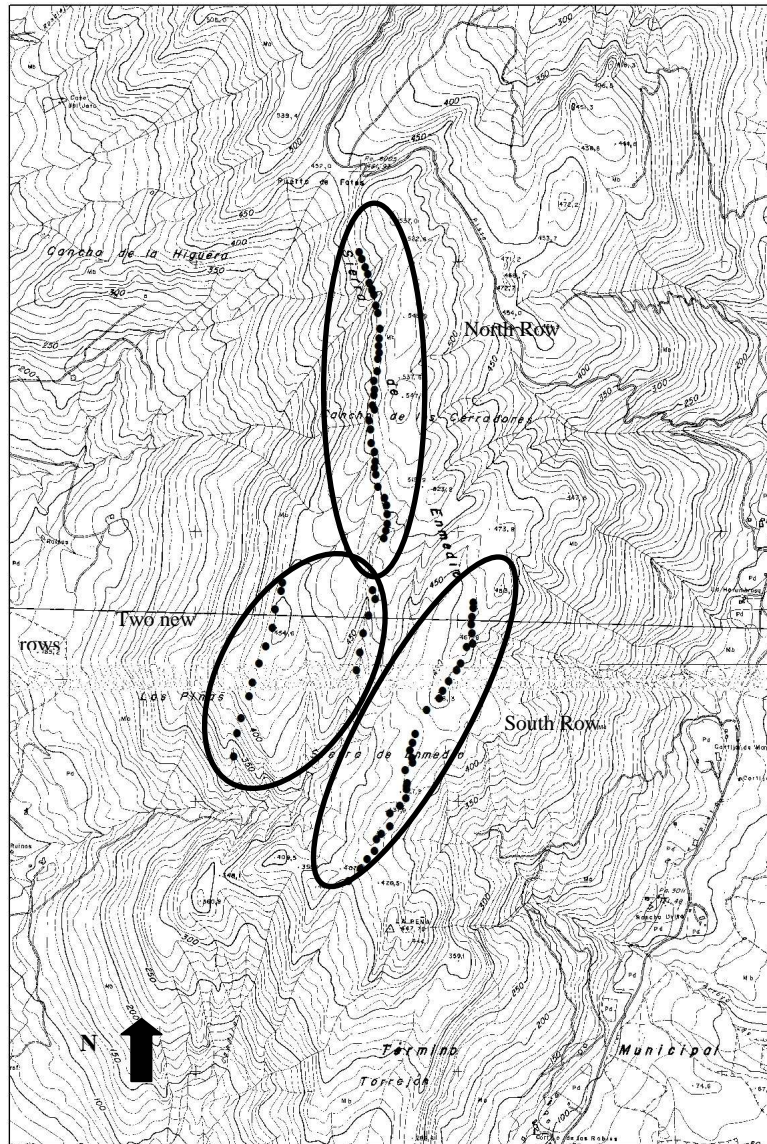


Figure 1. Energía Eólica del Estrecho (EEE) wind farm map (scale 1/10,000) with the North and the South rows and the two new rows (not included in this study).

Table 1. Turbine characteristics at EEE and PESUR wind farms.

	MADE AE-23	ECOTÉCNICA 20/150	AWP 56-100	MADE AE-20
Wind Farm	EEE	EEE	PESUR	PESUR
Power (kW)	180	150	100	150
Blades	3	3	3	3
Rotor diameter (m)	23	20	10 or 18	20
Tower height (m)	28	28	18 or 36	21-28
Tower type	Tubular	Tubular	Lattice	Tubular
Rotor velocity (rpm)	43	51	72	46
Speed (m/s)	4-28	4-25	5-20	5-25
Number	16	50	150	34

PESUR wind farm is situated in the Dehesa de los Zorrillos, on hills with peaks (250 m a.s.l maximum) (Fig. 2). It contained 190 wind turbines with three different designs, and all rotors were orientated leeward to the wind (Table 1). The AWP models made up a 'wind wall' configuration (Orloff & Flannery 1992) consisting of wind turbines closely aligned to each other but with alternating tower heights.

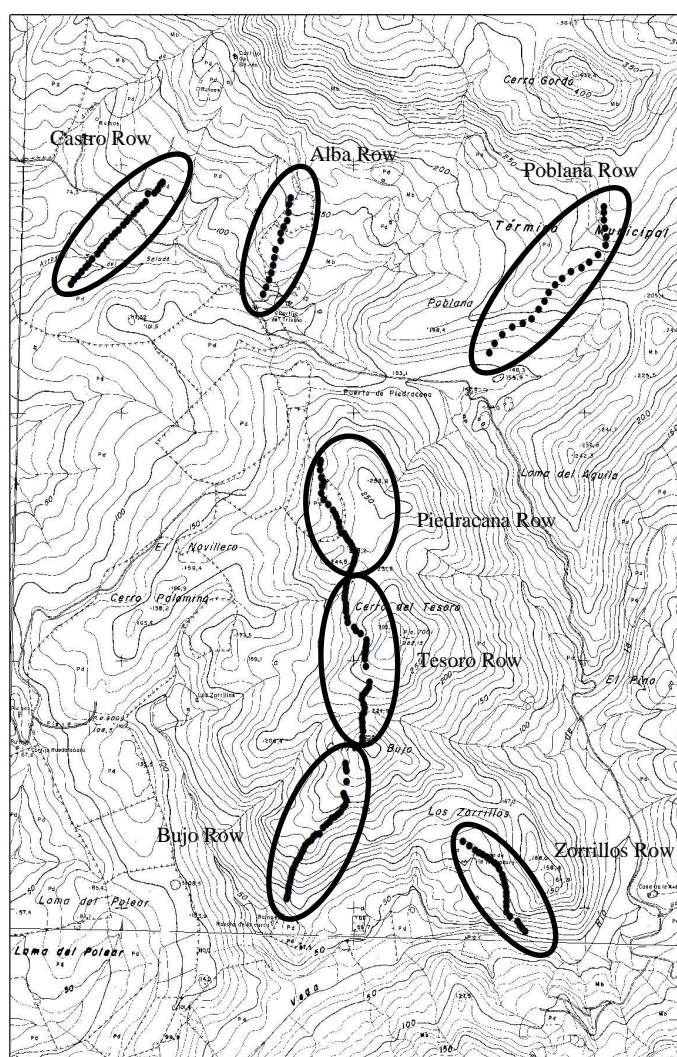


Figure 2. PESUR wind farm map (scale 1/10,000).

Cliff-nesting species such as griffon vultures *Gyps fulvus*, common kestrels *Falco tinnunculus*, Bonelli's eagles *Hieraaetus fasciatus*, peregrine falcons *Falco peregrinus*, eagle owls *Bubo bubo*, as well as a species forestall short-toed eagle *Circaetus gallicus*, are characteristic breeding or resident birds of prey in the study area with Bonelli's eagle and peregrine falcon classed as endangered in Spain (Madroño, González & Atienza 2004). Besides supporting an important breeding and resident bird community, the Strait of Gibraltar is one of the most important migration routes of Palearctic birds (Bernis 1980; Finlayson 1992; Bildstein & Zalles 2000), and during migration thousands of soaring species pass through the study area, including an abundance of honey buzzards *Pernis apivorus*, booted eagles *Hieraaetus pennatus*, black kites *Milvus migrans*, white storks *Ciconia ciconia*, and short-toed eagles.

Field methods and analytical approach

We used avian fatality data collected between November 1993 and June 2003 (116 months, 9.67 years) by the Department of Cadiz of the Andalusian Environmental Ministry in the wind resource areas, comprising records of dead birds collected mainly during specific studies and by maintenance personnel of the farms. The searches for collision victims were thus not standardised during the study period. However, nearly all data on dead birds were recorded on a standard data sheet, on which date, species, turbine identity, etc, was annotated. From our previous experience and other evidence (Barrios & Rodríguez 2004), we assumed that all dead birds of the size of black kite or larger were found. Large birds of non-raptor species were not found dead. Griffon vulture appears to be the principal species affected by collision at Spanish wind farms (e.g. Barrios & Rodríguez 2004, Lekuona & Ursúa 2007), and so our studies were especially focused on this species.

To determine the abundance and composition of the local bird community, bird observation surveys were conducted during four periods of the year: pre-breeding (from mid-January to mid-April), breeding (from mid-April to mid-July), post-breeding (from mid-July to mid-October) and winter (from mid-October to mid-January) (EEE, 2000-2001 and PESUR 2000-2002). In EEE birds counts were made over 150 h, and in PESUR windfarm over 250 h. Observations were done from fixed points within 200 m of turbines at a time and during each survey the number of each species of bird that crossed the turbine rows (within 250 m of a turbine) was recorded. Relative bird abundance was weighted per season when count efforts were not equal across seasons. Therefore, bird abundance was first averaged per season and the mean values were used to calculate the relative abundance of each species during a year.

We used the distance D , defined as 2.5 times the turbine rotor diameter, between a turbine to the nearest other turbine, to distinguish between different rows within each wind farm (if a turbine was $> D$ away from its neighbour it was classed as being in a different row or 'string'). D is the optimal distance to maximise wind energy capture as utilised by wind energy developers and computational research (Grady, Hussaini & Abdullah 2005). On this basis two different turbine rows were distinguished in EEE (called North and South), whereas PESUR consisted of seven rows, called Castro (26 turbines), Alba (14 turbines), Poblana (21 turbines), Piedracana (30 turbines), Tesoro (33

turbines), Bujo (42 turbines) and Zorrillos (24 turbines). All rows were orientated north to south but Zorrillos row was orientated northwest to southeast.

Failure time analysis measures the length of time from an arbitrary starting point until the first observed 'event' and compares the distributions of the lengths of time for each event occurrence (Muenchow 1986): in our analysis an event was the collision of a bird in a wind farm. Failure time analysis accommodates "censored" data. Censored data points are those in which an event was not observed, perhaps because the study ended before the event happened. For these censored data points, the actual time of event occurrence is thus not known, but failure time analysis allows use of censored data, such as those turbines with no recorded fatalities, for their partial information (Muenchow 1986). We also used bird fatality events to assess the factors associated with collisions, so that survival time in failure time analysis was calculated as the time taken for a bird collision (event) to occur.

Several authors have proposed that features of turbine design or their location may increase the risk of collision (e.g. Orloff & Flannery 1992, 1993, Hunt 2002, Percival 2003, Smallwood & Thelander 2004). In order to examine such potential effects on bird mortality, therefore, several variables concerning turbines were recorded: (1) tower design (tubular or lattice steel tower), (2) turbine hub height, (3) row, and (4) turbine position within the row (end or mid row). The elevation above sea level of each turbine was also recorded from topographic maps of the study area.

Statistical methods

Analysis of Chi-Squared (goodness of fit) tests were used to compare bird mortality (number of fatalities) between different rows of the wind farms. We used non-parametric statistics for those variables that did not fit a normal distribution. Kruskal-Wallis Test was used to compare number of fatalities between years and seasons. When statistical differences appeared, *post hoc* comparisons were made with Mann-Whitney *U*-Test.

A proportional hazard (Cox) regression for censored data was conducted to analyse the effect of turbine characteristics (height, tower model, elevation above sea level, row identity, and position within the row) and avian species (griffon vulture or others) on bird collision, stratified by the two types of turbine (lattice and tubular).

Statistica 6.0 and SPSS 13 software statistical packages were used to perform all statistical procedures and we used an alpha value of $p = 0.05$ to assess significance of results.

Results

Bird mortality

In the EEE wind farm a total of 26 dead birds of four raptor species were found during the study period (9.67 years) (Table 2). The raptor mortality rate in the wind farm (n° dead birds / year) was 2.69, and by turbine per year was 0.040. Griffon vulture mortality rate was 0.031 dead birds / turbine / year.

Table 2. Number and species of dead birds in EEE windfarm during the study period (9.67 years), species mortality rates (n° dead birds /turbine/year) and species relative abundance.

Species	N° dead birds	EEE windfarm	
		Mortality rate	Relative abundance
<i>Gyps fulvus</i>	20	0.0313	89.7297
<i>Circaetus gallicus</i>	3	0.0047	0.8108
<i>Bubo bubo</i>	2	0.0031	0.0000
<i>Neophron percnopterus</i>	1	0.0016	1.0811
<i>Falco tinnunculus</i>	0	0.0000	3.7838
<i>Milvus migrans</i>	0	0.0000	3.7838
<i>Hieraaetus pennatus</i>	0	0.0000	0.8108
<i>Ciconia ciconia</i>	0	0.0000	0.0000
TOTAL	26	0.0407	100

In the PESUR windfarm a total of 125 dead birds from eight raptor species were recorded across the study period (9.67 years) (Table 3). The raptor mortality rate in the wind farm (n° dead birds / year) was 12.93, and by turbine per year was 0.068. Griffon vulture mortality rate was 0.0495 dead birds / turbine / year.

Table 3. Number and species of dead birds in PESUR windfarm during the study period (9.67 years), species mortality rates (n° dead birds /turbine/year) and species relative abundance.

Species	N° dead birds	PESUR windfarm	
		Mortality rate	Relative abundance
<i>Gyps fulvus</i>	91	0.0495	55.0847
<i>Circaetus gallicus</i>	4	0.0022	4.7669
<i>Bubo bubo</i>	5	0.0027	0.0000
<i>Neophron percnopterus</i>	0	0.0000	0.6356
<i>Falco tinnunculus</i>	19	0.0103	3.3898
<i>Falco naumanni</i>	3	0.0016	0.0000
<i>Pernis apivorus</i>	1	0.0005	8.4746
<i>Hieraaetus pennatus</i>	1	0.0005	2.2246
<i>Milvus migrans</i>	1	0.0005	14.7246
<i>Ciconia ciconia</i>	0	0.0000	10.5932
TOTAL	125	0.0680	100

No statistical differences in bird mortality between the two wind farms across the study period were detected for all raptor species (Mann-Whitney Test, $Z = -1.650$, $p = 0.099$) or for griffon vulture only (Mann-Whitney Test, $Z = -1.043$, $p = 0.297$). Hence, mortality data from EEE and PESUR were combined in subsequent analyses.

Statistical differences in bird mortality between seasons were detected (Kruskal-Wallis Test, $X^2 = 33.668$, $df = 3$, $p < 0.001$) as a result of more dead birds in winter than in other periods (Mann-Whitney Tests: vs. pre-breeding, $Z = -3.586$, $p < 0.001$; vs. breeding, $Z = -5.439$, $p < 0.001$, vs. post-breeding, $Z = -2.694$, $p = 0.007$) (Fig. 3). Statistical differences in griffon vulture mortality between seasons were also detected (Kruskal-Wallis Test, $X^2 = 34.272$, $df = 3$, $p < 0.001$), as a result of more dead vultures in winter than in other periods (Mann-Whitney Tests: vs. pre-breeding, $Z = -3.088$, $p = 0.002$; vs. breeding, $Z = -5.046$, $p < 0.001$; vs. post-breeding, $Z = -4.019$, $p < 0.001$) (Fig. 3).

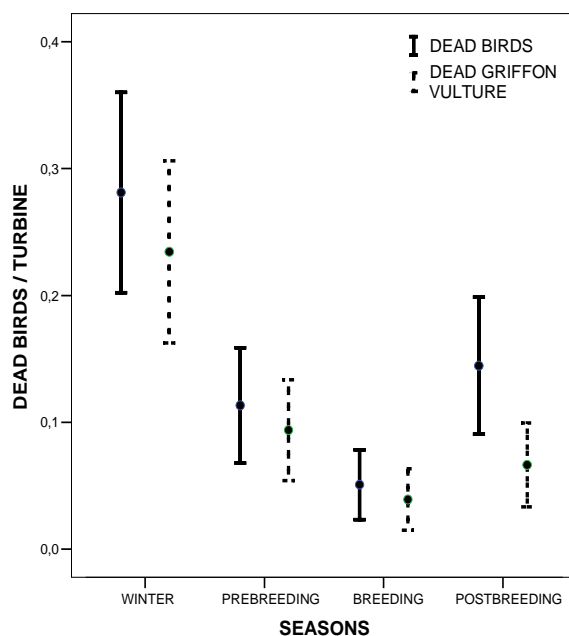


Figure 3. Mean (\pm standard error bars) number of dead birds per turbine and dead griffon vultures per turbine according to season.

Bird abundance

A total 1,314 birds crossed the two wind farms during the observation periods (Table 4). Significant differences were detected in number of birds recorded between seasons (Kruskal-Wallis Test, $X^2 = 75.981$, $df = 3$, $p < 0.001$) due to a higher abundance pre-breeding than in other periods (Mann-Whitney Tests: vs. breeding, $Z = -7.147$, $p < 0.001$; vs. post-breeding, $Z = -6.131$, $p < 0.001$; vs. winter, $Z = -6.726$, $p < 0.001$). Probably as a result of being the dominant bird species recorded within 250 m of turbines, the same significant differences were also detected in griffon vulture abundance between seasons (Kruskal-Wallis Test, $X^2 = 61.108$, $df = 3$, $p < 0.001$), again due to a higher abundance pre-

breeding than in other periods (Mann-Whitney Tests: vs. breeding, $Z = -6.916$, $p < 0.001$; vs. post-breeding, $Z = -4.569$, $p < 0.001$; vs. winter, $Z = -5.609$, $p < 0.001$).

Table 4. Abundance (number of birds/hour) of birds recorded in the two wind farms.

Season	EEE Windfarm		PESUR Windfarm	
	Bird abundance	Griffon vulture abundance	Bird abundance	Griffon vulture abundance
Winter	0.43	0.43	2.28	1.30
Pre-breeding	6.52	5.67	8.06	3.99
Breeding	0.67	0.56	1.88	0.42
Post-breeding	3.45	3.27	2.38	1.30
OVERALL	2.61	2.34	3.78	2.08

Spatial mortality distribution

EEE windfarm

No significant differences were detected between the two rows of the wind farm for all raptor mortality (Chi-Squared goodness of fit Test, $X^2 = 0.023$, $df = 1$, $p = 0.877$) or for griffon vulture mortality (Chi-Squared goodness of fit Test, $X^2 = 0.018$, $df = 1$, $p = 0.892$).

PESUR windfarm

A significant difference was detected when we compared mortality between seven rows of the wind farm (Chi-Squared goodness of fit Test, $X^2 = 17.867$, $df = 6$, $p = 0.006$). Significant differences in griffon vulture mortality between rows were also apparent (Chi-Squared goodness of fit Test, $X^2 = 23.866$, $df = 6$, $p < 0.001$).

The significant differences in bird mortality between rows (Kruskal-Wallis Test, $X^2 = 13.208$, $df = 6$, $p = 0.040$) was largely due to most dead birds being detected in Piedracana (Mann-Whitney rank = 113.02) and Tesoro rows (Mann-Whitney rank = 108.55).

A stratified proportional hazard (Cox) regression for censored data was conducted to analyse the effect of turbine characteristics on bird collision. The model ($n = 231$, uncensored data 53.25%, log-likelihood of final solution = -512.236, null model = -577.539, $X^2 = 130.605$, $df = 5$, $p < 0.001$) included species ($B = 2.23$, $p < 0.001$, with griffon vulture the most likely to collide), turbine height ($B = 0.420$, $p = 0.039$) and elevation above sea level ($B = 0.005$, $p = 0.011$). The taller the turbines were and the higher their elevation above sea level, the lower time to a bird collision event.

Discussion

To date, several avian mortality rates have been presented for wind farms around the world (Winkelman 1990; Orloff and Flannery 1993; Musters, Noordervliet et al. 1996; Howell 1997; Dirksen, Winden et al. 1998; Morrison, Pollack et al. 1998; Osborn, Higgins et al. 2000; Erickson, Johnson et al. 2002; Johnson, Erickson et al. 2002; Thelander, Smallwood et al. 2003; Barrios and Rodríguez 2004; Arnett 2005; Dorin, Spiegel et al. 2005). Like the majority of studies (Erickson, Johnson et al. 2001; Percival 2003; Drewitt and Langston 2006), our mortality rates per turbine were relatively low. However, no long runs of data have been considered before and, to our knowledge, our study is the first to analyse long-term samples of bird mortality. Although not a formal component of our analyses we found no indication of a change in mortality rates across the study period, suggesting that there were no long-term temporal changes in birds' reactions to the wind farms (e.g. habituation) (see also Stewart et al. 2004, Hötter et al. 2006). Our estimates of mortality rates for EEE wind farm, gathered over 10 years, were very similar to those of Barrios & Rodríguez (2004) gathered over one year, but were lower for PESUR wind farm; perhaps an indication that in at least some situations long-term sampling may be required to derive reliable mortality estimates (see also Smallwood and Thelander 2004).

Griffon vulture mortality rates were 1.6 times higher at PESUR than at EEE; similar the North and South rows were detected over a shorter time period by Barrios and Rodríguez (2004). The different topography between the wind farms (see Figures 1 & 2) could explain the mortality difference: PESUR is a long windfarm situated on gentle and short slopes, while EEE windfarm is on the crests of steep-sided mountain ridges. Differences in mortality rates between PESUR rows also support this contention since the two rows with the highest mortality (Piedracana and Tesoro) were on the gentlest slopes within PESUR. Different vulture flight behaviour resulting from an interaction between topography and wind conditions could therefore be implicated (Barrios and Rodríguez 2004).

High wing loading is associated with low manoeuvrability in flight and a low capability for powered flight {Tucker, 1971 #91}, and is typical of some soaring birds like griffon vultures, and has also been noted by other authors as elevating risk of collision (Pennycuik 1975; Janss 2000). Updrafts from the gentle slopes surrounding PESUR (especially Piedracana and Tesoro rows) could be used in cross-country soaring flight by griffon vultures (Pennycuik 1998) but these will be much weaker than those generated by the steeper slopes of EEE. Being heavily reliant on wind conditions, rather than powered flight, griffin vultures may therefore be unable to fly above the turbines if wind conditions do not provide sufficient lift. We should expect, therefore, that as well as mortality being greater at PESUR than EEE (and at 'gentle slope rows' within PESUR) collision should also be most likely when winds are light, in winter (when thermal updrafts as additional sources of lift are less common) and at taller turbines at higher elevations (all else being equal, more lift is required to fly over a taller turbine at a higher elevation). These expectations were confirmed by our study and by Barrios and Rodríguez (2004) who recorded more griffin vulture deaths when winds were light (< 8 m/s). Therefore wind turbines situated on the top of hills with gentle slopes were probably more dangerous to griffin

vultures because wind conditions here were less likely to lift vultures above the turbines and the poor powered flight ability of vultures made collision avoidance more difficult.

Bird mortality and bird abundance varied markedly between seasons. Although numbers of dead birds, and especially dead griffon vultures, were higher during winter, bird abundance, and especially griffon vulture abundance, was higher during pre-breeding season. This is not consistent with the proposal of Barrios and Rodriguez (2004) that bird mortality increases with bird density (although Barrios and Rodriguez (2004) also note that vulture abundance did not explain the mortality differences between EEE and PESUR). A similar absence of a relationship between collision mortality and abundance has also been found by Fernley et al. (2006) and Whitfield and Madders (2006). It is frequently assumed that collision mortality should increase with bird abundance (since more birds are 'available' to collide) (e.g. Langston and Pullan 2003; Smallwood and Thelander 2004) but our study adds to mounting evidence that such an assumption may be too simplistic. This has important implications when attempting to predict the impacts of wind farm proposals. For example, a direct positive relationship between mortality and abundance is an implicit foundation of predictive collision risk models (CRMs) (e.g. Band et al. 2007) and so if this foundation is unrealistic the utility of CRMs as predictive tools is severely weakened.

In contrast we suggest that others factors, related to species-specific flight behaviour, weather and topography around the wind farm, might be more important in explaining differences in mortality rates. The different vulnerability of species to collision with turbines is well known (Orloff and Flannery 1993; Barrios and Rodriguez 2004; Drewitt and Langston 2006) and we found that griffon vulture was the most frequently killed species but at PESUR the contribution of griffin deaths to overall mortality was disproportionately higher than the relative abundance of griffins. Species-specific flight behaviours have been related to different mortality rates of different species inhabiting the same area in other studies (Orloff and Flannery 1993; Thelander, Smallwood et al. 2003; Drewitt and Langston 2006). Morphology and flight biomechanics of species are considered important factors for understanding collision with power lines (Janss 2000) and it is likely that similar factors influence collision with wind turbine blades.

Failure time analyses are not commonly used with ecological data (Muenchow 1986; Pyke and Thompson 1986) but the incorporation of censored data in failure time analysis adds more information when addressing ecological questions. Our failure time analysis model enabled us to assess the influence of different factors on the time for a bird collision to occur. Bird collision probabilities depended on species, turbine height and the ability of birds to pass above turbines. The effect of turbine height was probably related to the greater difficulty that taller turbines imposed on griffin vultures' ability to fly above the rotor blades in some circumstances. Lattice towers have been considered more dangerous to raptors (e.g. Orloff and Flannery 1992, 1993; although see Smallwood and Thelander 2004) but we found no evidence to support this supposition. The effect of a turbine's position in a row on collision has also been the subject of several investigations (e.g. Smallwood and Thelander 2004) but we found that this factor was not influential at Tarifa.

Thus it can be difficult to generalise on mitigating measures to minimise collision with wind turbines. However, repowering of older wind farms, such as those at Tarifa, could provide an opportunity to study such mitigation measures. Reducing turbine number may decrease rates of bird mortality but because the collision problem will not be eliminated (Janss 2000), we suggest that understanding the mechanisms involved in influencing collision risk, especially the interaction between bird flight behaviour, topography and weather, is essential for dealing with it effectively.

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Capítulo 4

Comparison between simulated wind currents and flight trajectories of the griffon vulture with possible application for reducing avian mortality in wind farms

Resumen

El aumento que han experimentado los parques eólicos durante los últimos 15 años ha sido espectacular. La mortalidad de aves debido a colisiones con las palas de los aerogeneradores es conocida como uno de los principales impactos adversos de los parques eólicos. En España, el buitre leonado es la especie con mayor índice de mortalidad en parques eólicos. Hasta donde nosotros conocemos, este estudio es el primero en predecir las trayectorias de vuelo con objeto de prever las áreas potencialmente conflictivas para el desarrollo eólico. Las simulaciones de las trayectorias del viento realizadas en un túnel de viento, fueron comparadas con las trayectorias de vuelo de los buitres leonados observados en el campo. No se detectaron diferencias estadísticas, lo que sugiere que los buitres leonados se mueven por las corrientes de viento predominantes en el área (es decir, siguen las rutas donde necesita menos esfuerzo para el vuelo). Sugerimos usar este tipo de simulaciones para predecir las trayectorias de vuelo y evitar la construcción de los parques eólicos en su proximidad con el fin de reducir la mortalidad de aves planeadoras.

Palabras clave: parques eólicos, buitres leonados, canales de vuelo, corrientes de viento, túnel de viento, simulaciones.

Abstract

Wind farms have shown a spectacular growth during the last 15 years. Avian mortality through collision with moving rotor blades is well-known as one of the main adverse impacts of wind farms. In Spain, the griffon vulture shows the highest mortality rates in wind farms. As far as we know, this study is the first attempt to predict flight trajectories in order to foresee potentially conflictive areas for wind farm development. Simulations of wind current trajectories in a wind tunnel were compared with observed flight paths of griffon vultures. No statistical differences were detected suggesting that griffon vulture were moved by predominant wind currents in the area (i.e. they followed the routes where less flight effort was needed). We suggest using this kind of simulations to predict flight paths and avoid the construction of wind farms in their proximity in order to reduce soaring bird mortality.

Keywords: wind farm, griffon vulture, flight paths, wind currents, wind tunnel, simulations.

Introduction

An increase in the numbers of wind farms in the world is currently in progress (Drewitt and Langston 2006). The last 15 years, Spain has become an important market for large scale development of wind power. Spain has the second largest wind resources in the world, with a production capacity of 10,027 MW (www.ewea.org). Wind energy technology has known a major enlargement since the first prototypes were installed just 25 years ago. Over two decades of technological progress have resulted in today's wind turbines being state-of-the-art modern equipment – modular and rapid to install, as well as a profitable industry. A single wind turbine can produce 200 times more electricity than its equivalent two decades ago (EWEA and Greenpeace 2005). The unprecedented rate and scale of growth of wind farms also have increased the environmental impacts on wildlife.

Large number of avian fatalities have been documented at some older wind power developments (e.g. Altamont Pass), but relatively small numbers of avian fatalities at many modern wind power developments (Erickson et al. 2001). Today we still have a high level of uncertainty when predicting the number of potential avian fatalities in future wind power developments (Mabee et al. 2006). There is a degree of consensus that raptors may be more vulnerable to collision than several other bird groups (Hoover and Morrison, 2005, Madders and Whitfield, 2006), suggesting that their specific flight behaviour may contribute to turbine-related fatalities (Orloff and Flannery, 1992, Barrios and Rodríguez, 2004, Hoover and Morrison, 2005). Of the raptor species inhabiting the Spanish windfarm areas, the griffon vulture shows the highest mortality rates in wind farms (Barrios and Rodríguez, 2004, de Lucas et al. submit.). Between 1993 and 2003 we recorded 151 collisions in two wind farms located in Tarifa (South of Spain), 73% (111) of which were griffon vultures (de Lucas et al. submit.).

Griffon vulture morphology is adapted for soaring flight, and they depend on wind currents for major movements. Relief and related terrain features, change the horizontal and vertical air movements which give important support to soaring flight movements. Nevertheless, the influence of wind currents in large raptors local movements have been rarely considered previously (McLeod et al., 2002). The overall premise is that raptor's movements through the landscape are analogous to wind currents. Air flows tend to channel along connected pathways of high conductivity (i.e., the path of least resistance). Similarly, soaring birds use pathways where the lowest effort is needed, taking advantage of thermals, ridge updrafts, and other sources of lift.

We tested the null hypothesis that griffon vultures followed dominant wind currents by their local movements through a wind farm area in Tarifa (Cadiz, Spain). We used a three-dimensional model of a contour map of the area in a wind tunnel to determine where wind currents concentrated and compared these wind passages with the flight routes used by griffon vulture according to field observations.

Material and methods

Study area

PESUR wind farm was located in Tarifa, Andalusia region, south of Spain in the proximity of the Strait of Gibraltar. The Strait of Gibraltar is one of the most important migrating routes of the Palearctic birds (Bernis 1980; Finlayson 1992; Bildstein and Zalles 2000). This area was the pioneer region installing turbines concerning the municipality of Tarifa in Spain. The Strait of Gibraltar is included among the four areas in Spain with the greatest potential for producing wind energy (IDAE 1996).

Cliff-breeding species such as griffon vultures *Gyps fulvus*, common kestrels *Falco tinnunculus*, Bonelli's eagles *Hieraetus fasciatus*, peregrine falcons *Falco peregrinus* and eagle owl *Bubo bubo* are dominant in this area, as well as some tree-breeding species as short-toed eagle *Circaetus gallicus*, concerning not endangered in Spain, except for the Bonelli's eagle and peregrine falcon (Madroño et al., 2004). Beside an important breeding community, during migration periods thousands of honey buzzards *Pernis apivorus*, black kites *Milvus migrans*, white storks *Ciconia ciconia*, booted eagles *Hieraetus pennatus* and short-toed eagles pass through this area, only mentioning the most abundant soaring species.

PESUR wind farm is situated in the Dehesa de los Zorrillos, on hills with peaks of 250 m a.s.l maximum (Figure 1). It contains 190 wind turbines with three different designs: AE-20 MADE (21 m tall tubular steel tower and 20 m in diameter rotor), AWP 56/100 (36 m tall lattice steel tower and 18 m in diameter rotor) and AWP 56/100 (18 m tall lattice steel tower and 10 m in diameter rotor). All rotors are orientated leeward and have three rotor blades. These AWP models made up a wind wall configuration consisting of wind turbines closely aligned to each other with alternating tower heights (Orloff and Flannery, 1992).

The vegetation in the study areas was characterised by brushwood and scattered trees (*Quercus suber*, *Q. rotundifolia*) on the mountain ridges, predominating pasture land used for cattle grazing in the lower areas.

Field methods

The study was carried out through four months (August, September, October and November) in 2002. Every second week of the month, observations were conducted of griffon vultures passing through the wind farm area, recording variables related to flight behaviour.

We selected a fixed observation point in the wind farm. A valley orientated from East to West, with two ridges orientated from North to South were observed. A wind wall configuration turbine string along the ridges was perpendicular to the valley (Figure 1) in such a way that prevailing Eastern and Western winds were optimised by the turbines.

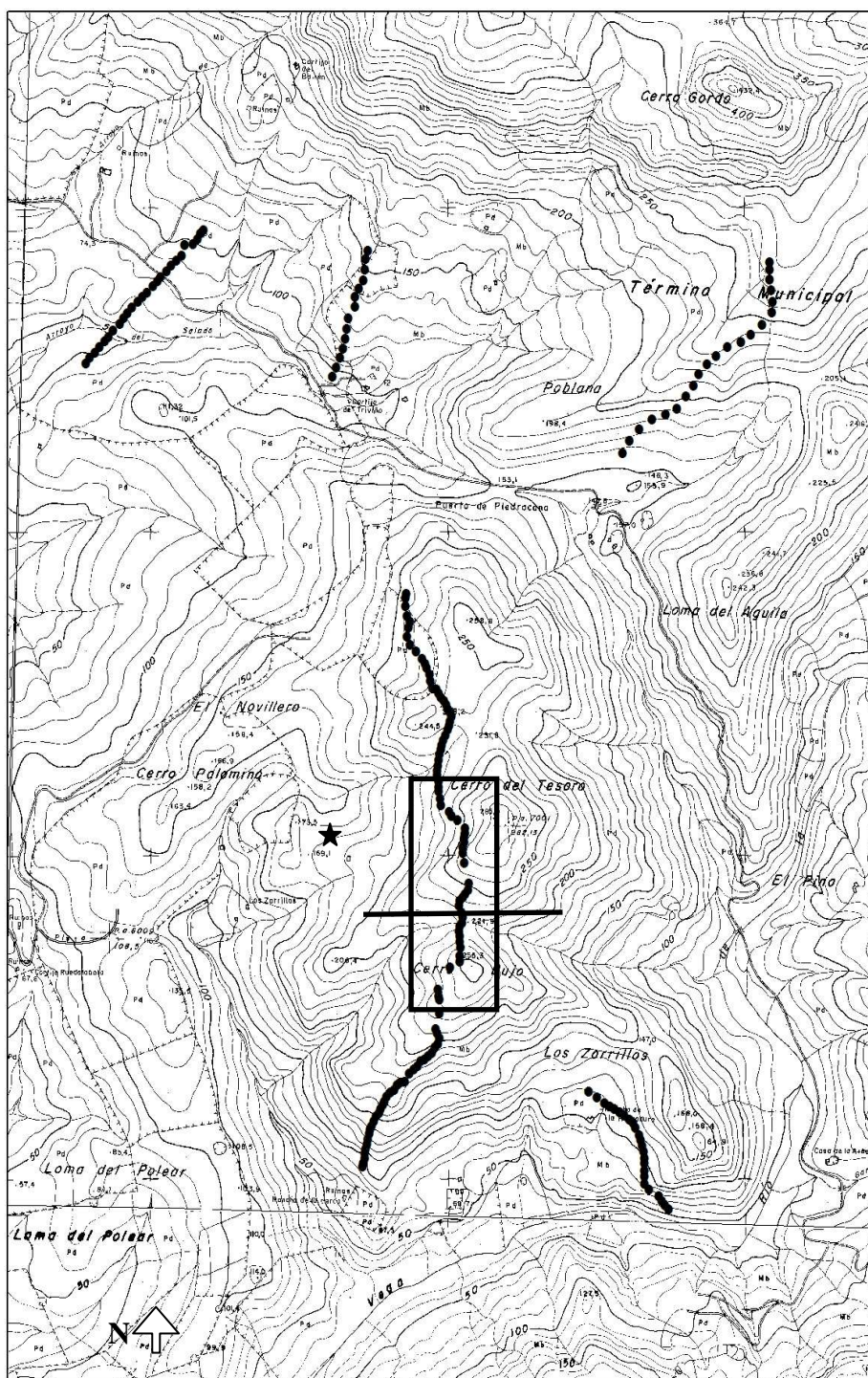


Figure 1. PESUR wind farm map, where the area of scaled model and the observation point were indicated. The valley was indicated by an straight line.

Flight behaviour in the proximity of wind turbines (200 meters height max. and 300 meters width max.) was recorded by direct observation and by video cameras from the fixed point. For each observation of an individual or groups, we recorded number of birds, climatic conditions (wind velocity and wind direction), flight direction and activity of the turbines. The flight trajectories were drawn in a map of our study area with an external 62.5x62.5 km grid, which permitted us to standardize and quantify the points where the vultures left our study area.

Aerodynamic model

An aerodynamic experiment was carried out at the Highest Technical School of Aeronautical Engineers of University of Madrid in a wind tunnel with a closed experiment camera and open fluid circuit. The wind tunnel used an aspirated flow. Video camera, located on the top, was connected to a monitor to permit the recording of the experiment.

A wood and scaled model (1/1,250) of the wind farm area was constructed with level curves each 12.5 m (1 cm in the model) (Figure 2) and introduced in the wind tunnel. Wool plumes were distributed regularly over the model to visualize wind currents and provide quantifiable data. Wind flows of three different directions were created over the model (Southern, Southeaster, and Eastern).

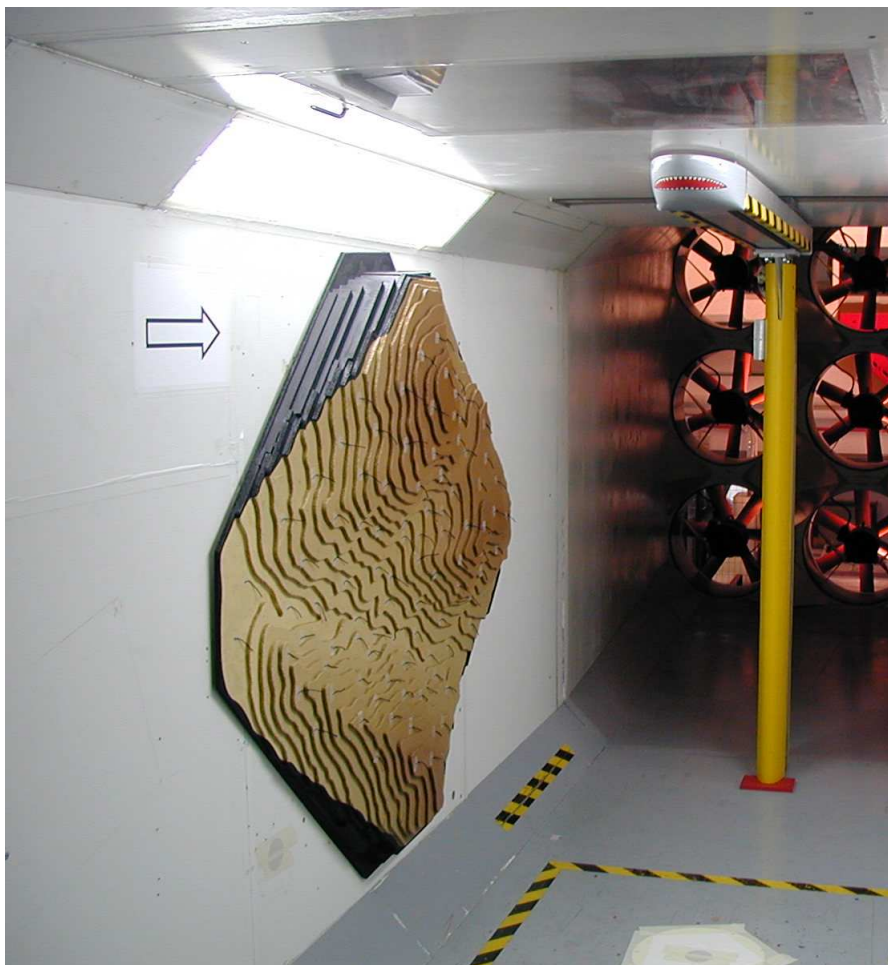


Figure 2. Scaled model inside the wind tunnel. Level curves and wood plumes can be observed.

The main wind passages in the scaled model were defined by observing the movement of the wool plumes. Arrows were drawn over the map to indicate the main wind currents observed. We added the same external grid we used to define the flight routes of the vultures (5 x 5 cm; Figure 3) to the model and counted the number of arrow ends from the main wind passages in each cell to quantify the wind currents (none, one or two), i.e. where the wind currents left our study area according to the model.

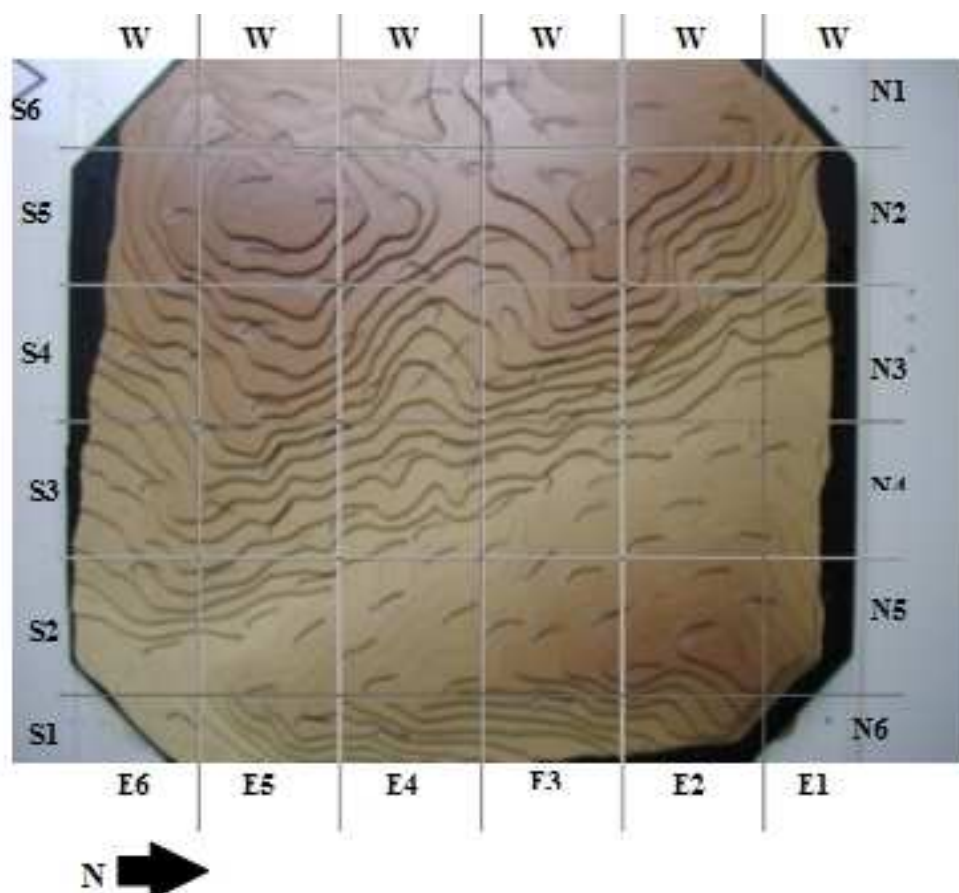


Figure 3. Scaled model with the wood plumes and external grid. The study cells were used to define the points of departure of vultures and of wind currents from the study area.

Statistical methods

Chi-Squared (goodness of fit) tests were used to compare the observed presence of vultures in each cell with (1) an expected ad random presence (no preferred flight routes existed) and (2) an expected presence according to the moving wool plumes (flight routes coincided with wind passages).

Statistica 6.0 software statistical package was used to perform statistical procedures and we used an alpha value of $p = 0.05$ to assess significance of results.

Results

A total of 764 griffon vultures during 176 hours of observations were recorded. A total of 486 griffon vultures were observed in 10 days with Eastern wind (Table 1). A total of 63 griffon vultures were observed in four days with Southern wind and a total of 57 griffon vultures were observed in four days with Southeaster winds.

Table 1. Total field observations

2002	Eastern		Southeast		Southern		TOTAL	
	N° days	N° birds	N° days	N° birds	N° days	N° birds	Days	Birds
August	3	206	1	11	2	25	6	242
September	2	28	2	29	1	14	6	74
October	2	59	1	17	1	24	5	110
November	3	193	0	0	0	0	5	338
TOTAL	10	486	4	57	4	63	22	764

Different wind currents for each studied wind direction in the aerodynamic model were observed. Five wind passages with Southern wind, six wind passages with southeaster wind and five wind passages with Eastern wind were detected by studying the wool plume's movements (Figure 4).

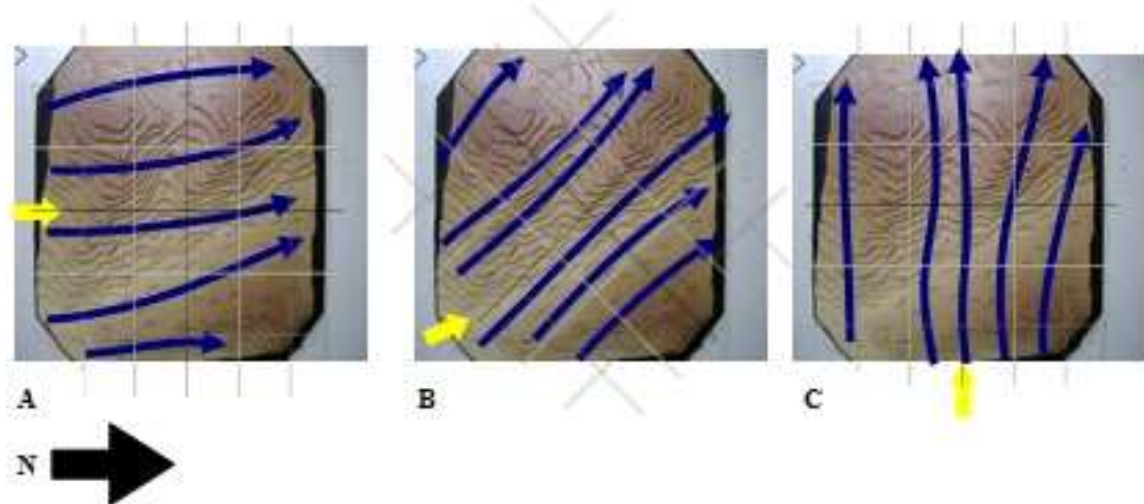


Figure 4. The three aerodynamic simulations done in the wind tunnel. The wind passages detected are indicated with blue lines. Yellow arrow indicated the simulated wind direction: A Southern wind, B Southeaster wind and C Eastern wind.

With Southern wind, significant differences were detected between expected and observed flight directions ($X^2 = 42.873$, $df = 9$, $p < 0.0001$), assuming an ad random presence in all cells. When we used the flight directions from wind tunnel model to calculate the expected values, no statistical differences were detected ($X^2 = 4.682$, $df = 9$, $p = 0.861$; Table 2).

Table 2. Number of griffon vultures flying during field observations with southern winds and relative presence of wind currents observed in the aerodynamic model. We indicate the cells where vultures left the study area.

Cells	Field observation	Relative aerodynamic model
W4	0	0
W5	2	0
W6/N1	15	20
N2	7	20
N3	12	20
N4	8	20
N5	1	0
N6/E1	6	0
E2	0	0
E3	12	20
TOTAL	63	100

With Southeaster wind, significant differences were detected between expected and observed flight directions ($X^2 = 79.466$, $df = 10$, $p < 0.0001$), assuming an ad random presence in all cells. When we used the flight directions from wind tunnel model to calculate the expected values, no statistical differences were detected ($X^2 = 8.368$, $df = 10$, $p = 0.593$; Table 3).

Table 3. Number of griffon vultures flying during field observations with southeaster winds and relative presence of wind currents observed in the aerodynamic model. We indicate the cells where vultures left the study area.

Cell	Field Observation	Relative aerodynamic model
S6/W1	4	0,00
W2	10	16,67
W3	0	0,00
W4	22	33,32
W5	0	0,00
W6/N1	6	0,00
N2	3	16,67
N3	5	16,67
N4	6	16,67
N5	0	0,00
N6/E1	1	0,00
TOTAL	57	100

With Eastern wind, significant differences were detected between expected and observed flight directions ($X^2 = 458.445$, $df = 9$, $p < 0.0001$), assuming an ad random presence in all cells. When we used the flight directions from wind tunnel model to calculate the expected values, no statistical differences were detected ($X^2 = 11.623$, $df = 9$, $p = 0.235$; Table 4).

Table 4. Number of griffon vultures flying during field observations with Eastern winds and relative presence of wind currents observed in the aerodynamic model. We indicate the cells where vultures left the study area.

Cell	Field observations	Relative aerodynamic model
S4	1	0
S5	5	0
S6/W1	1	0
W2	94	20
W3	120	20
W4	90	20
W5	95	20
W6/N1	0	0
N2	74	20
N3	6	0
TOTAL	486	100

Discussion

Several studies on wind farm impacts on birds published in the scientific literature are focused on fatality rates (Musters et al., 1996, Osborn et al., 2000, Johnson et al., 2002, Barrios and Rodríguez, 2004, de Lucas et al., submit.). However, to our knowledge, no data of flight trajectories have been considered before, and our study is the first to consider the flight behaviour to predict areas of greatest used for soaring birds. The observed flight trajectories of griffon vultures were similar to the wind passages observed in the aerodynamic model (i.e. the vultures left our study area at the same points where wind currents did), suggesting that griffon vultures use routes which require less energetically costly flight.

The location of a wind farm is one of the few certainties known to affect the impact of a wind energy scheme on birds (Madders and Whitfield, 2006). Therefore this aerodynamic model that attempt to predict areas of greatest use by soaring birds can be a useful tools for planning wind development, enabling to minimize the potential effects on soaring species. At a finer scale, these models can be used to evaluate the relative effects of individual turbines within particular locations. In our case study, with southern winds collision risk was lowest, observing flight passages parallel to the wind turbine rows.

The appropriate use of aerodynamic models at an early planning stage can help reduce the risk of collision with wind turbines for soaring birds. This will help to streamline the process of selecting

potential locations and reduce the uncertainty associated with wind farm development. On the other hand, the presence of soaring birds or their flight routes is not the only factor which should be taken into account when planning a wind farm construction. Therefore it is only a partial assessment of the adequacy of a location. The presence of not soaring birds and bats, as well as the information on potential concentration points of sensitive species (breeding colonies, foraging areas, etc.), are other crucial questions in this preliminary phase.

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Capítulo 5

Effects of a wind farm on a Montagu's Harrier *Circus pygargus* breeding population in the south of Spain

Resumen

Las molestias son uno de los impactos adversos de los parques eólicos. Estudiamos este efecto en una población nidificante de un ave rapaz (*Circus pygargus*). El diseño Antes/Después fue utilizado para testar la hipótesis nula de la no existencia de molestias por el parque eólico sobre una población nidificante de aguilucho cenizo. Se comparó la densidad de nidos, el número de huevos y la distancia desde los nidos a los aerogeneradores, a los caminos y el tendido eléctrico, entre los años de estudio. El uso de una función discriminante con variables del hábitat de nidificación, basada en las localizaciones de los nidos antes de la construcción, mostró que los nidos mantenían la clasificación como sitio de nidificación, lo que sugiere que el parque eólico no afecta a la calidad del hábitat. Ni la presencia de los aerogeneradores, ni de los caminos, parecen significar un problema para esta población. Sin embargo se detecta una mayor distancia al tendido eléctrico.

Palabras clave: parque eólico, *Circus pygargus*, Tarifa, molestias, diseño Antes/Después, hábitat.

Abstract

Disturbance effect is one of the adverse impacts of wind farms. We study this effect on a raptor breeding population (*Circus pygargus*). Before/After study design was used to test the null hypothesis of no disturbance of wind farm on a Montagu's Harrier breeding population. Nest density, number of eggs and distance from nests to turbines, unpaved roads and power line were compared between study years. A discriminate function of the breeding habitat based on the locations of the nests before the construction showed that these nests maintained their classifications as nest site suggesting that the wind farm did not affect the habitat quality. The presence of the turbines seemed not to be a significant problem for this population, nor did the presence of the roads. Yet a major distance to the power line was indicated.

Keywords: wind farm, *Circus pygargus*, Tarifa, disturbance effect, Before/After design, habitat.

Introduction

Disturbance is often implicated as having potentially damaging effects on wildlife (Hill et al., 1997, Drewitt, 2007). Animals respond to disturbance by avoiding areas of high risk, either completely or by using them for limited periods. West's model (2002) predicted that, for a given overall area disturbed, disturbance was more damaging if it arose from many small-scale sources rather than fewer, larger-scale sources. When the time and energy costs arising from disturbance were included, disturbance could be more damaging than permanent habitat loss (West and Caldw, 2006). In many cases disturbance acts in a more subtle way, by reducing access to resources such as food supplies or nesting sites (Gill et al., 1996)

The construction and operation of a wind farm may involve several features that could potentially displace birds from around the wind farm site (Percival, 2007). Any permanent disturbance effects from wind turbines would translate directly into habitat loss. Some studies concluded that disturbance to resting or foraging birds is the main impact of wind farms on birds, whereas collision is likely of minor concern (Guillemette and Larsen, 2002)

Disturbance can lead to displacement and exclusion from areas of suitable habitat, i.e. a quantitative loss of habitat for the birds. Disturbance potentially may arise from increased human activity in the vicinity of the wind farms, often in areas of little human activity before the construction of a wind farm. The presence/noise of turbines may also deter birds from using the area close to turbines (Langston and Pullan, 2003)

There are several reliable studies indicating negative effects up to 600 m from wind turbines, i.e. a reduction in use of, or absence from, the area close to the turbines, for several bird species (e.g. whooper swan *Cygnus cygnus*, pink-footed goose *Anser brachyrhynchus*, European white-fronted goose *A. albifrons*, Eurasian curlew *Numenius arquata*). In a large wind farm, even this relatively small exclusion around each turbine, may amount to a cumulative significant exclusion from the area, or a reduced use (Langston and Pullan, 2003).

Potential displacement of raptors from nest sites are far less common than those from foraging areas due to the low nesting density of breeding raptors (Newton, 1979). However Montagu's Harrier is a semi-colonial species and rarely pairs breed solitarily (Arroyo, 1995). We tested the null hypothesis of no effect of a wind farm on a Montagu's Harrier breeding population. Barros et al. (1995) studied the same population and provided data before the wind farm was built. We compared the (1) nest density and number of eggs, and (2) distance to the turbines locations, unpaved roads and power lines from the nests before (1995) and after (2002) the wind farm construction. The nest site classification by Barros et al. (1995), were used to classified the nest from 2002, using the discriminate function generated by these authors in order to verify if they are correctly classified as nest sites.

Materials and methods

The species

Montagu's Harrier *Circus pygargus* is a medium-sized migratory raptor. Birds breeding in Europe arrive from sub-Saharan Africa in early April. The species is considered monogamous although polygamy has occasionally been recorded (Arroyo, 1996). First breeding occurs generally in the third calendar year in females and in the fourth in male. Clutch size is typically 3 or 4 eggs (Cramp and Simmons, 1980). Mean productivity ranges from 1.40 to 2.75 fledglings per pair (Arroyo, 1995, Soutullo et al., 2006). Individuals generally hunt far from nests (Cramp and Simmons, 1980, Arroyo, 1995), and the main preys are insects, small passerines and mammals, and lizards (Cramp and Simmons 1980, Arroyo, 1997, Arroyo, 1998).

Across Europe, most population breed in crops, mainly in winter cereal fields (wheat and barley), sometimes rye-grass, alfalfa, or natural vegetation (Arroyo et al., 2002, García and Arroyo, 2005, Soutullo et al., 2006). In general, productivity is higher in natural habitats than in cereals. About 5,000 pairs breed in Spain, with 90% of them breeding in cereals. The conservation status for the species in the Iberian Peninsula, stronghold of Western Europe, is "vulnerable" (Madroño et al. 2004).

Study area

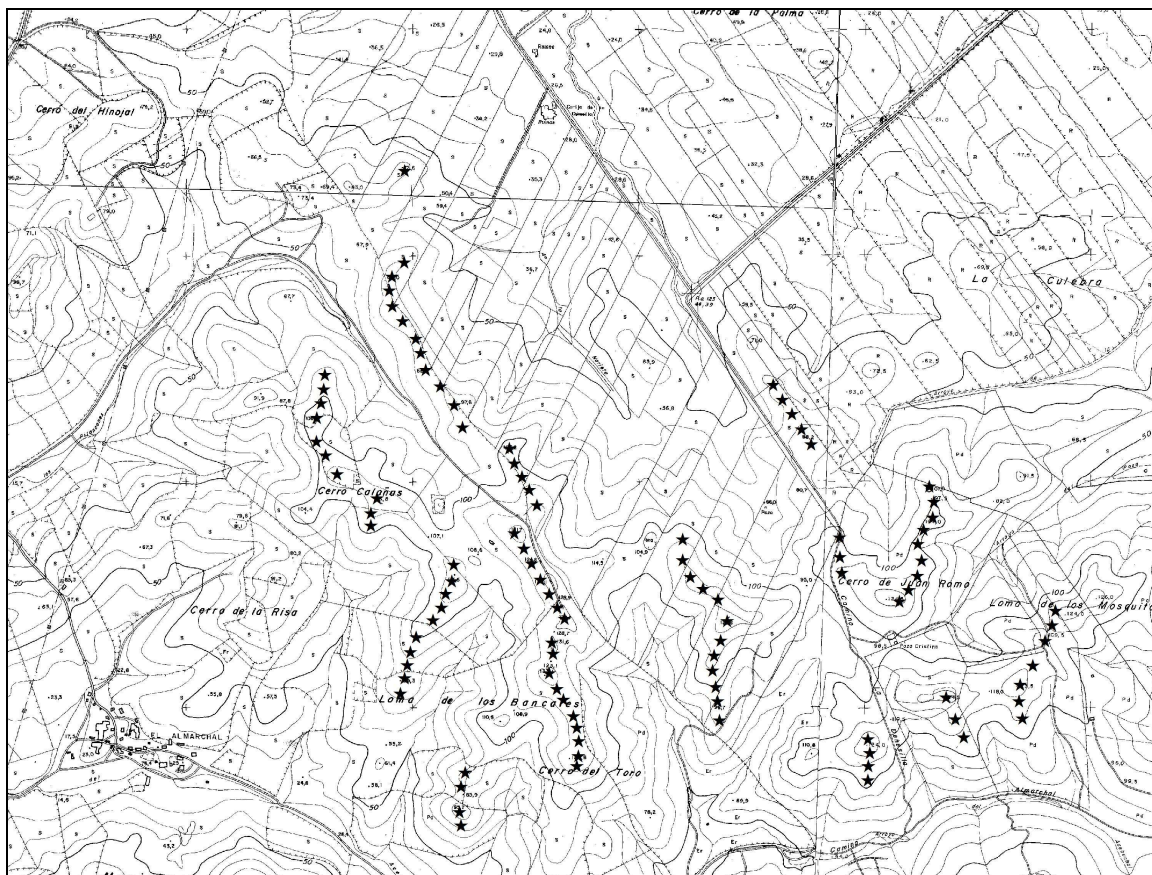
The study area covered some 125 km² and was located northwest from Tarifa (Cadiz, Andalusian region, south of Spain). It is located in a low land with an altitude of 20-120 m above sea level. In this area there is some small villages (Tahivilla, Almarchal, La Zarzuela and Zahara de los Atunes). Approximately 100 km² of the whole area was arable land, used mainly to cultivate cereal, beetroot and broad bean. The fields were bordered by fences and/or by unploughed between fields. Crops were cultivated on a biannual, rotational basis, so the general distribution of the crops was patchy, mixed with fallow land which was ploughed several times per year. In addition some small olive (*Olea europaea*), holm oak (*Quercus ilex*), and eucalyptus (*Eucalyptus globulus*) trees were found in this area. Cows pastured occasionally in some fields after crops were harvested.

The study wind farm, called Tahivilla Wind Farm, was located in Tahivilla, district of Tarifa. The wind farm is situated on mountain ridges with gentle slopes, which ranges in elevation from 30-120 m above sea level. The ridges were orientated from Northwest to Southeast. The wind farm consisted of 100 wind turbines AE-30 de 300 kW. This model has a 31 m tall tubular tower and its rotor is 30 m in diameter. Rotors are orientated windward, and have three blades. The wind turbines were located in several rows, on the mountain ridges. The Tahivilla Wind Farm was constructed in 1998 (Figure 1).

In this area, breeding species such as white storks *Ciconia ciconia*, griffon vultures *Gyps fulvus*, common kestrels *Falco tinnunculus*, Bonelli's eagles *Hieraaetus fasciatus*, peregrine falcons *Falco peregrinus*, Montagu's Harrier and short-toed eagles *Circaetus gallicus* can be found. Passerines were abundant in the study area, the most abundant of which were Stonechat *Saxicola torquata*,

Black-eared wheatear *Oenanthe hispanica*, Dartford warbler *Sylvia undata*, Blue rock thrush *Monticola solitarius*, Thekla lark *Galerida theklae*, and Wren *Troglodytes troglodytes*.

Figure 1. Study area with the Tahivilla Wind Farm (black stars).



Study design

The study was carried out between March and June 2002. In addition we used breeding data collected in 1995 by Barros et al. (1995). The same methodology was used in both.

All suitable areas for nesting in the study area were visited in the pre-laying period, in order to look for potential breeders. All areas were observed at least twice for periods of 2 hours. If no birds were seen during these periods, it was considered that those areas were not occupied, and observations were thereafter concentrated in areas with birds. In any case, 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 50 binoculars, and with a 30 x telescope, along several roads which crossed the study area. Nest position was located when the females brought in nest material. Every effort was made to minimise the marks left in the crops. Nest locations were plotted as precisely as possible (usually within 2-3 m) into the GIS.

The breeding territory was defined as the area around the nest site (50-150 m radius) where the females spend most of the time between pair formation and laying (Arroyo et al., 2002). A circumference of a 125 m radius around the nest from both study years was used to measure several habitat variables (Table 1), used in the discriminate model of habitat selection generated by Barrios et al. (1995).

Table 1. Habitat variables (with their abbreviations) taken around the nest site (150 m radius) and since the nest in 1995 and 2002.

Habitat variables	Abbreviation	
Cover	Wheat	COBTRIG
	Beetroot	COBREMOL
	Sunflower	COBGIRA
	Chickpea	COBGARB
	Broad bean	COBHAB
	Fallow land	COBBARB
	Hay	COBHENO
Distance	Wheat	DISTTRIG
	Beetroot	DISTREMOL
	Sunflower	DISTGIRA
	Chickpea	DISTGARB
	Broad bean	DISTHAB
	Fallow land	DISTBARB
	Hay	DISTHEN
	Nest	DISTNIDO
	Trees	DISTARB
	Villages	DISTPUEB
	Roads	DISTCARRET
	Paths	DISTCAMI
	Power lines	DISTTEND
	Turbines	DISTTURB
Height above sea level	ALT	
% Slope	XINCLINA	

Statistical methods

Kolmogorov-Smirnov Test was used to test normal distribution of variables. We used one way ANOVA to analyse the distance from nest to the nearest turbine between study years, the distance to the unpaved road, the distance to the power line and the number of eggs in each nest.

We used non-parametric statistics for those variables that were not normally distributed. Mann-Whitney U-Test was used to analysis the density of nests between years.

We used the discriminate function from Barros et al 1995:

$$D = -1.88180 + 0.15286 (XINCLINA)^{0.5} + 0.08009 (DISTNIDO)^{0.5} - 0.0136 (DISTREMOL)^{0.5} - 0.01391 (DISTEND)^{0.5}.$$

With this model the authors obtained a correct classification of 88.46% of the case.

We used an alfa value of $P = 0.05$. STATISTICA 6.0 software statistical package was used to perform all statistical procedures.

Results

No statistical difference in density of nests between 1995 and 2002 (1995 rank = 19.47, 2002 rank = 18.50; Mann-Whitney Test, $Z = -0.274$, $n = 37$, $p = 0.799$) was detected (Table 2).

Table 2. Comparison of different variables (mean) between study years to detect a possible disturbance effect of a wind farm. In case of the distance, the values for 1995 were measured to future locations of the indicated infrastructures.

	1995 (before construction)	2002 (after construction)	p
Nest density	16.00	15.20	0.799
Distance to turbines	1,339.61	1,483.91	0.615
Distance to power lines	1,375.89	2,235.61	0.008
Distance to windfarm path	760.27	551.40	0.129
Nº eggs	3.47	3.45	0.956

No statistical difference in distance from nest to future turbine site (1995) and actual turbines sites (2002) was detected (one-way ANOVA, $F_{1,35} = 0.256$, $p = 0.615$) (Table 2).

A statistical difference in distance from nest to the future power line (1995) and the actual power line (2002), increasing the distance to the power line in the second study year (one-way ANOVA, $F_{1,35} = 7.675$, $p = 0.008$). (Table 2).

No statistical differences in distance from nest to future unpaved road (1995) the actual unpaved road (2002) was (one-way ANOVA, $F_{1,35} = 2.414$, $p = 0.129$) were detected (Table 2).

No statistical differences in number of eggs between study years (one-way ANOVA, $F_{1,35} = 0.003$, $p = 0.956$) were detected (Table 2).

All nests from 2002 were classified correctly using discriminate model from 1995. When comparing relative wheat cover between study years (1995 rank = 258, 2002 rank = 445; Mann-Whitney Test, $Z = -3.129$, $p = 0.001$) were detected. In 2002, more wheat cover was selected by breeding pairs.

Discussion

Wind farms have been considered a potential and concentrated source of disturbance and are thus amenable to an experimental procedure (Orloff and Flannery 1993, Anderson et al., 1998, Morrison and Pollock, 1998, Hunt, 2000, Larsen and Madsen, 2000, Guillemette and Larsen, 2002, Langston and Pullan, 2003, Drewitt and Langston, 2006, Stillman et al., 2007). However, no raptor species have been considered before and, to our knowledge, our study is the first to analyse the potential disturbance of a wind farm on breeding population with a Before/After contrasts at a single site design.

In our study nest density and distance from the nest to the turbine do not differ between study years. So the presence of the turbines seemed not to be a significant problem for this Montagu's Harrier population. However, avoidance distances from turbines in rows and clusters were detected by Larsen et al. (2000) for geese *Anser brachyrhynchus*. Guillemette and Larsen (2002) concluded that the wind farm did not substantially affect wintering Common Eiders *Somateria mollissima*, but Larsen and Guillemette (2007) demonstrated that they avoided flying close to and within the wind farm to a large degree.

Wind farm also includes a power line and unpaved roads used for maintenance. These roads are accessible to all persons using the area and the traffic volume is increased. Some researches suggest that several territories species have lower breeding in areas adjacent to roads than in control areas, due to disturbance by car traffic (Keller, 1991, Reijnen and Foppen, 1994). In contrast, our results no detect a increasing distance from nests to the new roads. However a increasing distance from nests to the power lines in 2002 was detected. Montagu's Harrier could identified power lines as disturbance source.

Disturbance impact can affect demographic parameters such as survival or reproductive success (Gill et al., 2001). So in our results, no difference in the number of eggs in nest between study years indicate no wind farm disturbance. More studies are needed in order to know the possible disturbance effects on other demographic parameters.

On the other hand, no change in Montagu's Harrier habitat between study years were detected. Cereal crops appear to be the commonest nesting habitat of this species in Spain (Arroyo et al., 2002). In our study area, two more times wheat in 2002 than in 1995 are available (Ganadería, 2002), and Montagu's Harrier nests use more wheat for breeding in 2002 than in 1995.

In conclusion, our results support no effect of wind farm on the Montagu's Harrier breeding population. The study design we had used could be improve adding data from the construction period. Future researches could be focused in this and in the study of other breeding raptor species.

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Conclusiones

Aves y parques eólicos: efectos e interacciones

Conclusiones

1. Las aves planeadoras pueden detectar y evitar la presencia de los aerogeneradores, cambiando su dirección de vuelo o aumentando su altura de vuelo. Su abundancia no parece verse afectada por la presencia del parque eólico.
2. No se detecta una clara afección de los parques eólicos ni sobre la composición de las poblaciones ni sobre la altura de vuelo de aves nidificantes y no nidificantes. El uso del diseño BACI (Before After Control and Impact, siglas en inglés), considerado el diseño óptimo en los estudios de impacto, permitió comparar poblaciones de aves utilizando una zona adyacente como control, antes, durante y después de la instalación del parque eólico.
3. El ratón de campo *Apodemus sylvaticus* parece no verse afectado por la presencia de los parques eólicos. Sus fluctuaciones poblacionales son debidas a los factores intrínsecos de esta especie.
4. Los estudios con una larga serie temporal de datos, en nuestro caso sobre la mortalidad de aves por colisión contra aerogeneradores, permiten obtener una visión más amplia del potencial impacto.
5. La mortalidad de aves en un parque eólico varía entre épocas del año, pero no es mayor en la época de mayor abundancia de aves. La relación de la mortalidad con la abundancia no es lineal.
6. La probabilidad de colisión depende de las características de cada especie (siendo el buitre leonado *Gyps fulvus* la víctima más frecuente), la altura de los aerogeneradores y la altura sobre el nivel del mar. En zonas donde la mortalidad no se distribuye de forma homogénea a lo largo del parque eólico, los aerogeneradores más altos y situados a mayor altura son más peligrosos. Factores específicos de las especies de aves y factores topográficos son los que más contribuyen a la probabilidad de colisión.
7. La población nidificante de aguilucho cenizo *Circus pygargus*, no se ve alterada por la presencia del parque eólico. El parque eólico no provoca cambios ni en la densidad de nidos, ni en el tamaño de la puesta, ni en la distancia de los nidos a los aerogeneradores, ni al camino del parque eólico.
8. El hábitat utilizado para la nidificación por el aguilucho cenizo *C. pygargus* no se ve alterado por la instalación del parque eólico.
9. Simulaciones en un túnel de viento de las corrientes de viento se ajustan a las trayectorias de vuelo observadas de buitres leonados *G. fulvus*. Esto sugiere que los buitres leonados, especie

típicamente planeadora, se dejan mover por las corrientes de viento predominantes en el área, es decir, siguiendo las rutas de menor gasto energético.

10. Conocimientos sobre las corrientes principales de viento en una zona pueden utilizarse como herramienta de planificación del desarrollo eólico con el fin de reducir la incidencia sobre la avifauna por colisión.

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