Ardeola 57(1), 2010, 41-53

IMPACT OF TERRESTRIAL WIND FARMS ON DIURNAL RAPTORS: DEVELOPING A SPATIAL VULNERABILITY INDEX AND POTENTIAL VULNERABILITY MAPS

IMPACTO DE CAMPOS EÓLICOS TERRESTRES SOBRE RAPACES DIURNAS: DESARROLLO DE UN ÍNDICE DE VULNERABILIDAD ESPACIAL Y MAPAS DE VULNERABILIDAD POTENCIAL

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SUMMARY.—*Impact of terrestrial wind farms on diurnal raptors: developing a spatial vulnerability index and potential vulnerability maps*.

The use of wind energy resources is currently increasing worldwide as a method of obtaining renewable and non-polluting energy. Nevertheless, wind energy development has several potential adverse effects on avian communities. Therefore, suitable location for futures wind farms seems critical to minimise adverse effects on birds. In this study we adapted the indices proposed by Garthe and Hüpop (2004) for offshore wind farms to a terrestrial wind farm as a method to identify more sensitive raptors and to detect high vulnerability areas for wind farms. We constructed two indices: a raptor sensitivity index (RSI) and a spatial vulnerability index (SVI). The RSI included seven factors derived from the attributes of species that have been considered important in assessing the impact of wind farms on birds. Using an RSI and relative habitat use estimation, an SVI was calculated and a potential vulnerability map was produced for Boquerón mountain range in Valencia region. Golden eagle *Aquila chrysaetos*, short-toed eagle *Circaetus gallicus* and booted eagle *Hieraaetus pennatus*, together with other species such as griffon vulture *Gyps fulvus* were the more sensitive species to wind farm. The SVI distinguished zones in which either the elimination or change of position of turbines might reduce the impact of the wind farm foreseen. The SVI might be a useful tool for environmental impact assessment (EIA) to select the best location of new terrestrial wind farms or the sections of them.

Key words: conservation, raptors, spatial vulnerability index, vulnerability maps, wind farms.

RESUMEN.—*Impacto de campos eólicos terrestres sobre rapaces diurnas: desarrollo de un índice de vulnerabilidad espacial y mapas de vulnerabilidad potencial*.

El uso del viento como fuente energética esta siendo empleado cada vez más como método de obtención de energía renovable y no contaminante. Sin embargo, el desarrollo de la energía eólica tiene

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potencialmente diversos efectos adversos sobre las comunidades de aves. Por este motivo, la adecuada localización de los futuros campos eólicos es crucial para minimizar los posibles efectos adversos sobre las comunidades de aves. En el presente estudio se han adaptado los índices propuestos por Garthe and Hüppop (2004) en campos eólicos marinos para campos eólicos terrestres, como método para identificar las especies más sensibles de rapaces y detectar zonas de alta vulnerabilidad frente a su instalación. Se desarrollaron dos índices: uno de sensibilidad para aves rapaces (RSI) y otro de vulnerabilidad espacial (SVI). El RSI incluyó siete factores derivados de los atributos de las especies y considerados importantes para evaluar el impacto de los campos eólicos sobre las aves. Mediante el empleo del RSI y la estimación del uso relativo del hábitat, se calculo el SVI y se construyó un mapa de vulnerabilidad potencial para la sierra del Boquerón, en la provincia de Valencia. El águila real *Aquila chrysaetos*, culebrera europea *Circaetus gallicus* y aguililla calzada *Hieraaetus pennatus,* junto con otras especies como el buitre leonado *Gyps fulvus,* fueron las especies mas sensibles frente a la futura instalación de campos eólicos. El SVI distinguió zonas en las que tanto la eliminación como el cambio de posición de turbinas podrían reducir el impacto de los futuros parques eólicos. El SVI podría ser una herramienta útil en la evaluación de impacto ambiental (EIAs) con el fin de elegir la mejor ubicación de campos eólicos o las diferentes secciones de turbinas que los componen.

Palabras clave: conservación, índice de vulnerabilidad espacial, mapa de vulnerabilidad, parques eólicos, rapaces.

Introduction

The use of wind energy resources is currently increasing in many countries, notably within the European Union, and many wind parks are currently planned or are under construction. Although wind farms are a method of obtaining renewable and non-polluting energy, they entail several environmental impacts related to the aesthetic impact on landscape, increase of noise and how they affect birds (Percival, 2005; Drewitt and Langston, 2006). This taxonomic group, and particularly raptors, could be affected by terrestrial wind farms because of collision risk, barrier effects, disturbances and habitat loss (Orloff and Flannery, 1992; Barrios and Rodríguez, 2004; Garthe and Hüppop, 2004; Drewitt and Langston, 2006; Madders and Whitfield, 2006).

Much of the current research on wind farms focuses on assessing the impact of existing wind farms on birds. Specifically, different studies have assessed the mortality rates due to the collision of individual birds with single turbines (Orloff and Flannery, 1992; Erickson *et al*., 2001; Barrios and Rodríguez, 2004), to changes in bird communities (Orloff and Flannery, 1992; De Lucas *et al*., 2005) or habitat use (Walker *et al*., 2005; Fox *et al*., 2006). Other studies have determined the factors that might influence the collision risk for birds (e.g., features of wind turbines, attributes of species, or weather conditions and topography) (review in Drewitt and Langston, 2006, but also see reference therein).

Nevertheless, few studies and methods exist that focus on assessing the best emplacement of new planned wind farms and the specific location of individual turbines to minimise their impact on birds. Recently, Garthe and Hüppop (2004) developed an offshore wind farm vulnerability index in the North Sea to identify areas that are more sensitive to wind farm installation for seabirds. To date, only one study has tried to develop a spatial model to on-shore wind farms at a regional level in Scotland (Bright *et al*., 2008). Nevertheless, no similar index has been published for on-shore wind farms on a local scale (wind farm area) in Spain where the greatest number of on-shore wind farms is currently being planed.

In this study the model proposed by Garthe and Hüppop (2004) was adjusted to terrestrial areas as a method to identify raptors and zones that may be more sensitive to wind farms, in terms of collision risks. The index proposed was applied to the Boquerón mountain range (Valencia province, East Spain) where the construction of a new wind farm, composed of 59 wind turbines, is projected in the coming years. First, a raptor sensitivity index (RSI) was constructed to identify the species that are more sensitive to wind farms. This index is based on scoring several factors suggested by the literature, and is derived from the attributes of raptors. Based on the RSI and the relative habitat use estimations by raptor species in the study area, we constructed a spatial vulnerability index (SVI). SVI values were mapped to obtain potential vulnerability maps.

METHODS

Vulnerability factors

A bibliographic search for scientific publications was performed in order to select the factors to be included in the RSI. Search terms "TS = [(wind farm* or wind turbine* or wind farm* or wind park) and (bird* or raptor*)]" were used within titles, abstracts, and keywords to search in the ISI web of Science (http://portal.isiknowledge.com).

The search produced 60 manuscripts of which 30 were related manuscripts that cited 13 factors related to the attributes of species. Of these, 7 factors were selected to be included in the RSI (table 1) given their likely importance in terms of raptor sensitivity to wind farms and the ease with which they may be obtained through field work or a bibliographic search. The factors selected were scored on a 4-point scale, ranging from 1 (low vulnerability) to 4 (high vulnerability) as follows (table 1):

TABLE 1

Factors cited, mentioned or suggested in the bibliography related with the impact of wind farms on birds, which are included in the Raptor Sensitivity Index (RSI).
[Factores citados, mencionados o sugeridos en la bibliografía relacionada con el impacto de campos eólicos sobre las aves e incluidos en el índice de sensibilidad para aves rapaces (RSI).]

	Factor	**References**
A	*Flight type*	Barrios and Rodríguez, 2004; De Lucas *et al.*, 2005; Hoover and Morrison, 2005; Drewitt and Langstone, 2006.
B	*Flight altitude*	Larsen and Clausen, 2002; Barrios and Rodríguez, 2004; De Lucas *et al.*, 2004; Garthe and Hüppop, 2004; De Lucas *et al.*, 2005; Hoover and Morrison, 2005; Drewitt and Langstone, 2006; Fox *et al.*, 2006; Hüppop *et al.*, 2006; Madders and Whitfield, 2006; Perrow *et al.*, 2006; Larsen and Guillemette, 2007.
C	*Manoeuvrability*	Barrios and Rodríguez, 2004; Garthe and Hüppop, 2004; Chamberlain *et al.,* 2005; Hoover and Morrison, 2005; Drewitt and Langstone, 2006.

TABLE 1 (cont.)

	Factor	References
D	*Seasonality*	Barrios and Rodríguez, 2004; Garthe and Hüppop, 2004; Hoover and Morrison, 2005; Drewitt and Langstone, 2006; Hüppop *et al*., 2006.
E	*Population size*	Garthe and Hüppop, 2004; Drewitt and Langstone, 2006; Larsen and Guillemette, 2007.
F	*Conservation status*	Garthe and Hüppop, 2004; Drewitt and Langstone, 2006.
G	*Breeding capacity*	Drewitt and Langstone, 2006; Fox *et al.,* 2006

(A) Flight type

Firstly, a 4-point scale from 1 (low vulnerability) to 4 (high vulnerability) was established for each flight type, according to the suggestions of Barrios and Rodríguez (2004). This factor was scored by assigning the average score of the observations of each raptor noted in the study area (see details in the next section). Flight types observed in the study area were scored in the following sequence: score 1 for 'perch' (bird was resting and it did not fly at the contact moment); score 2 for 'slope flights' (flights where the bird motion was made by flapping along the hillside or flights where birds flew parallel to the ridge along the hillside but without intending to gain altitude); 3 for 'straight flight' (flight where bird was moving linearly and with rapid takeoff), and 4 for 'circling flight' (soaring flights on rising warm air currents where the bird was performing a circular movement).

(B) Flight altitude

As with flight types, a 4-point scale, ranging from 1 (low vulnerability) to 4 (high vulnerability) was established for the different flight altitude intervals, according to the suggestions of Barrios and Rodríguez (2004). Flight altitude was scored by assigning the average score of the observations of each raptor noted in the study area.

Altitude intervals were set up according to the mean dimensions of 56 turbine models produced by 6 international manufacturers (mean tower height = 69.5 m, SD = 14.47 m; mean rotor diameter = 71.95 m, SD = 14.36 m). Score 1 was given for a flight altitude exceeding 120 m (altitudes exceeding score 3); score 2 was for flight altitudes from 0 to 17 m (altitudes from the ground to 15 m under the lowest limit of the rotating blades), score 3 from 18 to 32 m (altitudes between the lowest limit of rotating blades and 15 m below it) and from 106 to 120 m (altitudes between the superior limit of rotating blades and 15 m above it), and score 4 for flight altitudes from 33 to 105 m (range of altitude of rotating blades). Flight altitude was estimated using binoculars and comparative height measures with reference points, especially trees and anemometric towers, which were dispersed in all the study area.

(C) Manoeuvrability

This factor was assessed by scoring the "wing loading" (C_1), calculated as the ratio between body mass and wing area, and "wing aspect" (C_2), as the ratio between wing spam and body mass of the species. Low manoeuvrability species are characterized by high wing loading and low wing aspect, which means that they show rapid flight combined with a heavy body mass and small wings, restricting swift reactions to unexpected obstacles (Bevanger, 1998). Thus, 4 equal intervals were created from wing loading and wing aspect for raptor species presented in the study area. Species were ranked from high flight manoeuvrability (score 1) to low flight manoeuvrability (score 4).

(D) Seasonality

This factor was scored according to the suggestions of several authors (Barrios and Rodríguez, 2004; Percival, 2005; Drewitt and Langston, 2006). According to these authors, this is when the species that frequent the wind farm area on a regular basis are exposed more commonly to risky situations. For this reason, resident species would be more sensitive than vagrant species because of their longer exposure to a risk situation. Consequently, species scored 1 if they were 'rare or vagrant' in the study area, 2 if they were 'migrant' (not breeder), 3 if they were 'wintering' or 'migrant breeders' and 4 if they were 'resident or breeding species' in the study area.

(E) Population size

To be able to score this factor, 4 equal intervals were created of the naperian logarithm of the Spanish breeding population sizes for raptor species presented in the study area (Martí and Del Moral, 2003). Score 1 was given for a population size exceeding 9.14, and population sizes of 8.27 - 9.14, 7.39 - 8.26, and less than 7.39 scored 2, 3 and, 4 respectively.

(F) Conservation status

This factor reflected the conservation status of the species in Europe according to BirdLife International (2004). The threat status of the raptors present in the study area was organized in four categories from greatest to least conservation concern. Thus, species of non-European concern scored 1 (SPEC). A score of 2 was given for species with a threat status of 'rare'; a threat status of 'declining' scored 3, while a score of 4 was given to a threat status of 'vulnerable' or 'endangered'.

(G) Breeding capacity

Species with a large clutch size could generate more offspring, implying higher capability to withstand and replace individual losses caused by wind turbines. In this sense, this factor was scored according to the clutch size described by Cramp and Simmons (1980) and Jutglar and Massó (1999). Species scored 1 if they had clutch sizes up to 4 eggs; and scores of 2, 3 and 4 were given if they laid 3 - 4 eggs, 2 eggs and only one egg, respectively.

Raptor sensitivity index calculation

The 7 factors were organised into 2 groups. In this way, the collision risk among raptors, due to flight behaviour and seasonality, is reflected (Factors A, B, C_1, C_2, D), as is species sensitivity (Factors E, F, G). For each group, an average score of the respective factors was calculated. These average scores were subsequently multiplied by each other to obtain the sensitivity index (RSI) for each raptor species.

$$RSI = \underbrace{\frac{(A + B + C_1 + C_2 + D)}{5}}_{\text{flight behaviour and seasonality}} * \underbrace{\frac{(E + F + G)}{3}}_{\text{species sensivity}}$$

Spatial vulnerability index

The SVI was calculated by applying the following formula (Garthe and Hüppop, 2004) for each km^2 grid cell in the study area:

$$SVI = \sum_{1}^{n}\left(\ln(\rho_i + 1) * RSI_i\right)$$

where 'ρ_i' is the observations number for species 'i' in the UTM grid cell, and the 'RSI_i' is the RSI value for species 'i'.

Potential vulnerability maps were constructed with the SVI values. On one hand, we constructed a potential vulnerability map including all raptor species, and on the other, we constructed a new potential vulnerability map including only those raptors species with a RSI values over the median. This second map permits us avoid the dilution effects that can produce the inclusion of all species in those species with high RSI values. Three levels of risk were established according to the 50 and 75 percentiles of the SVI values for a final assessment of the study area. Values under the 50 percentile were considered low risk areas, those between the 50 and 75 percentiles were taken as a moderate risk, while those over the 75 percentile were high risk areas.

Sensitivity analysis for the SVI

To verify how inaccurate scores for any of the 7 factors (see above section) might affect RSI values, a sensitivity analysis was carried out. Three species with a high, medium and low RSI were chosen and each score for the seven factors was randomly altered. By simulation, the scores were altered either by upgrading or downgrading them by 1 (determined at random and only if applicable, e.g. score 4 could not be increased and thus remained) and then, we calculated their new RSI values.

Study area

The SVI was applied to the Boquerón mountain range (39º 8' 40'' N, 1º 10' 0'' W) in the province of Valencia (East Spain), where the construction of a wind farm with 59 single turbines is planned. This area presents a series of mountains with a maximum altitude of 1,000 m. The main vegetation is composed of *Pinus halepensis* reforestations. Valleys and lowlands are extensively farmed.

An area of 2,000 m around each turbine was considered as a study area. We established 50 linear transects with a fixed length that covered all cells of 1x1 km of within the study area. Transects were performed every two weeks throughout one year (from March 2005 to March 2006). We also carried out 20-minute observations every two weeks in the observation points established in each UTM grid cell (1x1 km). Observation points, one per cell, were located at an elevated point where the observers were able to control the total UTM cell area. Transects and observation points were done on days with good meteorological conditions to avoid rainy and cloudy days that could affect the birds' detectability. All raptors or raptor groups and their species, the number of birds, flight type, UTM coordinates and flight altitude were recorded.

RESULTS

Raptor Sensitivity Index

During the study period 306 raptor observations from 13 species were recorded. All species with more than 5 observations were included in the RSI calculations (table 2).

Results of RSI (see table 2) showed that for factor "flight type" most of the species received a score 3 and only booted eagle *Hieraaetus pennatus* scored the highest punctuation. Most of the species flew at altitudes

TABLE 2

Score of sensitivity factors and the resulting RSI values for each of the nine raptors species included in the analysis.
[Puntuación de los factores de sensibilidad y valores resultantes de RSI para cada una de las nueve especies de rapaces incluidas en el análisis.]

Species	**n**	**Collision risk**					**Species sensitivity**			**RSI**
		Flight type	***Flight altitude***	***Manoeuvrability***		***Seasonality***	***Population size***	***Conservation status***	***Breeding capacity***	
				Wing loading	***Aspect ratio***					
		(A)	***(B)***	***(C_1)***	***(C_2)***	***(D)***	***(E)***	***(F)***	***(G)***	
Booted eagle *Hieraaetus pennatus*	6	4	2	1	3	3	3	2	3	6.93
Common kestrel *Falco tinnunculus*	74	2	3	1	1	4	1	3	1	3.67
Eurasian sparrowhawk *Accipiter nisus*	12	3	3	1	2	4	2	1	1	3.47
European honey-buzzard *Pernis apivorus*	9	3	3	1	3	2	4	1	3	6.40
Golden eagle *Aquila chrysaetos*	17	3	3	4	4	4	4	2	3	10.80
Griffon vulture *Gyps fulvus*	6	3	3	4	4	2	1	1	4	6.40
Northern goshawk *Accipiter gentilis*	10	3	3	2	2	4	2	1	2	4.67
Peregrin falcon *Falco peregrinus*	35	2	3	3	4	4	3	1	2	6.40
Short-toed eagle *Circaetus gallicus*	79	3	3	1	2	3	3	2	4	7.20
TOTAL	**248**	**26**	**26**	**18**	**25**	**30**	**23**	**14**	**23**	**55.93**

near to the rotation blades (score 3) except for booted eagle (score 2). Golden eagle *Aquila chrysaetos* and griffon vulture *Gyps fulvus* were the species with lowest manoeuvrability (score 4) unlike common kestrel *Falco tinnunculus* and Eurasian sparrowhawk *Accipiter nisus* (table 2). In the study area common kestrel, Eurasian sparrowhawk, golden eagle, northem goshawk *Accipiter gentilis* and peregrine falcon *Falco peregrinus* were resident or breeding species, thence these scored the highest punctuation for the factor "seasonality". On the basis of population size, golden eagle and European honey-buzzard *Pernis apivorus* were the species with lower population sizes (score 4), unlike griffon vulture and common kestrel (score 1). Finally, at European level common kestrel, golden eagle, short-toed eagle *Circaetus gallicus* and booted eagle were the most threatened species. Griffon vulture, as well as short-toed eagle, were the species with highest vulnerability on the basis of their breeding capacity (score 4) since they only lay one egg for clutch (see table 2).

According to our index, griffon vulture and golden eagle were the species which displayed the most dangerous flight behaviour (greatest scores for Factors A, B, and C) and together with peregrine falcon were the species with the highest collision risk in the study area (factors A, B, C, and D). None of the study species flew at the most dangerous altitude in the study area but most of them flew at altitudes near to rotating blades. Golden eagle and griffon vulture were the species scored with the lowest 'flight manoeuvrability' since they showed the highest values of wing loading and the lowest values of wing aspect.

Golden eagle and short-toed eagle, followed by booted eagle and european honey-buzzard, were the most sensitive species to wind farms owing to their 'population size' (Factor E), 'conservation status' (Factor F), and 'breeding capacity' (Factor G). Griffon vulture and short-toed eagle scored the lowest 'breeding capacity', so they obtained the highest value for this factor. According to 'population size', European honey-buzzard and golden eagle were the species most sensitive to lost individuals.

If the total score of the RSI is considered, its values varied markedly among species (table 2). Golden eagle and short-toed eagle ranked the highest values of RSI, that is, they were potentially the most sensitive to wind farms in the study area, and they were followed by booted eagle, griffon vulture, European honey-buzzard and peregrin falcon. The lowest values were recorded for Eurasian sparrowhawk and common kestrel (table 2).

Spatial Vulnerability Index

The SVI values in the study area ranged from 0 to 41.71 when all the raptor species are included in the analysis. Most of the study area (58 %, 41 km^2) had low SVI values, whereas 21 % (15 km^2) had moderate SVI values, and 21 % (15 km^2) showed high SVI values (figure 1). In relation to the wind farms planned in the study area, 25 turbines (42.4 %) would be placed in areas with moderate potential risks, 22 turbines (37.3 %) would be located in low risk areas, while 12 turbines (20.3 %) would be in a high risk area.

SVI values and the corresponding vulnerability map changed when only we included the species which presented high RSI values. Although the total surface for each risk level did not vary when we included the species with high RSI values, several UTM grid cells changed their risk level (figure 2). Similarly, the number of turbines planned in relation to potential risk areas changed. As results, 26 turbines (44.1 %) would be placed on areas with low potential risks, 20 turbines (33.9 %) would be located in moderate risk areas, while 13 turbines (22 %) would be in a high risk area.

Sensitivity analyses of RSI carried out to verify how the SVI might be affected by

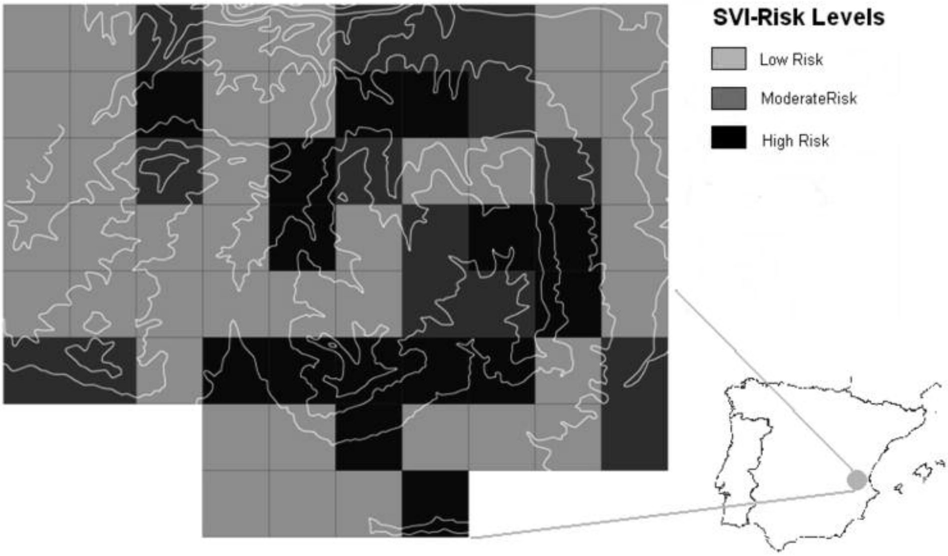

FIG. 1.—Spatial distribution of the SVI values transformed in Risk Levels in the study area (1 km x 1 km) including the nine raptors species incorporated in the analysis.
[Distribución espacial de los valores de SVI transformados en niveles de riesgo para el área de estudio incluyendo las nueve especies de rapaces incorporadas en el análisis.]

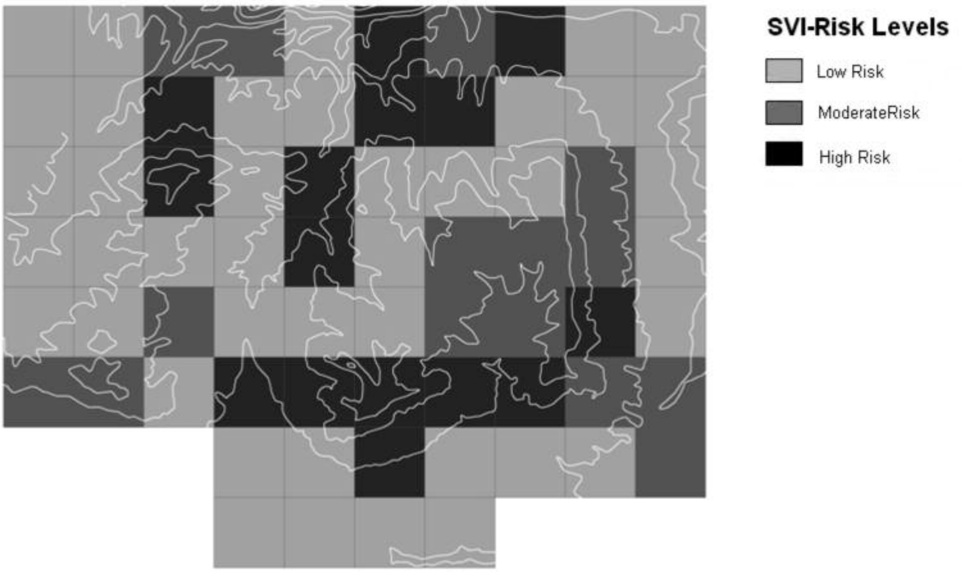

FIG. 2.—Spatial distribution of the SVI values transformed in Risk Levels in the study area including only the raptor species with RSI values over the median.
[Distribución espacial de los valores de SVI transformados en niveles de riesgo para el área de estudio e incluyendo sólo las especies de rapaces con valores de RSI por encima de la mediana.]

inaccurate scores for any of the vulnerability factors showed that minor changes in the scores did not much affect the RSI (mean of 10 simulations of each species). Thus, RSI for Eurasian sparrowhawk changed from 3.47 to 4.17, the RSI for European honey-buzzard from 6.40 to 7.03 and short-toed eagle from 7.2 to 7.13.

Discussion

The negative impact of wind farms on the raptor community not only depends on the individuals' attributes, but also on the location of the turbines (Hoover and Morrison, 2005; Madders and Whitfield, 2006). In this sense, the adaptation of the model proposed by Garthe and Hüppop (2004) to a specific terrestrial area, which includes the attributes of local species, has identified the potentially more sensitive raptors and more vulnerable areas for the installation of wind farms.

Vulnerability factors

The factors incorporated in SVI allowed us to perform a preliminary approximation to the species most sensitive to wind farms owing to the highest collision risk with turbines because of the flight behaviour of the raptors (Factors A, B, and $C_{1,2}$) and seasonality (Factor D). Additionally, those species for which an increase of mortality by turbines may have serious consequences due their threat status, population size and breeding characteristics were also identified (Factors E, F, and G). These factors are easily calculated or are normally available in the scientific and technical bibliography.

Others species attributes not included in SVI, such as flexibility in habitat use, home-range location, local meteorological conditions, familiarity with turbines or reproductive and survival parameters, have also been suggested as important factors in assessing the impact of wind farms on birds (Garthe and Hüppop, 2004; Drewitt and Langstone, 2006; Fox *et al*., 2006). However, the information needed to calculate these other factors is not frequently available in bibliographic sources or for specific areas, and the calculation of these factors needs intensive field work and detailed behavioural studies to control the raptor community. For this general model we have not controlled for these local factors in order to reduce the needed information and construct a model applicable in a major number of circumstances and places with more easy information available. Although the inclusion of this information might complicate the impact assessment, given a lack of information and because the efforts involved in their calculation cannot be carried out in a normal impact assessment, for the future models the inclusion of this type of information and more intensive data is of interest for the purpose of improving the model results.

On the other hand, the score scales for the factors included in the RSI could be adjusted to improve impact assessment by the use of more accurate information from the study area, depending on the information available. In this sense, for instance, we could employ regional or autonomic population estimates to score the factor 'population size'. Additionally, the factor 'conservation status' could be valued on the basis of national or autonomic threat levels and finally, 'flight altitude' intervals could be adjusted to the dimensions of foreseen turbines models in the study area.

Raptor sensitivity index and vulnerability maps

The results showed that raptors present substantial differences in RSI values and sensitivity analyses of RSI showed that minor changes in the scores did not affect the

RSI much. Thus, although indices depend strongly on the factors selected and the way they are weighed against each other, our RSI and as a consequence our SVI seems to be well suited to fulfil the urgent need to assess the vulnerability of raptor communities to the future installation of wind fams. Golden eagle, short-toed eagle, and booted eagle were the raptor species most sensitive to wind farms in the study area. The first species besides griffon vulture presented the highest sensitivity when only flight behaviour is considered. These results match those obtained by other authors (Erickson *et al*., 2001; Barrios and Rodríguez, 2004; De Lucas *et al*., 2004) who observed that these raptor species were more prone to colliding into turbines. In the same way, the Eurasian sparrowhawk, with less dangerous flight behaviour, has been scarcely cited in mortality studies conducted on wind farms (Erickson *et al*., 2001; Percival, 2003). However, the common kestrel presented a low RSI value and a non-dangerous flight behaviour but this species has been reported as one of the species with more collisions on wind farms in South Spain (Barrios and Rodríguez, 2004). Nevertheless, these high mortality rates can be influenced by edge (aggregation in the post-fledging period) and the type of turbine installed (old lattice turbines) as the same author discussed. The higher number of juvenile kestrels and their lack of flight experience at this wind farm may be simplest explanation of their collision (Barrios and Rodríguez, 2004).

The mortality rate of raptors on wind farms can be influenced by the location of a low number of turbines where a high collision risk is present (Madders and Whitfield, 2006). In this sense, the application of the SVI to the study area has revealed the spatial differential impact of turbines on the raptors community. Since the wind farm planed in our study area extended over a great surface, we employed grid cell of 1 km x 1 km to construct the potential vulnerability maps. Thus, results showed that approximately one fifth of the planned turbines would be installed in places which present a high risk for raptors. Nevertheless, in some cases wind farms planned are composed of a low number of turbines and in these cases, the use of a 1km x 1km grid cell could result in a loss of information. Consequently, we recommend the employment of 500 x 500 m grid cells to construct SVI and potential vulnerability maps for wind farms with a low number of turbines (< 30 turbines).

Management applications

To reduce the impact of wind farms on birds, specific locations should be evaluated *a priori* when a new wind farm is planned. Our SVI might be a useful preliminary tool for environmental impact assessment (EIA) in order to compare different areas and to select the best location for the planned wind farm in order to minimise the future risks of collision for raptors.

The combination of our SVI with other methods, such as BACI designs (Before - After design) (Smith, 2002; De Lucas *et al.*, 2005), Collision Risk Models (Podolski, 2003; Band *et al*., 2005; Chamberlain *et al.,* 2005) and methods based on the radio telemetry of the individuals (Walker *et al*., 2005; Perrow *et al*., 2006) when more sensitive species exist might help to reduce and obtain a better assessment of the effects that currently occur among raptor communities because of this kind of renewable energy.

ACKNOWLEDGEMENTS.—We wish to thank GUADALAVIAR for funding support. We especially thank B. Bejarano and R. de la Revilla for their advice during this study. Three anonymous referees made valuable comments on earlier versions of this manuscript.

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