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Identifying suitable habitat for dispersal in Bonelli's eagle: An important issue in halting its decline in Europe

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Abstract

Bonelli's eagle (*Hieraaetus fasciatus*) is an endangered bird of prey that is suffering a rapid decline in most of its distribution range in Europe. The aim of this study is to identify suitable areas used by juvenile eagles during their dispersal phase. Knowing the location of these target areas will help to plan adequate conservation programs to reduce the high juvenile mortality rates this species is suffering presently. The combined use of radio-telemetry for identifying core areas, Generalised Linear Models (G.L.M.) for producing predictive mathematical models and Geographic Information Systems (G.I.S.) for transferring predictive models into digital cartography predict well the presence of juvenile Bonelli's eagles in dispersal areas. We built three different Generalised Lineal Models using topography, land-use/land-cover and human disturbance as explanatory variables. Our sample units were 11 settlement areas used by juvenile eagles during dispersal and 11 other areas within available habitat generated at random. Settlement areas were identified as the core areas used by radio-tagged eagles monitored during their first years of life. Immature eagles preferred habitats with greater percentages of pasture within the circular sampling area. Topographic features showed that the most intensively used areas by immature birds were generally steeper southeast-facing slopes. Settlement areas were also situated farther from villages and roads than expected. The land-use model performed well classifying correctly 85.9% of cases validated using a data-splitting strategy. The topographic model also performed well, classifying correctly 81.39% of cases validated by the same methodology. Predictive cartography showed suitable dispersal areas within potential juvenile distribution ranges that enable more efficient design of special conservation programmes.

Keywords: Predictive cartography; Habitat selection; Juvenile; Dispersal; Raptor; Model performance; G.I.S.; Core areas; GLM; Radio telemetry

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1. Introduction

Historically, the study of the distribution of organisms within their environments has been of major concern to ecologists (Gaston and Blackburn, 1995; Lawton, 1996). Recently, numerous studies have incorporated models predicting either the presence/absence or the abundance of individuals in a particular geographical area (González et al., 1992; Donazar et al., 1993; Ferrer and Harte, 1997; Penteriani et al., 2001; Suárez et al., 2000; Seoane et al., 2003; Fernández et al., 2003; Sergio et al., 2003, 2004). Habitat variables at different scales – macro-variables for describing landscape features or micro-variables for describing immediate surroundings – have been used as explanatory variables in the majority of these models (Sergio et al., 2003). Predicting habitat suitability has multiple applications in conservation biology (Manel et al., 2001). For instance, with endangered species there is a need to prioritise conservation efforts and to distribute available resources more efficiently amongst habitats. Identifying the habitat features that favour a species' survival and

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reproduction is a fundamental step that should be taken before planning any conservation programme. Recently, the Geographic Information Systems (G.I.S.) have been shown to be important tools for ecologists, given these systems' ability to permit the incorporation of predictive models into digital cartography. This information is fundamental for managers of conservation programmes, who, with the aid of a G.I.S., can now identify gaps in the distribution of a species, diagnosis causes and improve site management by manipulating habitat features known to favour target species (Li et al., 1999; Bradbury et al., 2000; Sergio et al., 2003). As well, planned land-use changes may be avoided wherever they are detrimental for the species in question (Buckland and Elston, 1993).

The Bonelli's eagle (*Hieraaetus fasciatus*) is a long-lived bird of prey (Newton, 1979), characterised by a modal clutch size of two eggs (range 1–3) and a mature reproduction age of about 3.5 years (Cramp and Simmons, 1980). Their populations have declined sharply in Spain and most of the rest of its European distribution (Cugnasse, 1984; Palma et al., 1984; Hallmann, 1985; Arroyo et al., 1990). Demographic declines are due to habitat pressure that indirectly increases the pre-adult and adult mortality rates (Real and Mañosa, 1997; Carrete et al., 2002; Balbontín et al., 2003; Gil-Sánchez et al., 2004; Gil-Sánchez et al., 2005). The Andalusia region represents one of the most important breeding areas for this species in Spain (Balbontín et al., 2003). The European population is currently estimated at 938–1039 breeding pairs (Real et al., 1996) and is classified as 'endangered' (level SPEC 3, Unfavourable Conservation Status and not concentrated in Europe) (Tucker and Heath, 1994).

The dispersal period is relatively long in this eagle (Newton, 1979; Del Hoyo et al., 1994; Real and Mañosa, 1997) and factors affecting survival during the non-breeding stage will have important consequences on the stability of the population as a whole (Real and Mañosa, 1997; Carrete et al., 2005). The aim of our study was to identify habitat preference in juveniles during the dispersal period and to produce cartography to identify those areas in which juveniles are most likely to be found. This will allow suitable areas to be better managed and help reduce mortality rates in juveniles. Thus, we radio-tagged 21 young birds and identified the areas that they used most intensively (core areas) by 11 juvenile birds. We compared the habitat features at landscape level of these areas with randomly generated points within available habitat and built occurrence models (presence/absence) with a logistic regression analysis. Nowadays the European populations are restricted to the Iberian Peninsula (Real et al., 1996) and therefore identifying the dispersal areas in this region unquestionably have conservation priority.

2. Methods

2.1. Geographical area

We studied a breeding population of Bonelli's eagles in the province of Cádiz (southern Spain, 5°32′W, 36°41′N). The monitored breeding populations were located in the Cordilleras Béticas, the main mountain system of the region, which is composed of the Sierras Penibéticas in the south, close to the Mediterranean sea, and the Sierras Subbéticas further north. Altitude ranges from 80 to 3482 m a.s.l., and the climate is sub-arid Mediterranean (Rivas-Martínez, 1986), with mean annual rainfall ranging from 200 to 1500 mm. Juveniles eagles disperse out of mountain areas into stretches of flatter farmland. Habitat availability for juveniles during the dispersal period (see Section 2 for details) consisted of 70.6% non-irrigated crops, mainly wheat, 9.4% irrigated crops, mainly beetroot, cotton and rice, 0.3% forest (*Quercus suber*, *Q. rotundifolia* and *Pinus* spp.), 7.8% scrub (*Quercus coccifera*, *Thymus vulgaris* and *Rosmarinus officinalis*), 9.2% pasture and 2.3% built-up areas (information obtained by G.I.S. analysis by the author).

2.2. Radio-marking procedures

Breeding territories were visited to mark young at a time when nestlings were between 47 and 53 days old, approximately about 10 days before fledging. Young were ringed and equipped with 30–35 g transmitters representing 2–3% of their body weight at the time of their first flights. The radio tags were provided by Biotrack (Wareham, BH20 5AX, UK) and were fixed on the back of the eagles by a harness using Teflon (Kenward, 1987). We marked 21 young, 14 in 1998 and seven in 1999, in 12 territories. In total nine males and 12 females were tagged.

We monitored radio-tagged young on a daily basis (five days per week) from the date the first young bird was marked in April 1998 until September 2000. The date at which young eagles dispersed from the territory of their parents (independence date) was determined when offspring were triangulated as being located over 3.5 km from the nest (half the Nearest Neighbour Distance (NND), Balbontín, 2004) on two successive days. After independence, we prospected for radio signals from uniformly distributed observational spots situated at a certain height in order to improve the distance at which signals could be detected. This allowed us to receive a signal at an average distance of 40 km (range: 5–80 km). In total, we worked 590 days in the field, prospecting an area of about 16,000 km^2 every week. Each young eagle was located at least three times every month by short-distance triangulation (2 km) with 100 m tracking resolution, using a Stabo receiver provided by GFT (Eichenbeg 26, Horst, Germany) and a tree-element Yagui antenna. We used positional fixes taken at least 24 h apart to assure the independence of the radio-tracked data. Finally, we obtained an average of 47.7 ± 9.1 (range: 36–61) positional fixes per young bird from independence to the second year of life. We considered temporary settlement areas to be those areas that were most intensively used by the young eagles. For this purpose, by excluding the percentage of fixes that provoked a discontinuity in the cumulative home range size, we calculated core areas using the utilisation distribution (UD) curve (Kenward and Hodder, 1992) and the harmonic mean as a measurement of the focal spot (Dixon and Chapman, 1980). We used Ranges V software (Kenward and Hodder, 1992) and animal movement analysis: an extension for Arcview GIS (Hooge and Eichenlaub, 1997) to analyse home range data.

2.3. Measurement of habitat variables

We measured 19 macro-variables to describe the landscape of 11 temporary settlement areas and 11 random areas (Table 1). Random points were chosen inside the habitat available for immature eagles. Habitat availability was defined as the polygon enclosing all positional fixes obtained during the radio-tracking period for all the monitored individuals (Fig. 1). We excluded all movement found within the breeding areas, which are not used by immature birds as settlement areas. The analysis of the landscape features was based on circular plots centred on the focal spot (harmonic mean) of each settlement area and of each group of randomly generated points. Plots had a radius of 1365 m in order to form an area of 585.3 ha. (the mean size of the 11 core areas used by the track eagles). Landscape characteristics were analysed by means of a Geographic Information System (GIS; IDRISI program, Eastman, 1997). Variables relating to land cover were calculated from the 1:50,000 scale land-use/land-cover maps (1995) of the *Sistema de Información Ambiental de Andalucía* (Andalucian Environmental Information System), which are based on interpretations of Landsat 5 TM 1:60,000 colour aerial photographs (Moreira and Fernández-Palacios, 1995). Topography related variables were measured using a Digital Elevation Model (D.E.M.) with a resolution of 20 m, produced for the Andalucian government (RediaM, 1999). Other variables measured included the distance from the focal point (harmonic mean or random point) of each settlement or random area to the nearest element of human disturbance using the Ministry of Public Works and Transport (Ministerio de Obras Pú blicas y Transporte) 1:100,000 scale Digital Map of Andalusia.

Table 1
Variables used to characterised temporary settlement and random sites of Bonelli's eagle

Code	Meaning
Topography variables	
MINALT	Minimum altitude (m) in circular sampling area
MAXALT	Maximum altitude (m) in circular sampling area
MEANALT	Mean altitude (m) in circular sampling area
MAXSLOPE	Maximum slope (%) in circular sampling area
AVESLOPE	Mean slope (%) in circular sampling area
ASPECT	Mean aspect (°) in circular sampling area
Land use variables	
NIRRIGA	% Non-irrigated crops in circular sampling area
IRRIGA	% Irrigated crops in circular sampling area
FOREST	% Forest in circular sampling area
SCRUB	% Scrub in circular sampling area
PASTU	% Pasture in circular sampling area
NIRRIGA-SCR	Edge between non-irrigated crop and scrub (ha)
NIRRIGA-PAS	Edge between non-irrigated crop and pasture (ha)
NIRRIGA-IRR	Edge between non-irrigated crop and irrigated crop (ha)
SCR-PAS	Edge between scrub and pasture (ha)
Human disturbance	
URB	% Urban in circular sampling area
DVILLA	Distance (km) to nearest village
DROAD	Distance (km) to nearest road
DELPOW	Distance (km) to nearest electric power line

2.4. Statistical analysis

2.4.1. Univariated statistics

Mean values for settlement and random area variables were compared using Wilconxon rank sum normal statistics with correction tests for the difference between means. The mean difference in aspects was checked with appropriate circular statistics (Rayleigh's test). All tests were two-tailed and statistical significance was set at $p < 0.05$. Means are given with ±1 SD.

2.4.2. Presence–absence model

We used logistic regression through a Generalised Lineal Model (using the GLM procedure of S-Plus 2000 (Mathsoft, 1999)) to identify the set of variables that best separated settlement areas from random areas. The explanatory variables were those that described habitat at a landscape level (Table 1). We used a binomial error distribution and a logistic link function, and models were fitted by using a maximum likelihood method (McCullags and Nelder, 1989). The statistical significance of each variable was tested in turn in the model (forward stepwise procedure), and we retained those that contributed to the largest significant change in deviance from the null model. At each step the significance of the variables included in the model was tested with the likelihood ratio test and any falling below the criterion level of $p = 0.05$ was discarded. The final model was considered to have been reached when all the variables had a significant effect at $p < 0.05$ (McCullags and Nelder, 1989; Collet, 1991). For the GLM, the data were used without transformations for normality as this is not a requirement of logistic regression.

We developed three different occurrence (presence/absence) models using three different sets of explanatory variables: (1) a topography model, in which only variables related to topography were fitted to the model; (2) a land-cover/land-use model, in which only variables related to land-cover/land-use were fitted to the model, and (3) a human disturbance model, in which only variables indicating human disturbance were fitted to the model (see Table 1). We build three different models because introducing a large number of explanatory variables is not statistically recommended when sample size is small. Moreover, a better model could not be built by considering in just one model all the variables related with topography, land-use/land-cover and human disturbance as possible explanatory variables. The variables fitted to the final models showed a slight correlation ($r < 0.3$).

We used two different methods to compare the performance of the models. Firstly, we employed a jackknife procedure using one-at-a-time cross-validations to isolate calibration sites ($n = 21$) from independent test sites ($n = 1$), the latter iterated for each separate observation (i.e., 22 times; Manel et al., 1999). Secondly, we used a data-splitting strategy, developing the models with a random selection of 75% ($n = 16$) of the sample (the training set) and using the rest of the data ($n = 6$) to evaluate the models (the test set). To accomplish this we chose at random 74,613 different samples of $n = 16$, which correspond to the number of combinations of 16 sites taken from a total of 22 elements, using a MATLAB script. For both methods, the output variables (predicted values) in each case had a value of between 0 and 1. The presence or absence of predicted values was accepted at a threshold probability at which the sum of sensitivity and specificity was maximised (Albert and Harris, 1987; Zweig and Campbell, 1993). Finally, we constructed a confusion matrix (Fielding and Bell, 1997) and Cohen's Kappa was calculated (Cohen, 1960). This statistic objectively computed the chance-corrected percentage of agreement between observed and predicted group memberships. Values of 0.0–0.4 indicate slight-to-fair, values of 0.4–0.6 moderate, 0.6–0.8 substantial and 0.8–1.0 almost perfect model performance (after Landis and Koch (1997)).

Fitted models were also compared by means of a modification of Akaike's Information Criterion (AIC_c), which is suitable for situations of low sample size when compared to the number of estimate parameters (Fernández et al., 2003; Burnham and Anderson, 1998), and with likelihood ratio tests.

2.5. Habitat predictive cartography

We incorporated the topographic and land-use models into a Geographic Information System using Idrisi software (Eastman, 1997). For convenience we divided our study area into $3 \times 3\,km^2$ (900 ha) UTM squares, which are slightly larger than the 585 ha sample units we used to build the logistics models. However, variables such as MAXSLOPE and ASPECT incorporated into the fitted models showed similar values at both scales ($R^2 = 0.986$ for MAXSLOPE and $R^2 = 0.987$ for ASPECT). The probability was obtained by applying two logistic models after calculating the MAXSLOPE and ASPECT for the topographic model and PASTU for the land-use model for each UTM square. Predicted images were finally reclassified as one (presence), if the predicted probability was above the threshold of $Z = 0.5$, or zero (absence), if the predicted probability was below this threshold. Initially, UTM squares within breeding areas were given a value of zero, because these areas were not used as temporary settlement areas by immature birds.

3. Results

As indicated by maximum and average slopes, temporary settlement areas had a more irregular topography than would be expected for available habitat. Furthermore, slopes found in settlement areas were more often oriented southeastwards (range: 109.8–158.9°, $n = 11$) than slopes in random areas, which were not oriented in any preferred direction (range: 0.95–194.5°, $n = 11$) (Table 2). Temporary settlement areas were also characterised by a greater percentage of scrub and pastureland within the circular sampling areas. Immature birds also preferred habitats with more surface area occupied by edge habitats. For example, settlement areas had more surface area occupied by ecotones between non-irrigated crops and pastureland, and between scrubland and pastureland, than random areas (Table 2). Temporary settlement areas were situated further away from villages and roads than random areas, indicating a tendency to avoid areas occupied by humans.

The topographic and land-cover/land-use occurrence GLM models were highly significant ($p < 0.0001$). The human disturbance model was also significant, although

Table 2
Comparison between 19 macrovariables quantifying 11 temporary settlement areas and 11 random sites in available habitat of juvenile Bonelli's eagle in Cádiz (south Spain)

	Temporary settlements		Random sites			
	Mean ± SD		Mean ± SD		z	p
MINALT	63.7	34.1	98.0	68.2	0.98	0.32
MAXALT	162.7	44.6	146.8	88.0	−0.09	0.92
MEANALT	101.4	34.9	117.6	76.7	135^{b}	0.60
MAXSLOPE	70.2	19.1	24.7	22.5	5.7	<0.00001
AVESLOPE	9.4	3.4	3.6	3.9	3.9	<0.0001
ASPECT	139.0	14.9	97.7	68.1	10.3^{a}	<0.001
Land use variables						
NIRRIGA	62.0	34.0	78.9	38.1	1.8	0.06
IRRIGA	0.1	0.4	17.4	37.0	1.5	0.12
FOREST	0.05	0.14	0.00	0.01	−0.66	0.50
SCRUB	4.3	6.3	0.02	0.09	−2.83	0.01
PASTU	27.9	25.5	0.92	2.06	−3.17	0.001
NIRRIGA-SCR	8.72	14.3	3.06	9.15	1.84	0.06
NIRRIGA-PAS	30.7	20.8	3.47	7.75	−3.27	0.001
NIRRIGA-IRR	0.25	0.82	3.93	8.11	1.12	0.26
SCR-PAS	15.9	21.1	1.06	3.00	−2.54	0.01
Human disturbance						
URB	0.18	0.44	0.20	0.56	−1.71	0.08
DVILLA	6659	2011	4372	2347	94^{b}	0.03
DROAD	2226	926	1262	955	93^{b}	0.02
DELPOW	2835	1679	6338	6916	0.32	0.74

The table shows the significance of Wilconxon rank-sum normal statistics with correction test for the differences between the means.

* $p < 0.05$.

** $p < 0.01$

*** $p < 0.001$ (see Table 1 for variables code).

[a] Mean difference in aspect was checked with Rayleig's test.

[b] Rank sum statistics.

Table 3
Deviance table for the occurrence model using topographic explanatory variables of immature Bonelli's eagle in temporary settlement areas and random sites in available habitat in south Spain

Term	Coefficient	SE	Residual df	Residual deviance	Change deviance	p
Null			21	30.498		
Intercept	−6.2116	3.17				
Maxslope	0.2473	0.13		14.584	−15.914	0.000065
Maxslope × aspect	−0.000833	0.0005		12.047	−2.537	0.0564

Table 4
Deviance table for the occurrence model using explanatory variables related with the vegetation structure of immature Bonelli's eagle

Term	Coefficient	SE	Residual df	Residual deviance	Change deviance	p
Null			21	30.498		
Intercept	−1.82803	0.82				
% Pastu	0.337175	0.15		14.160	−16.338	0.000238

with a lower degree of probability ($p = 0.008$). All models differ as to the number of variables entering into the final model and their performance.

The topographic model incorporated the maximum slope and the interaction between aspect and maximum slope as explanatory variables (Table 3). Therefore, as univariate analysis suggests, it seems that immature eagles prefer rugged southeast-facing slopes. Values of Cohen's Kappa indicated a good performance for this model (Table 6).

The land-use/land-cover model incorporated only the percentage of pastureland within the circular sampling area as an explanatory variable (Table 4). Despite the fact that the topographic model explained more change in deviance than the land-use model, the former was not statistically better than the latter ($\chi^2 = 2.11$, $P > 0.1$). The land-use/land-cover model gave the lowest value for Akaike's Information Criterion (AIC$_c$), suggesting that it should be preferred to the topographic model. Cohen's Kappa value, obtained using a data-splitting

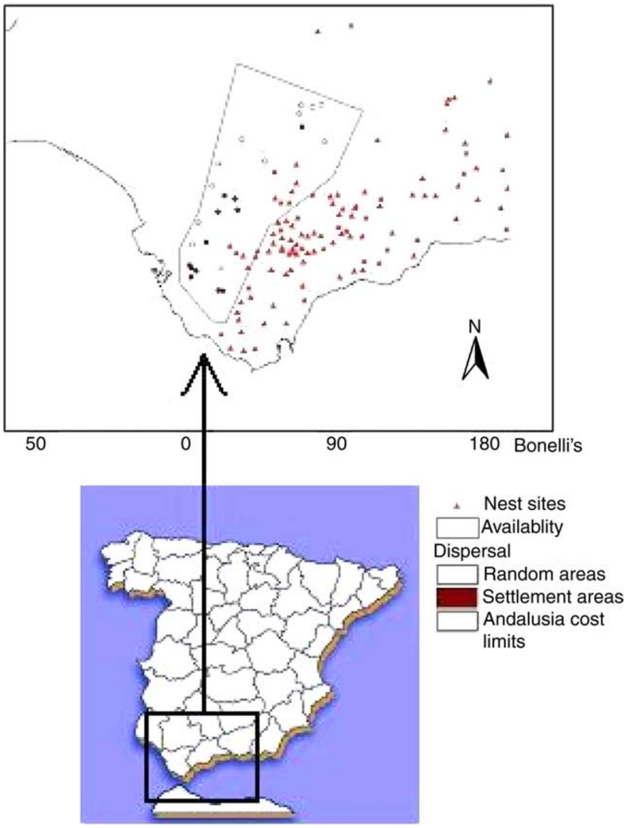

Fig. 1. Study area showing core areas (black solid circles), random areas (white unfilled circles) and breeding areas (triangles). The polygon represents the border of available habitat for immature Bonelli's eagle in South Spain.

strategy, indicates that the performance of the land-use model was the best of all compared models. The topographic model showed the highest Cohen's Kappa value (Table 6) when using one-at-a-time cross-validation (see Fig. 1).

The human disturbance model has a much lower predictive capability than both the topographic and land-use/land-cover models and incorporated two explanatory variables into the final model (Table 5). Cohen's Kappa using one-at-a-time cross-validation or a data-splitting strategy indicated moderate performance. Akaike's Information Criterion (AIC_c) gave the highest value, which suggests that this model has the lowest performance of the all compared models. The predictive cartography is shown in Fig. 2. The land-use model classified 21.83% of the UTM squares as possible areas for immature birds and showed that there is 2961 km^2 of suitable habitat for immature eagles in the study area. The topography model classified 50.23% of the UTM squares as possible areas for immature birds, corresponding to 13,563 km^2 of suitable habitat.

4. Discussion

Our results showed that juveniles selected habitat according to criteria related to topography, land-use/land-cover and human disturbance. The maximum slope was a good predictor of the presence or absence of juveniles in temporary settlement areas. This variable is highly correlated to the average slope found within the circular sampling areas and both variables are indicative of the ruggedness of the terrain (Carrete, 2002). Breeding individuals of this species (Balbontín et al., 2000), as well as other cliff-nesting raptors such as the Golden eagle *Aquila chrysaetos* (Carrete et al., 2000), select breeding habitats with steeper slopes than expected given habitat availability. For a cliff-nesting raptor, a preference in breeding habitat selection for rugged areas might be expected, since slopes are positively correlated with cliff availability (authors, personal observation). Unlike

Table 5
Deviance table for the occurrence model using explanatory variables related to human disturbance of immature Bonelli's eagle habitat selection in south Spain

Term	Coefficient	SE	Residual df	Residual deviance	Change deviance	*p*
Null			21	30.498		
Intercept	−4.90151	2.33				
Dvilla	0.00050	0.0002		24.936	−5.561	0.022
Droad	−0.001152	0.0006		20.927	−4.009	0.048

Table 6
Evaluation of the three habitat selection models, using as explanatory variables those related with the land use, topographic and human disturbance habitat features

	Land use model		Topographic model		Human disturbance
	Kappa	CC	Kappa	CC	Kappa
Cross validation	0.72 ± 0.14	81.8	0.81 ± 0.12	90.9	0.45 ± 0.18
Data splitting	0.71 ± 0.001	85.9	0.62 ± 0.001	81.3	0.29 ± 0.001
AIC_c	13.958		17.415		26.295
% Explained deviance	60.5		53.5		31.4

Cohen's Kappa statistics (±SE) and percentage of concordance are shown using two different strategies to evaluate the models. Akaike's Information Criterion (AIC) and the % of deviance explained by the models are also shown.

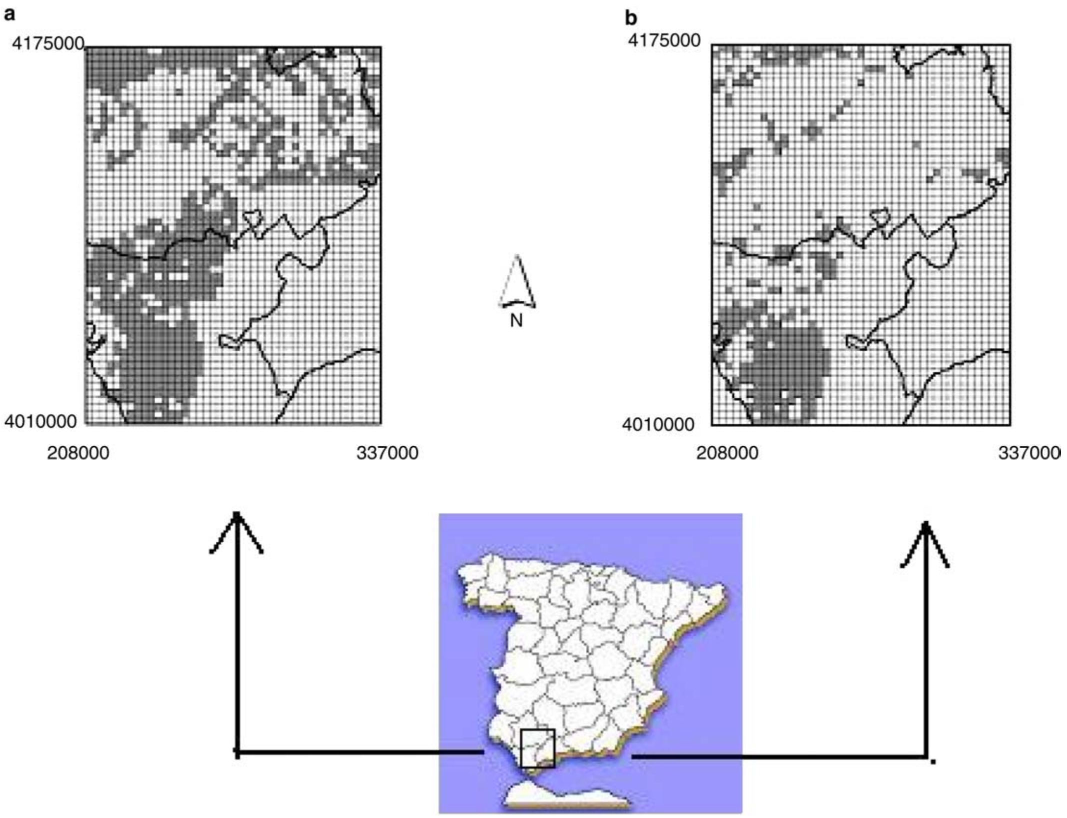

Fig. 2. Predictive cartography for the topographic (a) and land use/land cover (b). White 3 × 3 km UTM squares represent a predicted absence and 3 × 3 km UTM grey squares a predicted presence for immature Bonelli's eagle in South Spain.

breeding birds, juveniles spend most of their time outside breeding areas, mostly in places situated at lower altitudes where there are no cliffs available for nesting. Thus, juveniles would not encounter such an advantage (cliff availability) in dispersal areas. However, other advantages such as an increase in hunting success or energy-saving during flight may also come into play. Thus, we found that the interaction between slope and aspect had a significant effect. Slopes were predominantly oriented southeastwards in dispersal areas. During the morning in the northern hemisphere, the air warms up and ascends first on south-facing slopes. During the night the reverse occurs. Therefore, juveniles may prefer dispersal areas with a predominance of south- or southeast-facing slopes so that they can take advantage of air currents in order to save energy during gliding flight, the main type of hunting flight employed by this eagle.

Ontiveros (1999) found that areas selected by breeding Bonelli's eagle were characterised by steeper slopes than in the total available habitat. Moreover, this author also found that nest sites were oriented preferably southeastwards (mean 120°), and that breeding performance was higher in nests oriented this way (Ontiveros, 1999). Therefore, in Bonelli's eagles terrain ruggedness and orientation seem to be important features both in breeding and dispersal habitat selection. Furthermore, this species has a low wing-aspect ratio (Janes, 1984; Parellada et al., 1984), a fact that may make it more dependent upon air currents than other birds of prey.

Immature eagles also selected habitats with greater percentage of pasture and scrub than expected given availability. Rabbits (*Orictolagus cuniculus*) are the staple prey of this eagle (Gil-Sánchez et al., 1994) and this lagomorph is very common in scrubland and pastureland in the Iberian Peninsula (Moreno and Villafuerte, 1995; Palomares and Delibes, 1997). Furthermore, pastures are open habitats that favour prey detection and predator hunting success (Tjernberg, 1983; Marzluff et al., 1997; McGrady et al., 1997; Ontiveros et al., 2005). Therefore, immature birds selected habitats that were both suitable for its staple prey and open enough to easily detect prey. Breeding eagles also selected habitat with a higher percentage of scrub and pasture than expected given available habitat (Balbontín et al., 2000). Therefore, land-use/land-cover features selected by breeding individuals were similar to the habitats selected by dispersing eagles. The edges between two different land-use types were also important and positively selected by immature eagles. Ecotones can be considered good foraging habitats for raptors (Sánchez-Zapata and Calvo, 1999; Carrete et al., 2000; Sergio et al., 2005) and other rabbit predators (Fernández et al., 2003). In this type of habitats rabbits take refuge in one of the patches and feed in the other and reach here their highest densities

(Lombardi et al., 2003). Edge habitats were selected positively by four forest raptor species in semi-arid Mediterranean habitats (Sánchez-Zapata and Calvo, 1999). According to Carrete et al. (2000), in the Mediterranean Basin the Golden eagle, which also preys upon rabbits, prefers breeding habitats with a high surface area occupied by edges between two different land-cover/land-use patches. Although nearly 70% of available habitat consisted of non-irrigated crops, indicating that juveniles were found predominantly in humanised areas, our results showed that juveniles settled in areas located further away from roads and village than expected.

On the other hand, Mañosa et al. (1998) have studied habitat selection by juvenile Bonelli's eagles in Catalonia (NE Spain). In agreement with our findings, these authors found that juveniles appeared to select dispersal areas based on rabbit and gamebird abundance. Moreover, as we have observed, the quantity (ha) of low bush and dry grassland was significant higher in areas were eagles were present when compared with areas where eagles were absent (Mañosa et al., 1998). However, unlike our findings, these authors found no differences between occupied and unoccupied dispersal areas in either relief or altitude. We believe that these differences found in habitat selection with regard to topographic features may be caused by the different methodology employed in these two studies. Whereas we used radio-telemetry, Mañosa et al. (1998) conducted car counts in the main non-breeding areas. The use of radio-telemetry enabled us to identify more intensively used areas (core areas) and to compare them with known available habitat. In our study, immature eagles were considered to be absent from all areas that were not intensively used. However, the above-cited authors only considered eagles to be absent from those UTM squares in which no immature birds were observed during their car counts, a difference which could explain some of the inconsistencies found between the two studies.

Our study shows that the use of digital cartography of land-use/land-cover and/or topographic features, as well as Geographic Information Systems (G.I.S.) and Generalised Linear Models, could be useful for correctly predicting habitat suitability for immature Bonelli's eagles. More importantly, these models could be used to identify other areas that juveniles might use within their distribution ranges and thus facilitate the design of special conservation programmes for reducing the causes of mortality (for example, electrocution on power lines) in juvenile eagles or for managing habitat to protect this highly endangered bird of prey in Europe.

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