Identifying potentially suitable nesting habitat for golden eagles applied to 'important bird areas' design

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Abstract

Geographic information systems (GIS)-based habitat-suitability modelling is becoming an essential tool in conservation biology. A multi-scale approach has been proposed as a particularly useful way to identify different factors affecting habitat preferences. In this paper, we developed predictive models of potentially suitable habitat for golden eagles *Aquila chrysaetos* at three spatial scales in a representative Mediterranean area on the Iberian Peninsula. We used logistic regression through a generalized linear model (GLM) to model golden eagle breeding habitat preferences. The best-occurrence GLM models were those that involved topographic factors as independent predictors. Golden eagles seemed to prefer rugged and higher places of the study area for nesting. Climatic factors identified cold temperatures in January and temperate ones in July as the best predictors of eagles' occurrence. This was also higher in places with less agricultural areas and higher surface of pine forests. The distribution of potentially suitable area matches the distribution of mountain ranges, mainly in inner sectors of the study area. In contrast, potentially suitable nest sites in coastland areas remain unoccupied by golden eagles. Avoidance of coastland places for nesting may be due to the synergistic effects of human avoidance and the occurrence of potential competitors, like the endangered Bonelli's eagle *Hieraaetus fasciatus*. When mapped at a fine spatial resolution, the best GLM model identified large areas that fall outside the current network of protected areas. We therefore propose three new important bird areas for the region.

Introduction

The study of the distribution of organisms has been a major topic in ecology, especially the identification of underlying patterns and causal factors (Channell & Lomolino, 2000; Newton, 2003; Whitfield, 2005). Recently, the number of papers modelling species habitat selection has increased exponentially, mainly due to the wide use of geographical information systems (GIS) and the development of powerful statistical methods (Lehmann, Overton & Austin, 2002; Cabeza *et al*., 2004; Engler, Guisan & Rechsteiner, 2004; Beissinger *et al*., 2006; Piorecky & Prescott, 2006).

Predictive models have been used in conservation biology in many different fields, including the monitoring of scarce species, predicting range expansions, identifying suitable locations for reintroductions (Yanez & Floater, 2000), designing protected areas (Li *et al*., 1999; Larson *et al*., 2004), helping wildlife management (Bradbury *et al*., 2000; Nams, Mowat & Panian, 2006) and even assessment of processes of global impact, like climate change (Berry *et al*., 2002; Thuiller, 2003; Araújo *et al*., 2004; Skov & Svenning, 2004).

Habitat preference models aim to identify relationships between habitat features and species distribution (Nicholls, 1989; Buckland & Elston, 1993; Bustamante & Seoane, 2004; Gibson *et al*., 2004). Such models are static and assume equilibrium or at least pseudo-equilibrium in contrast to mechanistic or dynamic models (Guisan & Zimmermann, 2000). However, they are data based and rely on direct field observations so biotic interactions like competitive exclusion are intrinsically considered (Guisan & Zimmermann, 2000).

A multi-scale approach has been proposed as a particularly useful way to identify different factors affecting habitat preferences (Johnson, 1980; Jokimäki & Huhta, 1996; Martínez, Serrano & Zuberogoitia, 2003; Store & Jokimäki, 2003; Seoane *et al*., 2006), as ecological patterns depend on the spatial scale at which they are analyzed (Wiens, 1989; Levin, 1992; Bevers & Flather, 1999; Graf *et al*., 2005). Also, it has been suggested that hierarchical processes affect nest site selection (Orians & Wittenberger, 1991; Martínez *et al*.,

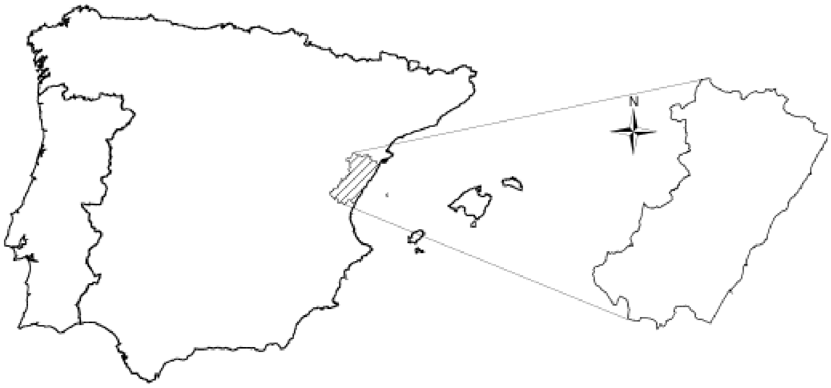

Figure 1 Study area. Left: The Iberian Peninsula. Castellón province is shaded. Right: Castellón province.

2003; López-López *et al.*, 2006); hence, a GIS-based multi-scale approach may be particularly useful when investigating habitat selection in species with special conservation concern such as large raptors.

The golden eagle *Aquila chrysaetos* is a large-sized raptor distributed along the Paleartic, Neartic and marginally in the Indomalayan and African region (Del Hoyo, Elliot & Sargatal, 1994; Ferguson-Lees & Christie, 2001). Global population trends have not been quantified, but well-monitored populations appear to be stable or increasing (Ferguson-Lees & Christie, 2001). At a global extent, it is considered as least concern (LC; BirdLife International, 2005). In Europe, population estimates range from 8400 to 11 000 breeding pairs and it is evaluated as Rare (BirdLife International, 2004). Spain holds between 1440 and 1500 breeding pairs (Arroyo, 2004; BirdLife International, 2004). The species experienced a population decline in Spain between 1960 and 1990 but is currently stable or even increasing and therefore is considered as near threatened (NT; Arroyo, Ferreiro & Garza, 1990; Arroyo, 2004). Shooting, bait poisoning, electrocution, trapping and habitat loss are considered the main causes of non-natural mortality (McGrady, 1997; Watson, 1997; Arroyo, 2004).

In the Iberian Peninsula, territorial breeding pairs of golden eagles occupy large home ranges and are mostly present alongside mountain ranges, with a regular or aggregated distribution pattern (Urios, 1986; López-López *et al.*, 2004). Many of these areas are currently the object of development plans like windfarms, wiring networks and urban plans that will introduce habitat changes. Consequently, golden eagles and other raptors could see their potential habitat reduced, which may in turn result in population declines. In this framework, studies aimed at identifying suitable areas for the species are of utmost importance.

Here, we develop predictive models that could aid in defining conservation strategies through identification of potentially suitable habitat for golden eagles. We use a multi-scale modelling approach to identify nesting habitat preferences of a population of golden eagles in the east of the Iberian Peninsula. We first identify habitat preferences at three spatial scales and then select the best models using a threshold-independent model assessment procedure. Finally, we implement the prediction of the best model on a digital fine-grain cartography.

Study area

Our study area comprises the Castellón province (located in the east of the Iberian Peninsula) (Fig. 1), encompassing 6670 km^2 (40°47′N, 39°42′S, 0°51′W, 0°32′E; 0–1814 m a.s.l.). We selected this area because it is a typical Mediterranean landscape with great habitat and climatic heterogeneity varying from sea level to higher mountains. The area is geomorphologically characterized as the confluence of two mountain ranges: the Iberian System, oriented north-west–south-east, on the one hand, and the east–north-east-orientated structures of the Catalánides, parallel to the coastline, resulting on a much folded peak line. Climatologically, it belongs to the Mediterranean area, with an annual mean temperature varying between 17 °C in the coast area and 8 °C in the inner highlands. The annual mean precipitation varies from 400 to 900 mm, with maximum values during the autumn and minimum values in summer (Quereda, Montón & Escrig, 1999). In terms of Bioclimatology, the study area supports an assortment in vegetation types and ecosystems (Rivas-Martínez, 1987). This heterogeneity is also manifest locally, where cultivation zones, both irrigated and non-irrigated, alternate with forest patches dominated by pines (*Pinus* spp.) and, to a lesser extent, oaks (*Quercus* spp.) and *Juniperus* spp. The area also includes six important bird areas (IBAs) protected according to regional laws as special bird protection areas (Viada, 1998) (the entire IBAs inventory is available at www.seo.org/ibas.cfm) (see Fig. 2).

Methods

Censuses

We monitored golden eagles from 2000 to 2005, counting 25 different breeding territories. During each breeding season, all known territories and potential ones were visited.

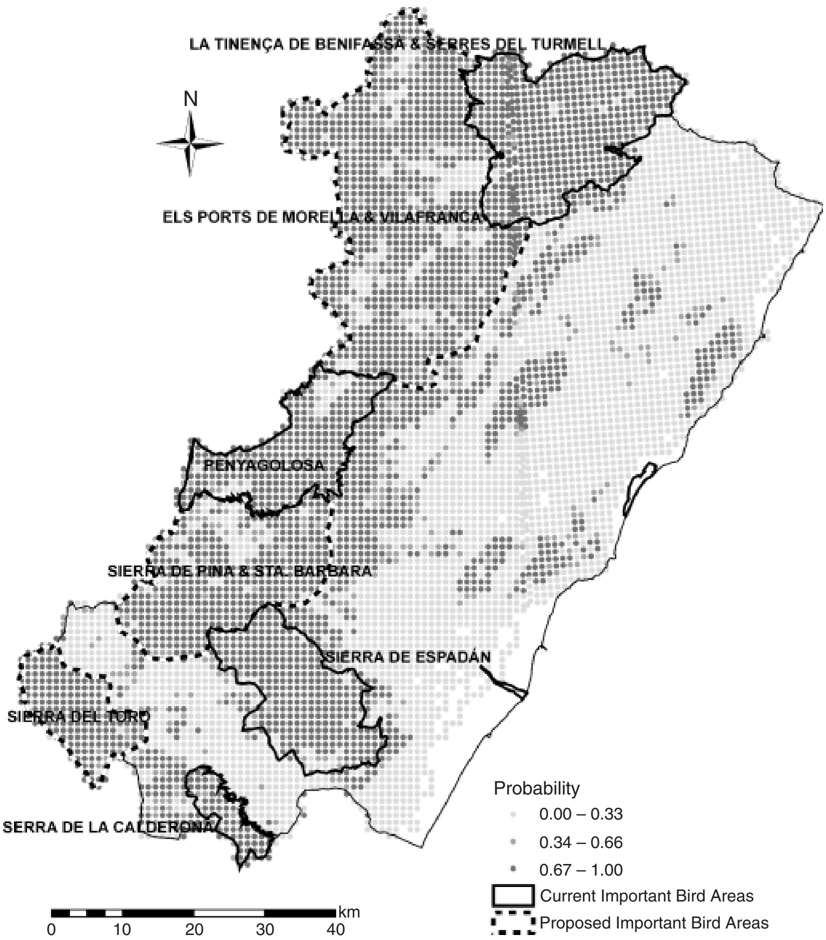

Figure 2 Potentially suitable habitats for Golden eagle *Aquila chrysaetos* nesting in the Castellón province according to the best logistic regression model. Protected and proposed Important Bird Areas are also shown.

Observations were made with a $\times 20$–60 © Leica Televid 77 telescope during clear days at 300 m from nesting cliffs to avoid disturbance to eagles. A territory was considered occupied if we observed nests with green branches, typical pair behavior, courtship, brood-rearing activity or young (Newton, 1979; Steenhof & Kochert, 1982). Many pairs changed their nests during the study period to alternative ones inside the same territory (in some cases, a few meters away in the same cliff). In these cases, we took as reference for calculations the most used nest. A minimum of three visits were made to every reproductive territory to confirm the presence/absence of the pairs, the existence of new nests and the presence of hatched chicks.

Selection of scales and measurement of habitat variables

To study breeding habitat preferences of golden eagle, a case–control design was used (Hosmer & Lemeshow, 2000; Keating & Cherry, 2004) corresponding to a sampling protocol C described in Manly *et al.* (2002). First of all, nest sites were georeferenced on a digital shape. Then, three concentric spatial scales were considered as follows: a nest site scale with a 1×1 km UTM square plot containing the nest; a near nest environment scale including a 3×3 km UTM square plot containing the previous plot; and finally a landscape-level scale with a 5×5 km UTM square plot containing the other two. Although there are other possible approaches in selection of the scales (i.e. concentric circles, radiotelemetry measurements, etc.), we used UTM squares because they are a common reference in ornithological studies (see e.g. Penteriani & Faivre, 1997; Ontiveros, 1999; Martínez *et al.*, 2003) and have been used in large-scale projects like the last Spanish Breeding Bird Atlas (Martí & Del Moral, 2003), allowing comparisons with other study areas.

Both occupied ($n = 25$) and randomly selected unoccupied ($n = 25$) squares were independently sampled to gather information on 22 variables using a GIS. Variables measured included topographic, climatic and land-use factors (Table 1). These independent predictors were selected because they are indirect measures of breeding habitat features, and thus, they are expected to predict the realized ecological niche (Guisan & Zimmermann, 2000).

Table 1 Explanatory variables used to characterize Golden eagle *Aquila chrysaetos* nesting habitat selection in a Mediterranean area

Group	Name	Description
Topographic	Altitude	Mean altitude (m) above sea level in the sampling unit (SU)
	Aspect	Mean orientation (°) in the SU
	Slope	Mean slope (%) in the SU
Climate	Tempjanuary	Mean temperature (°) in January in the SU
	Tempjuly	Mean temperature (°) in July in the SU
	Precipjanuary	Mean rainfall (L m^{-2}) in January in the SU
	Precipjuly	Mean rainfall (L m^{-2}) in July in the SU
	Evapjanuary	Mean potential evapotranspiration (cm) in January in the SU
	Evapjuly	Mean potential evapotranspiration (cm) in July in the SU
	Frostdays	Mean number of freezing days in the SU
	Snowdays	Mean number of snow-covered days in the SU
	Gorzinsky	Gorzinsky continentality index [$K=(1.7\times$ thermal amplitude/sin latitude$)-20.4$]
Land use	Disperse forest	Surface (m^2) of forest with tree coverage <50% in the SU
	Agricultural	Surface (m^2) of irrigated and non-irrigated cultures (*Citrus* spp., *Rosa* spp., *Olea* spp., etc.) in the SU
	Unproductive	Surface (m^2) of abandoned cultures and water in the SU
	Scrubland	Surface (m^2) of Mediterranean scrubland areas (*Rosmarinus* spp., *Ulex* spp., *Cistus* spp., etc.) in the SU
	Fire	Surface (m^2) of burnt areas in the last 10 years in the SU
	Halepensis	Surface (m^2) of *Pinus halepensis* forests with tree coverage >50% in the SU
	Suber/faginea	Surface (m^2) of *Quercus suber* and *Quercus faginea* forests in the SU
	Pinaster/sylvestris	Surface (m^2) of *Pinus pinaster* and *Pinus sylvestris* forests in the SU
	Nigra	Surface (m^2) of *Pinus nigra* forests in the SU
	Ilex	Surface (m^2) of *Quercus ilex* forests in the SU

Habitat variables were calculated as reported by López-López *et al*. (2006). Topographic variables were obtained from a digital elevation model (DEM) with an accuracy of 50 m pixels of horizontal and vertical resolution. It was created by a triangular irregular network (TIN) method based on vector data of contour lines with a 10 m accuracy. The slope was considered as the maximum rate of change in elevation across triangles in the TIN. From the vectorial data of the TIN, we obtained a raster continuous grid from which values were obtained. Aspect was calculated as the mean orientation in each cell. Land-use variables were obtained from a land-use and land-cover digital map, based on aerial photography (0.5 m resolution), taken from 1996 to 2000 and edited from 2001 to 2003. This cartography is commercialized and available to the public in metadata shape format from the Valencian Cartographic Institute (scale 1:10 000) (www.gva.es/icv/). Climatic variables were obtained from the Climatic Atlas of the Valencian Community (Pérez-Cueva, 1994) and the Meteorological National Institute of Spain (www.inm.es). Data correspond to the period 1961–1990, and were improved on a digital shape by interpolation of 50-m contours using the inverse distance weighted (IDW) interpolation method with 50 m horizontal resolution. This method estimates grid cell values by averaging the values of sample data points in the vicinity of each cell and is useful to predict values in a raster from a limited sample of data points. In all cases, a shape containing the U.T.M. squares for each scale was superimposed. Then, we applied the summarizing method to compute the variables' average or value. All calculations were performed with ArcView v. 3.2. (ESRI Inc., 1999).

Statistical analysis

Preliminary analysis and univariate comparisons

Previous to model formulation, a multi-colinearity test based on the variance inflation factor (VIF) analysis was performed (Montgomery & Peck, 1982) to avoid overparametrization (Edwards, 1985; Grand & Cushman, 2003; Poirazidis *et al*., 2004). The mean values for occupied and unoccupied variables were compared by means of two-tailed Wilcoxon's rank sum statistics (Sokal & Rohlf, 1981). Difference in mean aspect was tested with circular statistics (Watson–Williams test for two samples; Zar, 1984). Statistical significance was set at $P<0.05$.

Model formulation

We used logistic regression through a generalized linear model (GLM) to model golden eagle breeding habitat preferences. The dependent variable (presence/absence of eagles) was binomial, and we subsequently used the logit as the link function. The error structure was assumed to be binomial (McCullagh & Nelder, 1989). A forward stepwise procedure was performed to test the statistical significance of each variable in turn. Those variables that contributed to the largest significant change in the deviance from the null model were selected as best predictors. Model fit was assessed by examining deviance and Pearson' χ^2 residuals (Nicholls, 1989; S-PLUS, 2001). All models were performed using S-PLUS version 6.1 for Windows (Insightful Corp., 2002).

We built three different occurrence models at each scale by including each subset of topographic, climate and land-use variables as independent predictors separately. Hence, nine models were created (three models by three spatial scales). We did not perform a general model including all variables because introducing a large number of predictors results in overparametrization and overfitting problems, and consequently is not statistically recommended (Harrel, 2001; Grand & Cushman, 2003; Poirazidis *et al.*, 2004; Balbontín, 2005).

Model evaluation

To select the most parsimonious model, and taking into account that our sample size divided by the number of variables was less than 40, a second-order Akaike's information criterion corrected for small sample size (AIC_c) was computed for each model (Burnham & Anderson, 2002; Johnson & Omland, 2004). The lesser the AIC_c, the better the model (Sakamoto, Ishiguro & Kitagawa, 1986). Furthermore, to test the predictive performance of each model, a receiver operating characteristic plot (ROC curve) was computed to asses the power of the logistic models (Pearce & Ferrier, 2000; Gibson *et al.*, 2004). This is a threshold-independent approach in the assessment of logistic regression models (Manel *et al.*, 1999; Osborne, Alonso & Bryant, 2001; Luck, 2002; Suárez-Seoane, Osborne & Alonso, 2002) and represents a plot of true positive cases (sensitivity) against corresponding false-positive cases (1–specificity) across a range of threshold values (Fielding & Bell, 1997). The larger the area under the ROC function (AUC), the better the model (Pearce & Ferrier, 2000). The AUC varies from 0.5 to 1. A completely random predictor would yield 0.5 and a perfect classification would yield 1. The AUC was based on a non-parametric assumption (Manel, Williams & Ormenrod, 2001). All computations were performed using SPSS version 12.0 for Windows (SPSS Inc., 2003).

Predictive cartography

The best predictive model was implemented in a GIS using ArcView v. 3.2. (ESRI Inc., 1999). In order to obtain values on the scale of the original response variable predictions were transformed into values between 0 and 1 by calculating the inverse of the link function (Guisan, Weiss & Weiss, 1999). With binomial GLM, the inverse logit transformation was calculated as: $p(y) = \exp(\mathrm{LP})/(1+\exp(\mathrm{LP}))$, where LP is the linear predictor (Guisan & Zimmermann, 2000).

With the GIS, those variables selected in the best logistic predictive model were calculated for all UTM squares in Castellón province ($n = 6715$). Subsequently, we applied the best model with these values and we built a raster data shape containing all predictive values of golden eagle probability of occurrence in the study area. Three different groups were represented in the predictive map, according to three intervals of probability of occurrence: low-suitability habitat (values from 0 to 0.33); medium-suitability habitat (from 0.34 to 0.66); and high-suitability habitat (from 0.67 to 1). Unlike other studies, we did not use a unique threshold (usually probability values equal to 0.5) to classify the squares as expected presence or absence because it lacks biological meaning (Hosmer & Lemeshow, 2000).

Results

Significant differences were found when comparing occupied versus unoccupied squares (Table 2). Note that all tests are still significant after sequential Bonferroni's corrections (Rice, 1989). Yet, following Gotelli & Ellison (2004) we opted to report the original *P*-values. At all scales, occupied and unoccupied squares showed similar differences regarding topographic, climatic and land-use variables. In relation to topographic factors, areas where golden eagles were present were higher and more rugged than unoccupied ones (Table 2). Aspect was not different between them. In terms of climate, only rainfall in January did not differ between occupied and unoccupied sites. Finally, occupied and unoccupied sample units showed significant differences in surface occupied by *Pinus nigra* forests (higher in occupied sites) and agricultural areas (higher in unoccupied ones; Table 2).

Initially, we fitted GLMs including all cases ($n = 50$), but after analysis of residuals we found that four cases (two occupied and two unoccupied squares) displayed high residual deviances (more than two units). Consequently, we performed all models using only 46 cases (23 occupied vs. 23 unoccupied squares).

The best model was that found for topographic variables at a 1×1 scale (Table 3). This model included the altitude and slope as best predictors of golden eagle occurrence, and showed the lowest AIC_c value (Table 4). Similar results were found at the three scales when considering topographic models: altitude and slope were selected as the best predictors. No model included aspect as a significant predictor (Table 3).

The same occurred in relation to climatic and land-use occurrence GLM models. At the three scales considered, temperature in January (negatively) and temperature in July (positively) were selected as the best predictors, thus indicating a preference for cold places in winter and temperate ones in summer. Furthermore, when considering land-use models, surface occupied by *P. nigra* forests and both irrigated and non-irrigated cultures were included as the best predictors (Table 3) with a good model performance according to the AUC (Table 4).

According to the topographic occurrence model, the suitable habitat for nesting extends along inner areas and mountain ranges (Fig. 2). The high-suitability area includes $3167\,km^2$ (about 47.17% of the total extent of the study area). By contrast, the low-suitability area covers $3001\,km^2$ (about 44.70% of the Castellón province) and the medium-suitability area covers only $546\,km^2$. The IBAs, now protected by regional laws, comprise around 33.34% of the high-suitability habitat within the entire study area.

Table 2 Differences between Golden eagle's *Aquila chrysaetos* occupied and unoccupied sample units at three different spatial scales

			Mean ± SD				
Scale	Group	Variable	Occupied sites	Random sites	*W*	*Z*	*P*
1 × 1	Topographic	Altitude	850.54 ± 196.84	503.98 ± 351.89	450.00	−3.638	0.0002747
		Slope	21.27 ± 5.82	11.12 ± 6.39	409.00	−4.434	0.0000093
	Climate	Tempjanuary	6.30 ± 1.53	8.39 ± 2.06	447.00	−3.696	0.0002188
		Tempjuly	21.68 ± 1.06	23.03 ± 1.68	454.00	−3.560	0.0003703
		Precipjuly	27.13 ± 7.23	18.95 ± 6.98	123.00	−3.677	0.0002361
		Evapjanuary	1.61 ± 0.24	1.91 ± 0.29	442.00	−3.793	0.0001487
		Evapjuly	13.18 ± 0.51	13.91 ± 0.80	451.00	−3.619	0.0002962
		Frostdays	40.51 ± 14.96	22.58 ± 22.87	441.00	−3.813	0.0001375
		Snowdays	4.56 ± 3.52	1.24 ± 1.74	415.00	−4.317	0.0000158
		Gorzinsky	20.41 ± 1.34	18.65 ± 1.18	429.00	−4.045	0.0000522
	Land use[a]	Nigra	0.18 ± 0.30	0.04 ± 0.20	529.00	−2.904	0.0036856
		Agricultural	0.05 ± 0.09	0.30 ± 0.31	453.00	−3.652	0.0002601
3 × 3	Topographic	Altitude	856.73 ± 199.25	516.55 ± 342.67	447.00	−3.696	0.0002188
		Slope	17.39 ± 3.95	10.99 ± 5.52	418.00	−4.259	0.0000205
	Climate	Tempjanuary	6.31 ± 1.52	8.39 ± 2.05	447.00	−3.696	0.0002188
		Tempjuly	21.68 ± 1.06	23.03 ± 1.66	454.00	−3.560	0.0003703
		Precipjuly	27.09 ± 7.21	18.94 ± 6.92	449.00	−3.657	0.0002547
		Evapjanuary	1.61 ± 0.24	1.91 ± 0.29	444.00	−3.754	0.0001737
		Evapjuly	13.18 ± 0.51	13.90 ± 0.79	449.50	−3.648	0.0002645
		Frostdays	40.52 ± 14.94	22.53 ± 22.67	442.00	−3.793	0.0001487
		Snowdays	4.55 ± 3.52	1.24 ± 1.73	414.00	−4.337	0.0000145
		Gorzinsky	20.41 ± 1.33	18.65 ± 1.19	429.00	−4.045	0.0000522
	Land use[a]	Nigra	1.67 ± 2.57	0.24 ± 1.13	524.50	−2.648	0.0081036
		Agricultural	0.99 ± 1.05	3.37 ± 2.22	420.00	−4.220	0.0000244
5 × 5	Topographic	Altitude	865.52 ± 209.72	527.19 ± 336.51	454.00	−3.560	0.0003702
		Slope	15.79 ± 3.26	11.33 ± 5.60	480.00	−3.056	0.0022435
	Climate	Tempjanuary	6.31 ± 1.52	8.40 ± 2.03	448.00	−3.677	0.0002361
		Tempjuly	21.68 ± 1.05	23.04 ± 1.64	453.00	−3.580	0.0003438
		Precipjuly	27.07 ± 7.15	18.93 ± 6.83	448.00	−3.677	0.0002361
		Evapjanuary	1.61 ± 0.24	1.91 ± 0.29	443.00	−3.774	0.0001607
		Evapjuly	13.18 ± 0.51	13.90 ± 0.78	451.00	−3.619	0.0002962
		Frostdays	40.48 ± 14.88	22.42 ± 22.30	442.00	−3.793	0.0001487
		Snowdays	4.54 ± 3.51	1.24 ± 1.71	414.00	−4.337	0.0000145
		Gorzinsky	20.41 ± 1.32	18.64 ± 1.19	430.00	−4.026	0.0000567
	Land use[a]	Nigra	3.84 ± 5.78	0.52 ± 2.35	506.00	−2.923	0.0003464
		Agricultural	3.55 ± 2.99	10.31 ± 6.21	417.00	−4.278	0.0000188

Only significant variables are shown.
[a]Units expressed in km^2.

Furthermore, the high-suitability habitat represents between 81.58 and 92.72% of these areas (Table 5).

Discussion

We used data on nest locations to develop predictive models of a potentially suitable habitat for golden eagle breeding in a Mediterranean landscape. Our results show that golden eagles' habitat preferences are shaped by similar factors at the three spatial scales considered. These results were different from those found with similar methodology with other cliff-nesting raptors like Bonelli's eagles *Hieraaetus fasciatus* or Eurasian eagle owls *Bubo bubo*, where different factors were selected at different spatial scales (Martínez *et al.*, 2003; López-López *et al.*, 2006).

The best occurrence GLM models were those that involved topographic factors as independent predictors. Among them, altitude and slope were selected as the best predictors. The species seems to prefer rugged and higher places of the study area for nesting. As cliff availability is correlated to the ruggedness of the terrain (Carrete, Sánchez-Zapata & Calvo, 2000; Balbontín, 2005), it is likely that the observed preference for rugged places is actually reflecting the availability of cliffs for nesting. Furthermore, climatic factors identified cold temperatures in January and temperate ones in July as the best predictors of eagles' occurrence. Finally, golden eagle's probability of occurrence is also higher in places with less agricultural areas and higher surface of pine forests.

Table 3 Deviance table for the occurrence models of Golden eagle *Aquila chrysaetos* nesting habitat selection in a Mediterranean area at different spatial scales

Scale	Model	Term	Coefficient	SE	*t*-ratio	Residual d.f.	Residual deviance	Change deviance	*P*
1 × 1	Topographic	Null				42	63.770		
		Intercept	−11.8542	5.7042	−2.0781720				
		Altitude	0.0069	0.0031	2.2145192		47.567	−16.203	0.0000569
		Slope	0.5835	0.2210	2.6397782		19.930	−27.637	0.0000001
	Climatic	Null				36	63.770		
		Intercept	−74.7389	157.1393	−0.4756217				
		Tempjanuary	−6.3859	9.3463	−0.6832581		50.322	−13.448	0.0002453
		Tempjuly	3.9962	7.8381	0.5098419		44.161	−6.160	0.0130659
	Land use	Null				35	63.770		
		Intercept	6.7715	10.9860	0.6163736				
		Agricultural	-1.74×10^{-5}	1.19×10^{-5}	−1.4637825		43.278	−20.492	0.0000060
3 × 3	Topographic	Null				42	63.770		
		Intercept	−4.7277	4.0389	−1.1705560				
		Altitude	0.0043	0.0019	2.2305178		49.933	−13.837	0.0001994
		Slope	0.4528	0.1724	2.6258108		34.944	−14.989	0.0001081
	Climatic	Null				36	63.770		
		Intercept	−41.7580	162.2745	−0.2573294				
		Tempjanuary	−8.8076	10.8789	−0.8096043		51.728	−12.042	0.0005203
		Tempjuly	6.7741	9.3197	0.7268598		46.583	−5.145	0.0233114
	Land use	Null				36	63.770		
		Intercept	8.6482	12.8639	0.6722802				
		Nigra	-5.74×10^{-7}	1.45×10^{-6}	−0.3959649		58.088	−5.682	0.0171439
		Agricultural	-1.91×10^{-6}	1.62×10^{-6}	−1.1766797		41.927	−16.161	0.0000582
5 × 5	Topographic	Null				42	63.770		
		Intercept	−8.7849	4.6305	−1.8971649				
		Altitude	0.0047	0.0019	2.5332555		47.219	−16.551	0.0000474
		Slope	0.3045	0.1706	1.7852136		37.419	−9.800	0.0017450
	Climatic	Null				36	63.770		
		Intercept	−72.5270	157.6468	−0.4600601				
		Tempjanuary	−6.1443	9.3117	−0.6598458		49.976	−13.794	0.0002041
		Tempjuly	3.7981	7.8197	0.4857112		44.004	−5.972	0.0145302
	Land use	Null				36	63.770		
		Intercept	4.5078	23.3296	0.1932233				
		Nigra	5.40×10^{-8}	9.31×10^{-7}	0.0580210		57.128	−6.642	0.0099641
		Agricultural	-4.87×10^{-7}	1.01×10^{-6}	−0.4842661		37.793	−19.335	0.0000110

Only significant predictors are shown; SE, standard error.

Table 4 Performance of the habitat selection models for Golden eagle *Aquila chrysaetos* at three different spatial scales using topographic, climate and land use as independent predictors

Scale	Model	AIC_c	ΔAIC_c	AUC	SE	Lower CI	Upper CI	*P*
1 × 1	Topographic	27.955	0.000	0.972	0.020	0.933	1.010	4.22×10^{-8}
	Climatic	64.961	37.006	0.887	0.053	0.783	0.990	7.03×10^{-6}
	Land use	65.719	37.764	0.879	0.049	0.783	0.975	1.06×10^{-5}
3 × 3	Topographic	43.070	15.115	0.907	0.042	0.825	0.989	2.20×10^{-6}
	Climatic	66.572	38.618	0.879	0.053	0.776	0.982	4.22×10^{-8}
	Land use	62.790	34.835	0.900	0.044	0.813	0.987	3.38×10^{-6}
5 × 5	Topographic	46.368	18.414	0.888	0.051	0.788	0.989	1.06×10^{-5}
	Climatic	64.914	36.960	0.892	0.051	0.792	0.992	2.20×10^{-6}
	Land use	58.237	30.282	0.932	0.035	0.864	1.000	5.17×10^{-7}

AIC_c, small sample unbiased Akaike information criterion; ΔAIC_c, difference in AIC_c in relation to the best model; AUC, Area under curve; SE, standard error; CI, confidence interval.

Table 5 Potentially suitable habitat for Golden eagle *Aquila chrysaetos* nesting included in important bird areas (IBA) protected by regional laws and proposed in this study

Legal status	IBA	Low	Medium	High	Total
Protected	Tinença de Benifassà	21 (4.02)	17 (3.26)	484 (92.72)	522
	Penyagolosa	29 (10.47)	10 (3.61)	238 (85.92)	277
	Sierra de Espadán	25 (8.07)	13 (4.19)	272 (87.74)	310
	Sierra de la Calderona	4 (5.26)	10 (13.16)	62 (81.58)	76
Proposed	Els Ports de Morella & Vilafranca	133 (12.70)	114 (10.89)	800 (76.41)	1047
	Sierra de Pina & Sta. Bárbara	57 (12.50)	55 (12.06)	344 (75.44)	456
	Sierra del Toro	5 (2.86)	14 (8.00)	156 (89.14)	175

Units are expressed in km^2 and percentage of total extent of the IBA is shown in parentheses.

The distribution of potentially suitable area matches the distribution of mountain ranges, mainly in inner sectors of the study area (Fig. 2). In contrast, coastland areas, where there is also a potentially suitable habitat for nesting, remain unoccupied by golden eagles. We consider that there is a possible avoidance of coastland places for nesting in our study area due to the synergistic effect of human avoidance and potential competitor occurrence.

Persecution has been identified as a negative factor affecting breeding performance and population spatial distribution. Whitfield *et al.* (2004) found that persecution was associated with a reduction in the age of first breeding, territory vacancies and even the use of territories by non-breeding immatures. In our study area, human population is congregated along the coast line (population density about 284.7 inhabitants km^{-2}) with low densities towards inner sectors of the province (about 5.7 inhabitants km^{-2}; IVE, 2005). As other studies suggest, golden eagles might be avoiding coastal humanized places for nesting because of their potential 'low quality' for breeding (Carrete *et al.*, 2002; Whitfield *et al.*, 2004).

The presence of potential competitors has been suggested as a possible limitation factor of potential territories occupation (Carrete *et al.*, 2005, 2006). In our study area, golden eagles coexist sympatrically with Bonelli's eagles, exhibiting a marked segregated distribution pattern among them (López-López *et al.*, 2004). In nearby geographic areas (like Murcia and Andalucía, in Spain), a site-dependent population framework for both and similar species like Spanish imperial eagle *Aquila adalberti* has been reported, with a density-dependent regulation by habitat heterogeneity generating differences in the age of breeders (Ferrer & Bisson, 2003; Carrete *et al.*, 2006). Carrete *et al.* (2006) proposed that, in areas of high density, the proximity of other eagle territories resulted in a lower breeding performance of both species in combination with age effects.

Climate might also restrict potential distribution of the species. In other study areas, a negative relationship between percentage of successful laying pairs and the frequency of hot days during the breeding season for golden eagle has been reported (Steenhof, Kochert & McDonald, 1997). In addition, these authors did not find a relationship between winter severity and the number of breeding pairs occupying nesting territories. We consider that eagles could be selecting inner sectors of our study area because of the combination effect of higher tolerance to climatic severities (in contrast to potential competitors like Bonelli's eagle), and human and competitor avoidance.

Habitat modelling is becoming an important management tool in conservation biology. However, model applications in conservation assessment require the understanding of model attributes, methodological assumptions and accurate testing of model predictions (Keating & Cherry, 2004; Beissinger *et al.*, 2006). Recently, some studies had emphasized some biases and shortcomings of stepwise multiple regression (Whittingham *et al.*, 2006). To prevent it, we used an information theoretic approach by means of AIC_c for model selection. It allows model uncertainty to be measured at the same time as parameter uncertainty to assess the likely bias in parameters resulting from the selection procedure. In our case, our models could be considered heuristic, and causal relationships between predictors and model outcomes have been considered cautiously (MacNally, 2000; Burnham & Anderson, 2002; Beissinger *et al.*, 2006). Finally, conservation decisions should not be taken on the basis of a single species requirements (Pressey *et al.*, 1993). Yet, top predators like golden eagle have been postulated as useful 'focal species' for reserve design due to their 'umbrella effect' over other species (Lambeck, 1997; Roberge & Angelstam, 2004; Sergio, Newton & Marchesi, 2005; Sergio *et al.*, 2006).

The Valencian community, which includes the study area, lacks enough IBAs protected by regional laws, and European community has pronounced sentence on this issue, forcing regional government to declare more IBAs. Our results suggest that IBAs protected now a days include large surface of high suitability habitat for golden eagle nesting. However, there are many high suitability areas outside the IBAs that remain unprotected. In the light of these considerations, we suggest that three new IBAs, that would include an important fraction of golden eagle population could be declared (Table 5, Fig. 2). With the three new IBAs, around 41.05% of the high-suitability area of golden eagle would be protected.

We consider that models obtained in this study are useful to manage golden eagles in Mediterranean landscapes. The predictive cartography of suitable habitat shown could serve to adopt conservation measures in relation to IBA design. Finally, a multi-scale approach should be considered in further modelling habitat preferences in relation to conservation purposes (Vaughan & Ormerod, 2003; Nams *et al*., 2006; Seoane *et al*., 2006).

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