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Distribution of Bonelli's Eagle *Aquila fasciata* in southern Spain: scale may matter

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Abstract. Understanding factors that determine the distribution of the endangered Bonelli's Eagle requires different approaches and analytical tools. These factors may differ depending on the spatial scale at which they act. Bonelli's Eagle distribution in Spain has been studied previously using local and large (nation-wide) study area sizes, and human activities seemed not to affect negatively the occupancy of breeding territories. To study the factors affecting the species at an intermediate spatial scale we modelled Bonelli's Eagle distribution in Málaga province (S Spain), where the breeding density is the highest known in Europe. We applied a favourability function based on generalized linear models using the presence/absence of breeding territories of the species, and the values of a set of variables related to climate, topography, interspecific competition with Golden Eagle *Aquila chrysaetos* and human activity. We obtained a parsimonious model that included cliff availability and distance to highways as predictors of Bonelli's Eagle distribution. As highways may be seen as surrogates of intensive human activity, we conclude that, contrary to what was previously found at local or at nation-wide scales, human actions negatively affect the distribution of breeding territories at an intermediate scale. The construction of new roads and highways in the Mediterranean area of mainland Spain, which is the most climatically favourable region for the species, could have negative consequences for the Spanish metapopulation of Bonelli's Eagle, particularly in peripheral populations or distant areas that depend on the arrival of immigrants to persist.

Key words: *Aquila fasciata*, human disturbance, *Hieraaetus fasciatus*, predictive models, spatial scale, variation partitioning

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INTRODUCTION

Spatial distribution patterns of animal populations are mainly induced by environmental heterogeneity that determines gradients of habitat quality and may have profound effects on the spatial structure and abundance of species (Brown 1984, Orians & Wittenberger 1991, Rahbek et al. 2007). Local studies analysing the surroundings of breeding sites are normally biased to good quality habitats, as they focus on relatively homogeneous areas. Local factors influencing the distribution of a species may be different from those acting over larger areas that include a broader range of habitat quality. Indeed some recent studies do include more than one spatial scale in their analyses (e.g. Sergio et al. 2003). Determining the relative contributions of local versus regional factors affecting the distribution of a species may be the key to understanding its overall distribution pattern. This requires linking the spatial scale being considered to the effects of the hypothesized processes operating at that scale. If we are to attribute relative impacts of various factors influencing the distribution of the species, we should consider how results vary as a function of scale, and also search for consistent patterns across scales.

During the second half of the 20th century, Bonelli's Eagle *Aquila fasciata* suffered one of the most severe population declines recorded among birds of prey, and was consequently listed as endangered in Europe (BirdLife International 2004). Although the population appears to have stabilized in recent years, there are still areas where threats persist for this species, mainly due to habitat degradation and unnatural mortality

(Ponchon 2011, López-López et al. 2012). In Spain, which supports about 80% of the European breeding population, it has changed its status from "Vulnerable" (Blanco & González 1992) to "Endangered" (Madroño et al. 2004), and local extinction rates ranged from 32.1% to 48.6% for the years 1980–1997 (Real & Mañosa 1997, Carrete et al. 2002). Because of this, different authors have analysed influential factors acting at diverse scales on this species. Hengeveld (1990) distinguished between the scale of variation that refers to the size of the territory analysed, and the scale which refers to the size of the unit used to lattice the territory. López-López et al. (2006) analysed the effects of different scales of resolution on Bonelli's Eagle's habitat preferences maintaining the scale of variation. As regards the scale of variation, most analyses of Bonelli's Eagle distribution are local studies involving nest-centred areas smaller than 100 km^2 (e.g. Gil-Sánchez et al. 2004, but see Niamir et al. 2011), with recent contributions of national scale studies (Muñoz et al. 2005, Carrascal & Seoane 2009), including different scales of variation.

Bonelli's Eagle is traditionally considered as remarkably tolerant of human activity. Most of the local-scale ecological studies (e.g. Gil-Sánchez et al. 1996, Rico et al. 1999, Carrete et al. 2002, Gil-Sánchez et al. 2004, López-López et al. 2006) discounted human-related activities as a main cause of nest-site selection or abandonment of breeding territories. Muñoz et al. (2005) considered human activity as only a secondary factor at a national-scale, with cliff availability and climate as the primary explanatory factors, and Carrascal & Seoane (2009) did not find effects of the variables describing the degree of human pressure on the distribution of the species in Spain. In order to bridge the gap between these two approaches, local versus national analyses, we studied the factors affecting the absence/presence of breeding territories of the species at an intermediate spatial scale.

In this paper we model the distribution of Bonelli's Eagle to provide understanding of the species distribution using an intermediate study area size (larger than a territory but smaller than a national analysis) in Málaga province (southern Spain), which holds the highest breeding density in Europe. We then assess how the scale affects our perception of patterns of Bonelli's Eagle distribution, and our inference of causal processes, particularly human activity. We consider the implications of the obtained results for Bonelli's Eagle conservation.

MATERIALS AND METHODS

Study area

The study area comprises Málaga province (S Spain, Fig. 1), a mountainous region of 7267 km^2 with a typically Mediterranean climate (mean annual rainfall ranging from 400–1200 mm and annual temperature ranging from 12.6 to 19.2 °C). At present Málaga supports 80–82 breeding territories of Bonelli's Eagle (Bautista et al. 2003, Jiménez & Muñoz 2008), and is considered to be part of one of the last strongholds of the species in Europe (Balbontín et al. 2003).

Bird censuses

The breeding population of Bonelli's Eagles was monitored from 2001 to 2005 by visiting at least three times all potential territories during the breeding season. The first inspection was made in January to check for territory occupancy. The second check of the nesting areas was made during February and early March to record egg laying, and the third visit occurred during April or May, to confirm the reproduction (see Del Moral 2006). The breeding territories were considered as occupied if we observed the nests obviously repaired with green branches, typical pair behaviour, courtship, brood rearing activity or young eagles (Rico et al. 1999, Carrete et al. 2001). Golden Eagles *Aquila chrysaetos* were surveyed from 1999 to 2001, and territorial pairs were censused each year during the pre-incubation period. The population consisted of 20–22 breeding pairs.

Breeding density of Bonelli's Eagle reaches values up to 4 pairs/100 km^2 in contiguous 10×10-km squares. We took the presence/absence

Fig. 1. Iberian Peninsula and location of the study area (Málaga province, in black).

of breeding territories of Bonelli’s Eagle on the 104 UTM 10×10-km squares of Málaga province from Jiménez & Muñoz (2008), breeding territories were present in 67 squares. We selected this size of squares because it is considered to be a landscape resolution scale, as home ranges are typically smaller (López-López et al. 2006).

Predictor variables

To model Bonelli’s Eagle distribution we used 31 independent variables related to spatial situation, topography, climate, lithology, human activity, and Golden Eagle, its main competitor, breeding territories presence/absence (Table 1). These variables were chosen on the basis of potential predictive and explanatory power, include most of the factors influencing its distribution, and were assumed to be at least correlated with more proximal causal factors (Muñoz et al. 2005). As Robertson et al. (2003) suggested, models that rely on indirect links between species distribution records and environmental variables can predict distributions at least as well as mechanistic models that use more proximal variables (Austin 2002).

We digitized the variables, except for altitude, which is released as a DEM by US Geological Survey (1996), using the CartaLinx 1.2 software and processed them using the Idrisi32 GIS software. Isoline variables, from „mean relative air humidity in January” to „longitude” (Table 1) were interpolated from a triangulated irregular network performing parabolic bridge and tunnel edge removal, obtaining values in approximately 1-km^2 pixels. Area was calculated using the Idrisi32 AREA module. Secondary variables, defined in Table 1 were calculated from the maps of the primary variables by an algebraic operation in parentheses using the Idrisi Image Calculator. We also digitized the highways and major urban centers and calculated their distance to each 1-km^2 pixel using the Idrisi DISTANCE module. Soil permeability (*Perm*) was obtained from a map of syntheses of ground-water aquifers, a categorical map with three different permeability classes (IGME

Table 1. Environmental variables used to model the distribution of Bonelli’s Eagle in Málaga province. Data sources: 1 — US Geological Survey (1996), 2 — Font (1983), 3 — Font (2000), 4 — Montero de Burgos & González-Rebollar (1974), 5 — IGME (1979), 6 — IGN (1999), 7 — own data. Data on the number of inhabitants of urban centers taken from the Instituto Nacional de Estadística (http://www.ine.es).

Code	Variable	Source
Area	Surface area (km^2)	
Alti	Altitude (m)	1
EleR	Elevation Range (m)	1
Slop	Slope (degrees) (calculated from *Alti*)	
HJan	Mean relative air humidity in January at 07:00 hours (%)	2
HJul	Mean relative air humidity in July at 07:00 hours (%)	2
HRan	Annual relative air humidity range (%) (=|*HJan-HJul*|)	
PET	Mean annual potential evapotranspiration (mm)	2
AET	Mean annual actual evapotranspiration (mm) (=min[*PET*, *Prec*])	
Inso	Mean annual insolation (hours/year)	2
SRad	Mean annual solar radiation (kwh/m^2/day)	2
TJan	Mean temperature in January (°C)	2
TJul	Mean temperature in July (°C)	2
Temp	Mean annual temperature (°C)	2
TRan	Annual temperature range (°C) (=*TJul-TJan*)	
DFro	Mean annual number of frost days (minimum temperature ≤ 0°C)	2
DPre	Mean annual number of days with precipitation ≥ 0,1 mm	2
Prec	Mean annual precipitation (mm)	2
MP24	Maximum precipitation in 24 hours (mm)	2
RMP	Relative maximum precipitation (=*MP24/Prec*)	
Cont	Continentality index	3
Humi	Humidity index	3
PIrr	Pluviometric irregularity	4
ROff	Mean annual run-off (mm)	5
Perm	Soil permeability	5
Lati	Latitude (degrees N)	6
Long	Longitude (degrees E)	6
Aqch	Presence/absence of Golden Eagle	7
DHi	Distance to the nearest highway (km)	6
U100	Distance to the nearest town with more than 100,000 inhabitants (km)	6
U500	Distance to the nearest town with more than 500,000 inhabitants (km)	6

1979). For every variable, we determined the values of each UTM 10×10-km square by calculating the average of the values assigned to the pixels within the square.

Latitude and longitude were included to take into account the spatial structure in the distribution of the species. Legendre (1993) argued that this structure should be included in ecological models, as it is functional in ecosystems. Spatial structuring in species distributions may result from the influence of spatially autocorrelated conditioning factors (Legendre & Fortin 1989, Borcard et al. 1992), or from pure spatial effects due to contagious biotic processes inherent to their own population dynamics, such as migration (Legendre 1993, Real et al. 2003, Castro et al. 2008).

Statistical analyses and distribution modelling

To select a subset of significant predictors for each model we related each of the variables separately with the distribution of the species using generalized linear models (GLMs), and only those whose relationship was significant with $\alpha < 0.05$ were retained. Statistical theory predicts an increase of spurious findings when a large number of variables is analysed, due to the increase of type I error under repeated testing (i.e. the familywise error rate, FWER). García (2003) recommended controlling the FWER in ecological research by evaluating the false discovery rate (FDR, Benjamini & Hochberg 1995). We controlled the FWER using the procedure for all forms of dependency among test statistics (Benjamini & Yekutieli 2001) under a FDR value of $q = 0.05$. We only accepted those variables which were significantly related to the distribution of the species with $\alpha < 0.05$ under a FDR of $q < 0.05$.

We then grouped the resulting significant variables according to the explanatory factors to which they were related (see predictor variables), and used them to build different uni- and two-factor explanatory models for the species distribution using the method enter to include the variables in the model. Single-factor models were built using the most significant variable for each factor. Since topography has been found to be a consistent factor influencing the distribution of Bonelli's Eagle at different scales (Gil-Sánchez et al. 1996, Ontiveros & Pleguezuelos 2003, Muñoz et al. 2005), we tested a set of two-factor models that included topography combined with other factors (climate, human activity and interspecific competition) previously reported as important for the species. We compared the different models using the Akaike Information Criterion (AIC) (Akaike 1973), which weighs the deviance of a model by the number of parameters (Burnham & Anderson 2002). AIC is defined as:

$$\mathrm{AIC} = -2\log H + 2h$$

where H refers to the value of the maximized log likelihood and h to the number of parameters in the model. The smaller the AIC, the better the model. For each model we computed the AIC differences Δ_i (Burnham & Anderson 2002, p. 71).

We then used the environmental favourability function explained by Real et al. (2006). We selected this favourability function because probability values derived from logistic regression are affected by the prevalence, whereas the favourability function assesses the variation in the probability of occurrence of the species in certain local conditions with respect to the overall species prevalence, and so favourability values reflect only the environmental conditions which are appropriate for the species (Acevedo & Real 2012).

This function may be expressed as:

$$F = \frac{\frac{P}{(1-P)}}{\frac{n_1}{n_0} + \frac{P}{(1-P)}}$$

where P is the logistic probability value, n_1 is the number of presences and n_0 is the number of absences. We so obtained the favourability values for Bonelli's Eagle in each 10×10-km square in Málaga. We preferred the concept of favourability to that of suitability because favourability values are interpretable in absolute terms, as they indicate how local presence's probability differs from that expected by chance in the whole study area. Suitability values rank local sites according to their capacity to hold the species but they are not related to probability and thus are uninformative in absolute terms.

To assess the classification accuracy of the model we started from the values of a confusion matrix and calculated the sensitivity (ratio of correctly predicted presences to total number of presences), specificity (ratio of correctly predicted absences to total number of absences), correct classification rate (ratio of correctly predicted presences and absences to total number of localities), and Cohen's kappa (Fielding & Bell 1997, Muñoz & Real 2006). To take into account the interactions between the determinant variables, which often result in an overlaid effect in space due to collinearity between them (Borcard et al. 1992, Legendre 1993), we performed a variation partitioning procedure to specify how much of the variation of the final model accounted for the pure effect of each variable, which proportion was attributable to their interaction, and how these variables interact affecting the target variable (Legendre 1993, Legendre & Legendre 1998, Muñoz et al. 2007). The part of the variation of the final model explained by each variable (R_i^2) was obtained by using the squared value of the Pearson correlation coefficient between the values obtained in the final model and those yielded by the models based on each variable included in the model. The amount of variation explained by each pair, trio, etc. of explanatory variables ($R_{i+j+...+n}^2$) may be obtained by correlating the final model values with those yielded by the model using these variables. Then, the pure effect of each variable (R_{Pi}^2) may be assessed by subtracting the variation explained by the other variables together from the variation explained by all explanatory variables together ($R_{Pi}^2=R_{i+j+...+n}^2-R_{j+...+n}^2$). The variation attributable to the interaction of pairs of variables (R_{ij}^2) may be obtained by subtracting from $R_{i+j+...+n}^2$ the pure effect of the two variables ($R_{Pi}^2+R_{Pj}^2$) and the variation explained by the other variables together ($R_{k+...+n}^2$) (see Whittaker 1984, Legendre & Legendre 1998 pp. 532–534, Muñoz et al. 2005).

RESULTS

Twelve of the variables had a univariate significant relationship with the presence of breeding territories of Bonelli's Eagle, and were related to topography, climate, human activity, and interspecific competition (Table 2). The AIC values for the single and two-factor models derived from the combination of topography with the other factors ranged from 101.40 to 126.99 (Table 3). The evaluation scores of all previous models (sensitivity, specificity, correct classification rate, and Cohen´s kappa) are shown in Table 4.

Table 2. Variables significantly related with the distribution of Bonelli's Eagle in Málaga province, selected with the univariate analysis, and their significance (p). Variables are grouped into explanatory factors. Codes as in Table 1.

Factor	Variable	p
Topography	*Area*	0.0011
	Alti	0.0012
	EleR	0.0000
	Slop	0.0000
Climate	*Inso*	0.0012
	Temp	0.0006
	DPre	0.0037
	Prec	0.0044
	MP24	0.0068
	Humi	0.0044
Interspecific competition	*Aqch*	0.0010
Human activity	*DHi*	0.0000

The lowest AIC was obtained for the model combining topography and human activity, and so it was considered the best model. Following Altman (1991) the predictions of this model agree "good" with the observations ($0.6 < k < 0.8$). The results of the model variation partitioning indicate that 54% of variation is accounted for by elevation range, independent to the distance to highways; 24% is explained by distance to highways, independent to elevation range; and 22% is explained by the combined effects between both factors, that is to say, by the existence of squares that simultaneously have a high elevation range and are located far away from highways, or have little elevation range and are close to highways. Favourability values for Bonelli's Eagle in Málaga province UTM grid cells, for the model combining topography and human activity, are represented in Fig. 2, showing also the distributions of the highways.

Table 3. Most significant models explaining Bonelli's Eagle distribution obtained for each combination of explanatory factors using the variables in Table 2. Models are ranked according to their goodness. AIC: Akaike's Information Criterion. Δ_i: AIC differences. Variable codes as in Table 1.

Explanatory factor	Logit function	AIC	Δ_i
Topography + Human activity	2.49 + 0.07*DHi* + 0.003*EleR*	101.403	0
Topography + Climate	-5.52 + 0.04*EleR* + 0.07*DPre*	104.231	2.828
Topography	-1.87 + 0.04*EleR*	108.496	7.093
Topography + Interspecific competition	-1.7 + 0.003*EleR* + 1.295*Aqch*	108.794	7.391
Human activity	-0.51 + 0.10*DHi*	121.581	20.178
Interspecific competition	0.27 + 2.73*Aqch*	125.641	24.238
Climate	9.78 - 0.56*Temp*	126.988	25.585

Table 4. Measure of performance of the best uni- and two-factor explanatory models for the species distribution, indicating sensitivity, specificity, correct classification rate, and Cohen´s kappa. Sensitivity and specificity for Interspecific competition cannot be calculated since the denominator is zero.

Explanatory factor	Sensitivity	Specificity	CCR	Cohen´s kappa (k)
Topography + Human activity	0.91	0.70	0.83	0.63
Topography + Climate	0.86	0.67	0.79	0.55
Topography	0.88	0.62	0.79	0.52
Topography + Interspecific competition	0.88	0.62	0.79	0.52
Human activity	0.77	0.45	0.66	0.24
Interspecific competition	-	-	0.64	0
Climate	0.86	0.43	0.71	0.32

DISCUSSION

The environmental model for Bonelli's Eagle distribution in Málaga province is remarkably parsimonious, since it only includes two predictors to account for its distribution in 104 squares. The first variable entering the model is elevation range, which is closely related with mountainous areas. Mountains have been consistently found to be important in the distribution of Bonelli's Eagle at local (Gil-Sánchez et al. 1996, Sánchez-Zapata et al. 1996, Ontiveros 1999), large (Ontiveros & Pleguezuelos 2003, Muñoz et al. 2005, Carrascal & Seoane 2009), and intermediate spatial scales (López-López et al. 2006, and this paper). The pure effect of cliff availability on the distribution of the species is similar in Málaga province (54%) and mainland Spain (53%, Muñoz et al. 2005), which confirms the profound dependence of the species on mountain ranges at these two different scales in the studied areas. Mountains are normally associated with nest site availability for cliff nesters (Newton 1979), and Pérez-García et al. (2013) indicated for Bonelli's Eagles that topography and natural land-marks play an important role in home range segregation, helping to minimise antagonist neighbour conflicts.

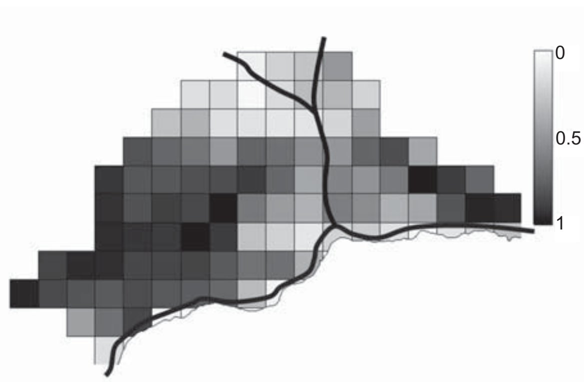

Fig. 2. Favourability values for Bonelli's Eagle in each UTM 10×10 km square of Málaga province, shown on a scale ranging from 0 (unfavourable, white) to 1 (favourable, black). Highways are also shown.

Climatic variables are absent from our intermediate-scale model, but they were important in the nation-wide model of Muñoz et al. (2005), which was performed using the same resolution scale (10×10-km squares). Climate is the second factor determining the distribution of the species in Spain, as suitable areas for Bonelli's Eagle are mountains with a Mediterranean climate (Muñoz et al. 2005). However, climate is a factor that typically changes over large areas, and the climate of Malaga province is completely Mediterranean, so the climatic factor loses its predictive and explanatory capacities at this intermediate study area size. As already stated Mackey & Lindenmayer (2001) the processes dominating the delivery of the primary environmental resources relevant to the distribution of animals are scale-specific, being the climate the more influential factor at a large extent, whereas topography create the finer-scale variations in climate that influence species distributions (see also Elith & Leathwick 2009).

The most important difference between the model obtained in this study (at an intermediate scale) and those made at local and nation-wide scales is the role of human-related variables. Distance to highways is the second most important variable in our analysis, explaining almost 25% of the species distribution at intermediate study area size, while it is not reflected at a larger scale. Maurer (1996) considered that roads should be seen as a surrogate for human density, economic activity and intervention in the landscape, which is certainly true in Malaga, where human activity is clearly associated to highways. Consequently, factors which were not available on UTM 10×10-km squares, such as prey availability, a factor influencing the selection of settlement areas by juvenile Bonelli's Eagles (Mañosa et al. 1998, Moleón et al. 2009), or density of power lines, a man-induced cause of mortality for big raptors (Rollan et al. 2010, López-López et al. 2011), could be partially affected by this variable. In general terms both abundance and occurrence of breeding birds are depressed near major roads, representing areas with lower-quality territories (Moreno-Mateos et al. 2011, Summers et al. 2011, Silva et al. 2012). Furthermore, some diseases such as trichomoniasis, one of the most important nestling mortality factor for Bonelli's eagle (Real et al. 2000), could be related to the consumption of domestic pigeons, and thus to human activity.

The results we present here show that the factors explaining the species distribution is likely to be scale dependent, as the ranking of the involved variables is dependent on the considered spatial scale. Studies on small study area sizes failed to detect any adverse effect of human disturbance on Bonelli's Eagle (e.g. Gil-Sánchez et al. 2004), and the national scale analyses detected this effect only marginally (Muñoz et al. 2005) or did not notice it (Carrascal & Seoane 2009), so the scale of the analyses is key for detecting the human effect on Bonelli's Eagle distribution. Local studies searched for disturbances in the near vicinity (< 5 km) of the nesting sites, whereas the distribution of the species in Spain varies over 500,000 km^2.

In our analysis, the mean distance of occupied squares to highways was 16.5 km, versus 7.7 km of mean distance to highways for unoccupied squares ($F = 17.6$, $p < 0.001$). As this process occurs at intermediate scale, local scale (< 5 km radius around the nest) analyses are unable to detect it because they are mainly affected by cliff availability, whereas broad-scale analyses (national distribution) are too coarse to account for it satisfactorily and are more influenced by climate. Although our model indicates that the species prefers to breed in cliffs separated from intense human disturbance, more than 50% of presences are accounted for by the pure effect of cliff availability, independently of the distance to highways, which renders the effect of highways quite difficult to detect intuitively during a field survey. Interestingly, López-López et al. (2006), who also analysed an area of similar size (aprox. 7000 km^2), also found some negative effect of roads on Bonelli's Eagle, although they did not quantified the relative influence of human disturbance on the species.

The influence of human activity in Málaga province, where the present status of the species is considered to be optimal is of particular concern. This province is part of a favourable area from which juveniles may disperse to other, less favourable territories (Muñoz et al. 2005), which means that human disturbance in this area may have far-reaching effects. In fact, a satellite tracking study (Cadahía et al. 2009) demonstrates high distances for natal dispersal in this species, with birds born in favourable areas attempting the first breeding in less favourable areas separated more than 400 km. Several EU funded LIFE projects have aimed at promoting Bonelli's Eagle conservation although, unfortunately, the effects associated to highways are not easily ameliorated by this kind of conservation efforts. Since more highways are planned for the near future in Málaga, and other favourable areas in Spain, we should take into account that an abusive development has a cost in biodiversity, even for a "human tolerant" species.

In summary, our results show that topography is the main driver of Bonelli's Eagle breeding distribution at all scales, climate is a major driver only at a broad scale, whereas human impact on the species distribution, and probably on the factors affecting human-induced mortality, is only detected as a major driver at intermediate scale. In this way, systematic analyses of the relative importance of the different factors affecting the distribution of a species as a function of spatial scale may provide new insights in distribution modelling studies and a better understanding of the patterns of occurrence and most likely in the abundance of a species.

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STRESZCZENIE

[Czynniki wpływające na występowanie orzełka południowego w południowej Hiszpanii]

Identyfikacja czynników, które mogą wpływać na rozmieszczenie zagrożonych gatunków zwierząt wymaga zastosowania różnych podejść oraz narzędzi analitycznych, gdyż ich znaczenie może zależeć od skali przestrzennej, w jakiej są one rozpatrywane. Do tej pory rozmieszczenie orzełka południowego badano w skali lokalnej (w oparciu o miejsca lęgowe) oraz w skali całej Hiszpanii. W obu tych skalach nie stwierdzono, aby różnie definiowane zmiany powodowane działaniami człowieka miały istotny wpływ na zajmowanie terytoriów lęgowych.

W pracy analizowano czynniki potencjalnie wpływające na występowanie orzełka, rozpatrując je w skale regionalnej. Analizy oparto o rozmieszczenie lęgowych par w prowincji Malaga, gdzie zagęszczenie tych ptaków jest najwyższe w Europie. Określano czynniki potencjalnie wpływające na występowanie orzełka, na podstawie występowania par lęgowych w 104 kwadratach 10×10 km. Pod uwagę wzięto 31 zmiennych (Tab. 1), przyporządkowanych następnie do grup zmiennych opisujących topografię, klimat, konkurencję międzygatunkową (określaną jako obecność orła przedniego) oraz działalność człowieka (Tab. 2).

Występowanie orzełka najlepiej wyjaśniane było przez czynniki związane z topografią (różnice w wysokości) oraz odległością od autostrad (Tab. 3). Model uwzględniający te czynniki był najlepiej dopasowany do danych (Tab. 4). W przeciwieństwie do wyników wcześniejszych prac wykazano negatywny wpływ działalności człowieka — tereny położone bliżej autostrad były mniej sprzyjające występowaniu orzełka (Fig. 2). Autorzy wskazują, ze dalsza planowana rozbudowa sieci autostrad może negatywnie wpływać na ten zagrożony gatunek.