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BREEDING DENSITIES AND HABITAT ATTRIBUTES OF GOLDEN EAGLES IN SOUTHEASTERN SPAIN

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Predictions on how animals respond to habitat changes are the primary aim of many conservation studies. Development of easy wildlife habitat models is an important tool for conservation and ecosystem management (González et al. 1992, Donázar et al. 1993). Progress has been made using Generalized Linear Models (GLMs) (Dobson 1983, McCullagh and Nelder 1989) to summarize the relationships between species distributions and environmental variables (Vincent and Haworth 1983, Nicholls 1989, Donázar et al. 1993).

It is known that patterns and processes in nature are sensitive to the scale at which they are viewed (Cody 1985, Wiens et al. 1987, Wiens 1989, Levin 1992, Lima and Zollner 1996). The scale at which systems are studied has a powerful influence on final conclusions and species-habitat relationships determined at one scale may not apply to others. Populations are influenced by the complex arrangement of habitat patches within landscapes and multiscaled studies seem to be the proper way to approach their study (Wiens 1989, Levin 1992).

The Golden Eagle (*Aquila chrysaetos*) is a raptor with a widespread distribution in the northern hemisphere. In North America, Steenhof et al. (1997) showed an important interaction between jackrabbit (*Lepus californicus*) abundance and weather on eagle reproduction and more recent work using radiotracking data (Marzluff et al. 1997) has noted the preference of Golden Eagles for some habitat types, particularly shrub and open lands. In

Europe, different qualitative descriptions around nest sites have been published (Tjernberg 1983, Watson 1997), and McGrady et al. (1997) constructed a model that delineated the area over which eagle pairs range and habitats of particular importance. More general approaches should be used as comparative parameters to consider entire populations and to reduce individual variability (White and Garrot 1990, Aebischer et al. 1993).

The purpose of this paper is to make a mathematical description of Golden Eagle breeding sites in southeastern Spain, where one of the highest densities of this species has been reported (Sánchez-Zapata et al. 1995). We propose a two-scale approach, considering at first responses around nest sites, and then a landscape-level analysis to evaluate the influence of the matrix on breeding territories.

STUDY AREA AND METHODS

The study area covered the Murcia region, a 11 317 km^2 area located in southeastern Spain with numerous mountains ranging from 0–2000 m elevation. The climate is Mediterranean arid and semiarid with a mean annual rainfall of 300 mm. Vegetation has a mosaic structure with cultivated lands (54%), grasslands and shrublands (28%), forest (15%) and open lands (3%) (Alcaraz et al. 1991).

All the territories known to be occupied by Golden Eagles at least once during the period 1985–97 were considered (Sánchez-Zapata et al. 1995). The location of breeding territories was incorporated into a Geographic Information System (IDRISI, Eastman 1992) using the UTM grid of 1 km^2 cells. For the first small-scale landscape approach the 1 km^2 cells were aggregated into 9 km^2 (3 × 3 km) cells, so the regional map of 11 317 km^2 cells was transformed into a map with 1381 cells of 9 km^2. The large-scale landscape analysis was focused on 88 cells of 100 km^2 (10 × 10 km).

The same GIS was used to characterize the breeding sites using the following variables (Table 1): (1) SLOPE and LAND USE—slope (° from horizontal) was calculated from a Digitized Land Model 1:100 000 (Servicio Cartográfico Español) by comparing the altitude of each basic cell (200 × 200 m) with that of neighboring cells to the north, south, east and west. An average value for the different 200 × 200 m cells was calculated. Slope for larger cells (3 × 3 km and 10 × 10 km) was obtained as the mean value of 200 × 200 m subcells. These values ranged from 0–24.2 at the 9 km^2 scale and from 0.2–13.5 at the 100 km^2 scale. Different land-use classes were obtained from maps of the Ministerio de Agricultura (1:200 000) as proportions of cell area (9 km^2 and 100 km^2) covered by each. New categories were formed by combining related land-use cover categories (e.g., lemon, orange and other fruit trees were combined to give a single arboreous intensive agriculture category). (2) EDGE—edge was measured as the length (km) of edges between different land uses using the digitalized land-use map and ATLAS GIS software. (3) STRUCTURE—number and size (ha) of the different patches of natural vegetation obtained from maps of the Dirección General de Producción Agraria (1:200 000).

Table 1. Variables used to characterize the breeding areas of Golden Eagles in southeastern Spain.

VARIABLES USED IN GENERAL LINEAR MODEL
LAND USE CATEGORIES
AINTA—% of cell covered by arboreous intensive agriculture, such as lemon and orange trees.
HINTA—% of cell covered by herbaceous intensive agriculture, such as vegetable crops.
AEXTA—% of cell covered by arboreous extensive agriculture, such as olive and almond trees.
HEXTA—% of cell covered by herbaceous extensive agriculture, such as cereal crops.
SHRUB—% of cell covered by shrubland.
FOREST—% of cell covered by forest, mainly *Pinus halepensis*.
SHF—% of cell covered by mixed shrubforest.
SLOPE—topographic irregularity index.
EDGES
EAEA—length (km) of edges between intensive and extensive agriculture.
FOIA—length (km) of edges between intensive agriculture and forest.
IASH–length (km) of edges between intensive agriculture and shrubland.
IASF—length (km) of edges between intensive agriculture and mixed shrubforest.
FOEA—length (km) of edges between forest and extensive agriculture.
EASH—length (km) of edges between extensive agriculture and shrubland.
EASF—length (km) of edges between extensive agriculture and mixed shrubforest.
FOSH—length (km) of edges between forest and shrubland.
FOSF—length (km) of edges between forest and mixed shrubforest.
SHSF—length (km) of edges between shrubland and mixed shrubforest.
STRUCTURE
PATCH—number of land-use patches per cell.
RICHNESS—number of different land-use patches per cell.
DIVERSITY—diversity (Shannon-Weiner) of land uses
NFOREST—number of forest patches per cell.
SFOREST—mean size (ha) of forest patches per cell
NSHRUB—number of shrubland patches per cell.
SSHRUB—mean size (ha) of shrubland patches per cell.
NSHF—number of mixed shrub-forest patches per cell
SSHF—mean size (ha) of mixed shrub-forest patches per cell.
NNAT—number of natural vegetation patches per cell.
SNAT—mean size (ha) of natural vegetation patches per cell.

Table 2. Response of Golden Eagles to the different habitat variables considered in southeastern Spain. % dev: deviance explained (ns—not significant, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$. Responses: + s-shaped function, ++ bell-shaped function, − s-shaped function.

	SCALE			
	3 × 3		10 × 10	
	% DEV	RESPONSE	% DEV	RESPONSE
LAND USE				
AINTA	ns		ns	
HINTA	9.18*	−	11.37*	−
AEXTA	ns		ns	
HEXTA	7.65**	−	ns	
SHRUB	ns		ns	
FOREST	13.09***	+	22.81***	+
SHF	7.60*	++	21.88***	+
SLOPE	28.89**	++	42.12***	+
EDGES				
EAIA	6.76**	−	9.61**	−
FOIA	ns		ns	
IASH	ns		ns	
IASF	ns		ns	
FOEA	5.46*	+	14.45*	++
EASH	3.98**	−	ns	
EASF	ns		ns	
FOSH	2.88**	+	ns	
FOSF	4.95*	++	26.94***	+
SHSF	9.59***	+	ns	
STRUCTURE				
PATCH	2.58**	−	ns	
RICHNESS	3.11*	++	ns	
DIVERSITY	1.88*	++	7.33*	++
NFOREST	7.80***	++	ns	
SFOREST	11.34***	++	17.84*	++
NSHRUB	ns		ns	
SSHRUB	ns		ns	
NSHF	9.80**	++	8.31**	+
SSHF	5.24*	++	ns	
NNAT	1.96**	+	ns	
SNAT	11.60***	++	15.64*	++

Due to the effect of increasing sizes of cells, many of them included large areas of sea and adjacent regions that were not censused. Therefore, these cells were excluded from the data analysis making fewer breeding territories in the large-scale study (76 vs. 40 territories).

We used Generalized Linear Models (GLMs) to construct models of the breeding density of Golden Eagles (Dobson 1983, McCullagh and Nelder 1989, Nicholls 1989). For density response variables (number of breeding territories), the Poisson distribution was an adequate error function (Vincent and Haworth 1983) and the discrete Poisson function an appropiate link function ($L = e^{(a+b_1x_1+...+b_kx_k)}$). This meant that the number of breeding sites in an area was a discrete, s-shaped function when the linear predictor was the first order polynomial or a bell-shaped function for second order polynomials (Sánchez-Zapata and Calvo 1999).

For regression analysis, we used the program STATISTIX (Analytical Software 1992) following a forward stepwise analysis (Donázar et al. 1993). Each explanatory variable was tested for significance in turn. The variable contributing to the largest significant change in deviance from the null model was then selected and fit to the model. Once a variable was fit to the model, we tested if the addition of a second variable significantly improved the model. We chose a 5% level of significance to include a variable in a model.

Table 3. General Linear Model for Golden Eagle breeding density in southeastern Spain. % dev: deviance explained.

	COEFFICIENT	SE	P	% DEV
9 km² SCALE				
Constant	−6.55778	0.62282	0.0000	30.16
SLOPE	0.60749	0.12321	0.0000	
SLOPE²	−0.0167	0.00562	0.0000	
SHSF	$2.034e^{-4}$	$8.296e^{-5}$	0.0142	
Constant	−6.64018	0.63324	0.0000	30.32
SLOPE	0.60065	0.12638	0.0000	
SLOPE²	−0.01693	0.0058	0.0035	
SHF	0.23580	0.10192	0.0207	
Constant	−6.86474	0.65345	0.0000	31.43
SLOPE	0.54579	0.13264	0.0000	
SLOPE²	−0.01445	0.00601	0.0162	
SSHF	$8.415e^{-7}$	$3.826e^{-7}$	0.0279	
SSHF²	$-1.447e^{-13}$	$7.055e^{-14}$	0.0402	
100 km² SCALE				
Constant	−0.75439	0.72879	0.0000	43.70
SLOPE	0.38313	0.05857	0.0000	
SHRUB	0.06663	0.03237	0.0396	

RESULTS AND DISCUSSION

SLOPE was the most important variable at both scales explaining a higher percentage at the 100 km² scale (28.89% and 42.12%, respectively). When scale changed, the response of eagles changed from quadratic to linear. *Pinus halepensis* forests (FOREST) was the second most important variable (13.09% and 22.81% for each scale) with a similar percentage of deviance explained by mixed shrubforest at the 10 × 10 km scale (21.88%). Intensive agriculture was negatively associated with eagles (HINTA 9.18 and 11.37%, respectively), while cereal crops were negatively correlated only at the smaller scale (HEXTA 7.65%) (Table 2).

Edges between land uses were also important at the larger scale, but explained low percentages of deviance at the 3 × 3 km scale. Edges between forest and mixed shrubforest (FOSF 26.94%) and edges between forest and extensive agriculture (FOEA 14.45%) were the most explanatory edge variable. Eagles responded negatively to edges between extensive and intensive agriculture at both scales (EAIA 6.76% and 9.61%, respectively). There was a negative relationship between eagle densities and edge between shrub and extensive agriculture only at the 9 km² scale (EASH 3.98%) (Table 2).

Percentages of deviance explained by landscape structure were generally low, except for natural vegetation and forest patch sizes (SNAT 11.60%, 15.64% and SFOREST 11.34%, 17.84% for each scale). At the 9 km² scale, the number of patches of natural vegetation and eagle densities seemed to be negatively related (PATCH 2.58%) (Table 2).

Because slope accounted for the higher percentages of deviance, models were constructed entering SLOPE as the first variable. Only a small reduction in deviance was obtained by including other variables. At the larger scale, the model was more explanatory than at the 3 × 3 km scale (Table 3).

Because most Golden Eagles in Murcia nest on cliffs, slope was the most important variable in predicting its breeding densities. The linear response at the larger scale suggested that eagles preferred the bigger mountain systems of the region.

The primary factor influencing Golden Eagle breeding success is food availability (Steenhof et al. 1997). Eagles prey on medium-sized mammals such as jackrabbits (*Lepus* spp.) and rabbits (*Oryctolagus cuniculus*) (Steenhof et al. 1988, 1997, Watson 1997), which are very common in shrublands in Mediterranean areas (Moreno and Villafuerte 1995, Palomares and Delibes 1997). These open lands, where vegetation structure favors prey detection and hunting success (Tjernberg 1983, Marzluff et al. 1997, McGrady et al. 1997), were the second most important variable after slope in modeling breeding densities. Although forests seemed to be an important factor, this could have been a consequence of their distribution in the mountain systems of the area (Chaparro 1996).

Eagle densities were negatively correlated with irrigated crops, possibly because of the high number of people working in fields and their low prey populations. The increase in power lines associated with irrigated land could have also been an important negative factor for Golden Eagles, as electrocution is the main cause of mortality for many eagle species (González et al. 1990, Ferrer and Hiraldo 1992, Sánchez-Zapata et al. 1995).

RESUMEN.—Utilizando Generalized Linear Models (GLMs) examinamos la densidad reproductiva del Aguila real *Aquila chrysaetos* en relación con los usos del suelo, los bordes entre usos y la estructura del paisaje en el sureste de España. Las respuestas se compararon a dos escalas de paisaje. La pendiente fue la variable más importante para predecir la densidad reproductiva. Las manchas de vegetación natural se relacionaron positivamente con las águilas mientras que la agricultura intensiva se correlacionó de manera negativa. El matorral parece tener efectos positivos importantes, probablemente al incrementar la disponibilidad de alimento.

[Traducción de Autores]

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