

## SELECTION OF NEST CLIFFS BY BONELLI'S EAGLE (*HIERAAETUS FASCIATUS*) IN SOUTHEASTERN SPAIN

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**ABSTRACT.**—A total of 119 nests and 52 cliffs occupied by 32 Bonelli's Eagle (*Hieraaetus fasciatus*) pairs was studied during 1995–97 in southeastern Spain. Mean number of nests built by pairs exceeded that reported in previous studies ( $\bar{x} = 3.7$ ;  $N = 32$ ) and there was a trend among eagles to build their nests with a southeastern orientation. Breeding density was directly related to the availability of cliffs. Eagles occupied higher cliffs ( $\bar{x} = 52.9$  m;  $N = 32$ ), located on steeper slopes ( $\bar{x} = 34.7^\circ$ ;  $N = 31$ ) than was available. Occupied cliffs were highly heterogeneous due to the fact that use of different areas by Bonelli's Eagles was dependent on human disturbance. Thus, occupied cliffs with the shortest linear distance to paved roads were higher than occupied cliffs far from paved roads. Selection of high cliffs located on steep slopes with southern orientations may have been associated with the additional lift provided eagles, since these types of nest sites enhanced the possibility of thermal and slope soaring. Preservation of nest cliffs free from disturbances should be undertaken to ensure the survival of Bonelli's Eagle in this area of Spain.

**KEY WORDS:** *Bonelli's Eagle*, *Hieraaetus fasciatus*; *southeastern Spain*; *cliff selection*; *breeding density*.

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Selección de los roquedos de nidificación del Águila Perdicera (*Hieraaetus fasciatus*) en el Sureste de España

**RESUMEN.**—119 nidos y 52 roquedos ocupados por 32 parejas de Águila Perdicera (*Hieraaetus fasciatus*), fueron analizados en el periodo 1995–97 en el sureste de España. El número medio de nidos construidos por pareja fue mayor que el descrito por otros autores ( $\bar{x} = 3,7$ ;  $N = 32$ ). Los resultados revelan una tendencia de las águilas de construir sus nidos hacia la orientación sureste. La densidad de parejas reproductoras estuvo directamente relacionada con la disponibilidad de roquedos. Los roquedos seleccionados para nidificar fueron de mayor altura ( $\bar{x} = 52,9$  m;  $N = 32$ ), y ubicados sobre laderas de mayor pendiente ( $\bar{x} = 34,7^\circ$ ;  $N = 31$ ), que la media disponible. Existió una gran versatilidad entre parejas en cuanto al tipo de roquedo ocupado, debido a que el Águila Perdicera nidificó en áreas muy diferentes en función de la presión humana. De esta forma, los roquedos ocupados más próximos a carreteras tuvieron una altura mayor que los que se encontraban lejos de las mismas. La selección de roquedos de gran altura, situados sobre pendientes elevadas, y con orientación sur, podría estar relacionado con la falta de sustentación en vuelo del Águila Perdicera, al favorecer este tipo de roquedos la formación de térmicas y el vuelo de ladera. La preservación de los roquedos de nidificación libres de la influencia antrópica, podría ser la medida más esencial requerida para la conservación del Águila Perdicera en el área de estudio.

[Traducción de Autores]

Among Mediterranean raptors, the Bonelli's Eagle (*Hieraaetus fasciatus*) has suffered one of the most severe population declines in Spain (Fernández and Insausti 1990, Real et al. 1991), Portugal (Palma et al. 1984), France (Cugnase 1984, Cheylan and Simeon 1985) and Greece (Hallmann 1985) that have resulted in its being listed as an Endangered European Raptor (Rocamora 1994). Recent data indicate that the principal European breeding population (80%) is located in Spain (Real et al. 1997), where the nesting population

has decreased 25% from 1980–90 (Arroyo et al. 1995). Consequently, this species has been catalogued as Vulnerable in Spain (Blanco and González 1992), and high-priority conservation has been urged (De Juana 1992).

Information concerning habitat is fundamental for the management of raptor populations (Moshier et al. 1987). Raptors are among the few groups of birds whose numbers can be limited by the availability of appropriate nesting places (Newton 1979). In Spain, Bonelli's Eagles most frequently

Table 1. Variables used to characterize Bonelli's Eagle nest-sites.

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CLIFFNEST—number of cliffs with nests built by a pair
NESTBUIL—number of nests built by a pair
DISTNEST—greatest distance between nests belonging to the same pair (m)
HEIGBAS—height from the base of the cliff to the nest (m)
NEIGDIST—nearest-neighbor distance between adjacent pairs of Bonelli's Eagles (km)
AVACLIFF—availability of cliffs (percentage of 1 km <sup>2</sup> squares with suitable cliffs for nesting in each territory)

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nest in cliffs and rarely in trees (Arroyo et al. 1995). While some aspects of the biology of this raptor are well-studied, nest-site selection has received only limited study. The two main studies in Spain (Gil-Sánchez et al. 1996, Sánchez-Zapata et al. 1996) refer to the selection and characteristics of used and unused territories. No detailed information is available concerning the choice of nest sites within territories or characteristics of nesting cliffs (Donázar et al. 1989).

The aim of my study was to determine which cliffs in each territory were used for nesting of Bonelli's Eagles, to describe characteristics of cliff nesting sites, and to determine how human activity affects this selection in southeastern Spain.

#### STUDY AREA AND METHODS

The study was conducted in the province of Granada, southeastern Spain (36°45'–37°49'N, 2°40'–4°13'W) from 1995–97. The area is largely mountainous with altitudes ranging from 0–3482 m, and highly variable temperatures and rainfall. The vegetation includes different species of pines (*Pinus* spp.) and evergreen oaks (*Quercus ilex*) mixed with cultivated areas, mainly with olive trees (*Olea europaea*) and cereals (Rivas-Martínez 1985).

A total of 119 nests located on 52 cliffs that were used by 32 different pairs of Bonelli's Eagle was studied. Raptors frequently build more than one nest and use them alternately in different years (Newton 1979). Thus, all nests (regardless of whether they were occupied or not during the present study) were considered equally for the analysis if they were in occupied territories.

The variables used in the analysis of nest-site characteristics are defined in Table 1. The nearest-neighbor distance method from the last nest used was used to estimate breeding density of the pairs (Newton et al. 1977).

For the analysis of cliff selection, 32 occupied cliffs (last cliff used for nesting by each pair) were compared with 32 unoccupied cliffs within the territories (one cliff per territory). The comparative analysis was performed with variables to characterize the cliffs and human disturbance in surrounding cliffs (Table 2). Because most pairs built nests in the highest cliff of each territory, the comparison was made with the highest unoccupied cliff suitable for nesting within each territory. I considered a cliff suitable for nesting when there were suitable cavities and ledges for nesting, when it was located at <1500 m elevation (the distributional limit of the Spanish population, Arroyo et al. 1995), when it was higher than 10 m, and farther than 500 m from an urban center (minimal distances found for the population studied). I chose the unoccupied cliffs within each territory to eliminate the possibility that limited prey availability was the reason

Table 2. Variables used to characterize occupied and unoccupied cliffs in territories used by Bonelli's Eagles.

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ALTITUDE—height above sea level measured in the middle of the cliff (m)
HEIGCLIFF—cliff height (m)
HEIGVAL—height from the bottom of the valley to the base of the cliff (m)
HEIGHLEV—height from the upper edge of the cliff to the summit of a hill located on the cliff (m)
WIDTHVAL—width of the valley at the base of the cliff (m)
SLOPE—inclination of the slope located at the base of the cliff (°)
TOPIND—topographic irregularity index (total number of 20 m contour lines, cut by two lines equivalent to 2 km designed on topographic 1:50 000 maps, in directions N–S and E–W, and crossed at the location of the cliff)
DISVIL—distance from cliff to nearest urban center (m)
DISPAVROAD—distance from cliff to the nearest paved road (m)
DISUNPAVROAD—distance from cliff to the nearest unpaved road passable by vehicle (m)
DISINHABUIL—distance from cliff to the nearest inhabited building (m)
DISCULTIV—distance from cliff to the nearest cultivated field (m)
KMPAVROAD—km of paved roads in the circular sampling area to the nearest 2 km
KMUNPAVROAD—km of unpaved roads in the circular sampling area to the nearest 2 km

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Table 3. Means, standard deviations (SD) and ranges of variables characterizing nest sites.

VARIABLE	MEAN	SD	RANGE
CLIFFNEST	1.6	0.9	1-5
NESTBUIL	3.7	3.6	1-18
DISTNEST	774.1	897.7	1-2800
HEIGBAS	29.8	18.3	5-90
NEIGDIST	10.0	3.2	5.8-16
AVACLIFF	10.0	4.3	4.7-22

the cliff was unoccupied given that food availability directly limits the distribution of some raptors (Newton 1979).

The territory of each pair was considered to be a radius equal to half the average distance between nests of neighboring pairs, based on the last nest occupied during the study (Howell et al. 1978, Bednarz and Dinsmore 1981, Gilmer and Stewart 1984, Rich 1986, González et al. 1992).

The orientation of nest cliffs was compared with the distribution of all available cliffs within territories ( $N = 172$ ). Cliff orientation was determined using a compass to the nearest 5°. To determine a mean angle of a circular distribution, a simple calculation of an arithmetic mean of the observed angles is inadequate. Thus, specific methods for circular statistics were used for analyses of preference in nest placement orientation (Fisher 1995). Other variables were measured with an altimeter (VZ Performance; precision  $\pm 1$  m), theodolite (Pentax PTH 20; precision  $\pm 10''$ ), clinometer, compass and 1:50 000 topographic maps prepared by the Spanish Army Cartographic Service.

A Pearson coefficient was used to determine the rela-

tionship between variables. For occupied and unoccupied cliffs, the mean values of the variables were compared using paired *t*-tests. As is usual in this type of analysis (González et al. 1992, Penteriani and Faivre 1997), a stepwise discriminant function analysis was conducted (STATISTICA statsoft Inc. 1993). The 0.05% level of significance was used for including variables in each step of the analysis. Because the sample size could not be increased to three times the number of variables measured (Willians and Titus 1988), a jackknifed classification was obtained for the analysis.

## RESULTS

Most of the cliffs occupied by Bonelli's Eagles (96%,  $N = 50$ ) were in river valleys and the nests were either in cavities (46.2%) or on ledges (53.8%). The remaining 4% of cliffs were surrounded by plains.

The number of nests built by a pair (Table 3) appeared to be dependent on nest-site availability since nests were built on the majority of suitable ledges and cavities. One pair had a surprising 18 nests with a maximum distance of only 350 m between them. The pairs with the highest availability of cliffs were closer to the nearest-neighbor pair (Table 1;  $r = -0.46$ ,  $P = 0.009$ ,  $N = 32$ ). Therefore, breeding density was directly related to the availability of cliffs.

Occupied and unoccupied cliffs differed significantly in height and slope at the base of the cliff (Table 4). Nests were built on the highest cliffs with the steepest slopes. In fact, most of the pairs (84%) built nests on the highest suitable cliff in

Table 4. Features of the cliffs analyzed. Mean, standard deviation (SD), and results of the Student's *t*-tests. An asterisk indicates those tests that remained significant ( $P < 0.05$ ) after Bonferroni sequential correction (Rice 1989).

VARIABLE	OCCUPIED CLIFFS	UNOCCUPIED CLIFFS	<i>t</i>	<i>P</i>
	( $N = 32$ )	( $N = 32$ )		
	MEAN $\pm$ SD	MEAN $\pm$ SD		
ALTITUDE	937.9 $\pm$ 324.2	969.4 $\pm$ 332.3	-1.37	0.18
HEIGCLIFF	52.9 $\pm$ 27.8	37.6 $\pm$ 19.2	4.85	0.00003*
HEIGVAL	135.9 $\pm$ 63.6	130.1 $\pm$ 65.9	0.48	0.63
HEIGHILEV	147.5 $\pm$ 255.1	165.9 $\pm$ 190.9	-0.78	0.44
WIDTHVAL	573.2 $\pm$ 410.0	698.3 $\pm$ 582.1	-1.01	0.32
SLOPE	34.7 $\pm$ 8.2	30.3 $\pm$ 5.9	3.63	0.001*
TOPIND	56.9 $\pm$ 15.9	54.4 $\pm$ 15.0	1.35	0.18
DISVIL	3362.5 $\pm$ 2047.6	3654.7 $\pm$ 2304.3	-1.46	0.15
DISPAVROAD	1640.6 $\pm$ 1273.1	1856.2 $\pm$ 1473.7	-1.24	0.22
DISUNPAVROAD	493.7 $\pm$ 342.9	554.7 $\pm$ 1017.2	-0.35	0.73
DISINHABUIL	917.2 $\pm$ 669.8	1092.2 $\pm$ 822.3	-1.22	0.23
DISCULTIV	1040.3 $\pm$ 1198.4	1219.1 $\pm$ 1138.8	-0.72	0.47
KMPAVROAD	3.7 $\pm$ 3.6	3.4 $\pm$ 3.5	0.53	0.59
KMUNPAVROAD	5.2 $\pm$ 2.5	6.0 $\pm$ 2.4	-1.80	0.08

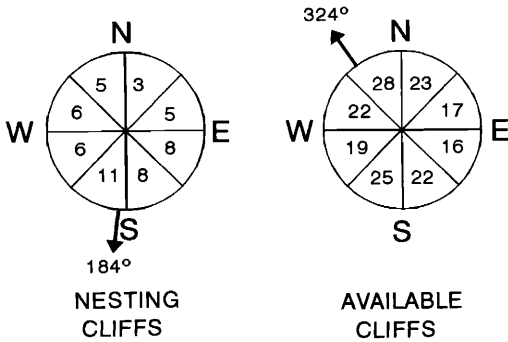


Figure 1. Orientation for Bonelli's Eagle nesting cliffs ( $N = 52$ ) and available cliffs within territories ( $N = 172$ ). Sample sizes are indicated in each direction and the mean orientation is indicated by arrows.

their territory. In the stepwise discriminant analysis, occupied and unoccupied cliffs were best distinguished by the following relationship:

$$\begin{aligned} \text{Occupied cliffs} &= -15.0262 + 0.6842\text{SLOPE} \\ &\quad + 0.0934\text{HEIGCLIFF} \\ \text{Unoccupied cliffs} &= -10.8732 + 0.5938\text{SLOPE} \\ &\quad + 0.0663\text{HEIGCLIFF}. \end{aligned}$$

Using these equations, 65.6% of occupied cliffs and 75.0% of unoccupied cliffs were correctly classified. A jackknife classification reduced the correct classification of occupied cliffs to 65.1% and unoccupied cliffs to 74.1%.

The mean orientations and angular deviations (equivalent to SD) obtained with the trigonometric method (Fisher 1995) were  $184^\circ \pm 74^\circ$  and  $324^\circ \pm 81^\circ$  for nesting cliffs ( $N = 52$ ) and available cliffs ( $N = 172$ ), respectively (Fig. 1). There were significant differences between study samples (Watson test:  $Y_2 = 4.96, P = 0.02$ ). The analysis of 119 nests revealed a trend toward a southeastward orientation (Rayleigh test:  $r = 0.178, P = 0.02$ ; mean orientation =  $121^\circ \pm 70^\circ$ ).

Due to the height of nest cliffs near paved roads, I compared these with the other nest sites. Nest cliffs closer to paved roads than 1859 m (mean value for the 52 cliffs with nests) were higher than nest cliffs located farther from paved roads ( $\bar{x} = 59.4 \pm 32.4$  m,  $N = 30$ ;  $\bar{x} = 33.3 \pm 20.8$  m,  $N = 22$ , respectively;  $t = 3.31, P = 0.001$ ).

DISCUSSION

The results obtained for the elevational distribution of the pairs coincided with those of the overall Spanish population (Arroyo et al. 1995), but the number of nests built by pairs and their orientation differed from those observed in the Sierra Morena region (Jordano 1981). This was probably due to smaller sample size ( $N = 10$  pairs) and lower availability of cliffs in the Sierra Morena area. In the Sierra Morena, a trend toward a north northwest orientation and an average of 1.8 nests per pair were observed. As in other raptor species, changes in nest orientation may be correlated with changes in latitude and elevation, which are both indicators of local temperature and insolation regimens (Mosher and White 1976). Nevertheless, a difference in the number of nests built was still found when the two pairs in this population with more than 10 nests were removed from the analysis ( $\bar{x} = 2.9 \pm 2.1$ ).

Some pairs occupied irregular cliffs with many cavities and ledges and built a large number of nests. In raptors, maintaining more than one nest is an obvious advantage, since pairs can shift nests if they are disturbed, if the nest has been taken over by another species, or if their first breeding attempt failed early (Newton 1979). Moreover, use of many nests may help in avoiding parasites which remain in nests (Winberger 1984) and kill young already weakened by starvation (Seidensticker and Reynolds 1971, Beecham and Kochert 1975).

My results indicated that breeding density should be highest in uneven terrain. A similar trend was found by Ceballos and Donázar (1989) in a population of Egyptian Vultures (*Neophron percnopterus*) and by Donázar et al. (1993) for the Bearded Vulture (*Gypaetus barbatus*), both cliff-nesting raptors. They found breeding density to be directly related to the availability of cliffs.

Overheating and sunstroke are two factors that directly can limit the distribution of Bonelli's Eagles due to their morphology which makes them agile and swift but limits the amount of lift they can generate (Parellada et al. 1984). This would explain why Bonelli's Eagles were not found at  $>1500$  m and why higher cliffs and steeper slopes were selected. Such nest-site selection improves the possibilities for thermal bubbles frequently used by Bonelli's Eagle (Cheylan 1979, Parellada et al. 1984) and favors slope soaring, a common technique in raptors with low aspect ratio wings such

as the Bonelli's Eagle (Janes 1984, Parellada et al. 1984). Because the southeastern area of Spain is rather cold during the Bonelli's Eagle breeding season, use of cliffs oriented toward the south, where the thermal bubbles are frequent, may be important for the reproductive success of Bonelli's Eagles. Selection of higher than average cliffs has also been demonstrated in the Bearded Vulture (Donazar et al. 1993), which inhabits cold mountain climates where lift problems are similar to those of the Bonelli's Eagle (Hiraldo et al. 1979, Brown 1988).

The discriminant function correctly classified 65.6% of the occupied cliffs. Lack of a higher discrimination was apparently due to the heterogeneity of the cliffs selected by Bonelli's Eagles and their potential for human disturbance. Paved roads were frequently located in river valleys inhabited by Bonelli's Eagle pairs. Human activity has been shown to influence the selection of nest sites in several species of raptors (Fyfe 1969, Hickey and Anderson 1969, Kumari 1974, Newton 1976, Sherrod et al. 1977), and for some, the minimum acceptable height of a cliff varies inversely with the degree of wilderness available (Newton 1979). Therefore, eagles can occupy lower cliffs far from paved roads, while in zones of heavy human use, higher cliffs must be used. The abandonment of some nests ( $N = 5$ ) located on low cliffs in areas with high levels of human disturbance corroborated this finding (Ontiveros 1997).

A previous study of this same population analyzed the habitat selection of Bonelli's Eagle with and without competition from Golden Eagles (*Aquila chrysaetos*) (Gil-Sánchez et al. 1996). Several authors have doubted that Bonelli's Eagles compete with Golden Eagles (Brosset 1961; Cheylan 1979; Jordano 1981; Clouet and Goar 1984). Rejecting such competition, Gil-Sánchez et al. (1996) found differences between occupied and unoccupied territories that only occurred in habitats undergoing cereal crop cultivation. This pattern of habitat selection and the results of my study on cliff selection within territories show that nest cliffs are the most important resource for habitat selection in Bonelli's Eagle, regardless of food supply.

The availability of adequate nesting areas directly influences habitat selection in raptors (Newton 1979, Janes 1985). My data indicate that, for Bonelli's Eagles, suitable nest sites may be a more limiting resource than in other raptors, causing territories of this eagle to overlap frequently with

human-populated areas (Brown 1976, Cheylan 1981, Parellada et al. 1984). Human activity in territories can negatively affect Bonelli's Eagles and might account for the decline in the Mediterranean population in recent years when other raptors have recovered in Spain (Arroyo et al. 1990, 1995). The preservation of nest cliffs and protection from surrounding disturbances (Cade 1974), is essential to ensure the survival of the Bonelli's Eagle.

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