Nesting habitat selection by booted eagles *Hieraaetus pennatus* and implications for management

SUSANA SUÁREZ*, JAVIER BALBONTÍN† and MIGUEL FERRER†

**Departamento de Ecología, Genética y Microbiología, Facultad de Biología, Universidad de León, Campus de Vegazana s/n, 24071 León, Spain; and †Estación Biológica de Doñana, Avda M̂ Luisa s/n, Pabellón del Perú, 41013 Sevilla, Spain*

Summary

1. The booted eagle *Hieraaetus pennatus* is a poorly known and scarce raptor that breeds in Spain. In Doñana National Park (south-west Spain) its population has increased from only six breeding pairs in the early 1980s to about 150 today.
2. In order to guide habitat management for this raptor in Doñana National Park, we related nesting habitat selection to breeding success.
3. Birds withstood some human disturbance when nesting, choosing sites closer to pastures besides marshes, footpaths and crops than would occur in a random distribution. Birds also selected areas near to marsh and stands of cork oak *Quercus suber*.
4. Trees used for nesting were wider and taller than would occur at random. They were usually in small groups or were large isolated trees, typically eucalyptus (*Eucaliptus* spp.).
5. The most productive nests were close to marshland and stone pine trees *Pinus pinea*.
6. Habitat management to improve the breeding success of booted eagles in Doñana should include: (i) retaining small groups of trees or large isolated trees, especially eucalyptus and cork oaks close to marshland, isolated buildings and crops; (ii) creating clearings in stone pine plantations; (iii) burying potentially dangerous power lines to reduce collision risks; (iv) clearing some areas of scrubland to increase the rabbit population; and (v) controlling forest activities, especially in the breeding season.
7. The increase in booted eagle populations in western Europe during recent decades may be a consequence of the species' capacity to adapt to environmental change. Deforestation policies designed to favour agricultural use implemented during the second half of the 20th century have not had a detrimental effect on this raptor.
8. Our work demonstrates how scarce and important organisms can be favoured by sensitive management in forestry and agricultural habitats.

Key-words: breeding success, conservation, Doñana National Park, nest site selection.

Introduction

The booted eagle *Hieraaetus pennatus* Gmelin is one of the least known of all the Old World raptor species. Many aspects of its biology are poorly known and only a few studies are reported in the scientific literature, most of them dealing with aspects of the reproductive cycle (Iribarren 1975; Stein & Grobler 1980), feeding habits (Veiga 1986; Nevado, García & Oña 1988) or distribution (Valverde 1967; Araújo 1973).

Booted eagles arrive in Spain at the beginning of March and leave for Africa late in September. They nest in all parts of the country except the Canary

*Present address and correspondence: Department of Environmental Sciences, University of Stirling, Stirling FK9 4LA, UK (e-mail s.s.seoane@stir.ac.uk).

Islands, but numbers vary in the different regions (De Juana 1989). The population is estimated at 2000–4000 breeding pairs in Spain, and 2800–6100 in the whole of Europe (Purroy 1997). In Doñana National Park, the population of this raptor has increased from only six breeding pairs in the early 1980s to about 150 today (L. García, unpublished data).

Booted eagles occupy territories mainly in four different biotopes within Doñana National Park, where the dominant tree species are eucalyptus *Eucaliptus* spp., stone pine *Pinus pinea* L. and cork oak *Quercus suber* L., which they use for nesting.

Doñana is a protected area where directed habitat management is used to enhance populations of endangered species (e.g. the Spanish imperial eagle *Aquila adalberti* G.L. Brehm). Thus traditional management techniques, such as burning or clearing of scrubland, have been used to increase rabbit populations. Forest management consists of re-afforestation with cork oak in some parts of the reserve. It is also planned to remove the eucalyptus trees, which were introduced into the area in 1969 and now occupy about 5000 ha in the northern part of the Park.

Habitat characterization has been applied frequently in ecology and has been useful in deriving conservation measures (Newton, Davis & Moss 1981; Ferrer & Harte 1997). The aim of this study was to build models to predict suitable breeding habitat for booted eagles in Doñana. We also tried to identify habitat differences between productive and less productive territories. Finally, we offer recommendations designed to increase the chances of this species occupying new territories and to avoid any loss of nesting habitat in areas where eucalyptus will be felled.

Study area

Doñana National Park is located in south-western Spain (37°N, 6°30′W) and its area is about 50 000 ha. The climate is Mediterranean with Atlantic influences. Marshes, Mediterranean scrubland mixed with scattered cork oaks or stone pines and coastal sand dunes are the main habitats. Other habitats include streams with riparian vegetation, woodlots of small stone pines planted 30 years ago, and eucalyptus. A more detailed description is presented in Rogers & Myers (1980).

The nests that are studied in this paper were located in seven different parts of the National Park (Fig. 1). (1) Reserva Biológica de Doñana (RBD), La Algaida, Las Mogeas and El Acebuche are situated in the centre of the National Park. Here, booted eagle nests occur in stone pines or cork oaks that are scattered within scrubland (matorral) comprising mainly *Halimium halimifolium* L., *Cistus libanotis* L. and *Erica scoparia* L. Large parts of these areas are also occupied by forests of small stone pines. (2) La Dehesa is situated on the north side and consists of cork oak scattered with scrub of *Pistacea lentiscus* L. Here, most nests are located in smaller cork oaks than those found in RBD. (3) Pinar del Vicioso is located in the northernmost part of the area and comprises mature woodland of *Pinus pinea* L. (4) Los Sotos is a plantation of eucalyptus located between RBD and La Dehesa. (5) La Rocina is a stream with riparian vegetation (poplars *Populus* spp., *Fraxinus angustifolia* L.) located in the west of the Park. (6) La Pequeña Holanda is located in the west of the Park and its main habitats are matorral with small groups of eucalyptus trees. (7) Crops are also grown extensively in the area, comprising mainly rice and other irrigated and non-irrigated crops.

Methods

A total of 84 nest sites used by booted eagles during 1994 and 1996 was used in this study: 50 nests from 1994 and 34 nests from 1996. There were only four cases of nests so closely set in pairs (eight nests) that pseudoreplication problems could arise, whereby each pair of nests belonged to one or two pairs of birds.

Nests were marked on aerial photographs (Andalusian Cartographic Institute, scale 1 : 20 000, years 1991–92) and on maps (1 : 50 000 topographic map of Spain, IGN; 1 : 50 000 farming and land-use map, MAPA; 1 : 100 000 ecological impact map of Doñana, Castroviejo). An equal number of random points was marked on the photos and maps. As the booted eagle is a forest species, open areas lacking potential nest sites (such as marsh, crops and the buildings) were excluded from the random points, as were wooded locations where tree heights and diameter at breast height (d.b.h.) were less than the minimum value used for nesting (d.b.h. = 68 cm, height = 430 cm) (Howell *et al.* 1978; González, Bustamante & Hiraldo 1992).

For each nest site and random point we measured 41 variables in order to quantify the habitat (Table 1). Thirty-three macrovariables were measured, such as distance from the site to selected habitat features or the percentage cover of habitat within a radius of 530 m, which was half the mean distance between nests (following the methodology of Bednarz & Dinsmore 1981; Gilmer & Stewart 1984). The percentage cover of vegetation types was measured using SYGMASCAN pro 4.0 image analysis software (Fox & Ulrich 1995). In addition, eight microvariables were measured in the field (Table 1). Tree height was measured using an optical height meter and orientation measurements were made using a compass.

STATISTICAL ANALYSIS

Nest sites from the 2 years were considered as independent samples, although some bias was possible

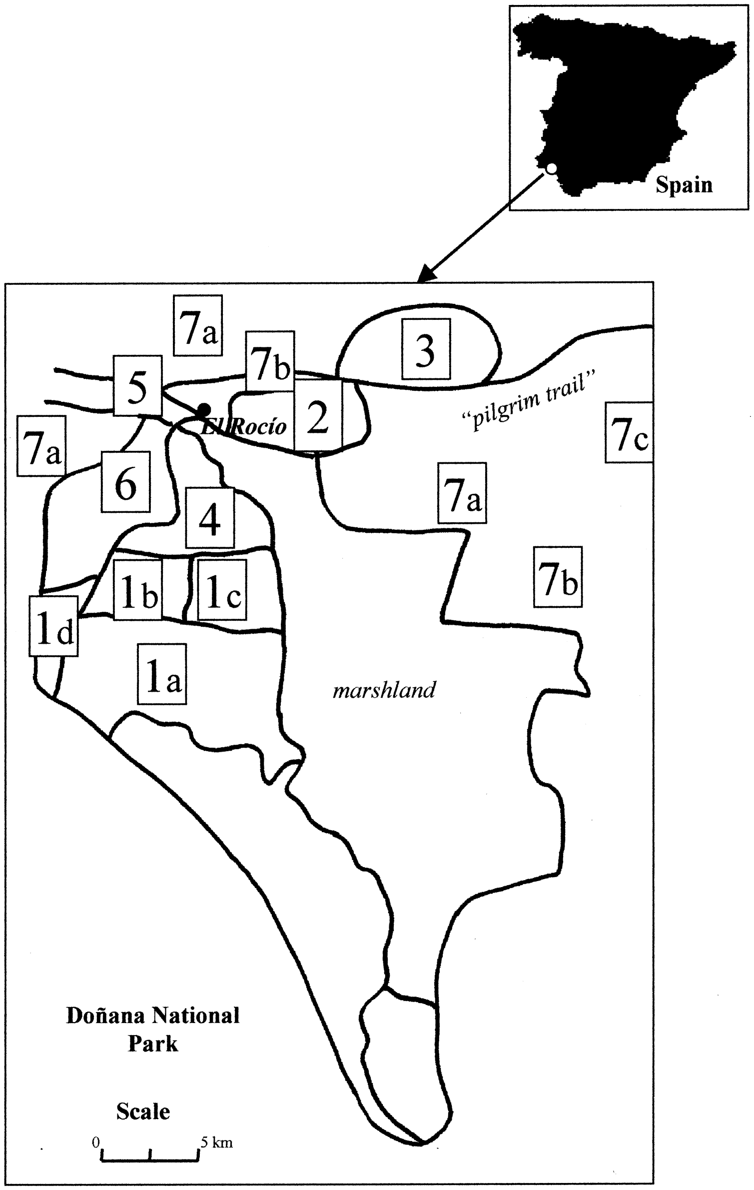

Fig. 1. Map of study area showing the different areas analysed in the paper. (1) RBD, Las Mogeas and La Algaida; (2) La Dehesa; (3) Pinar del Vicioso; (4) Los Sotos; (5) La Rocina; (6) La Pequeña Holanda; and (7) crops.

due to different nests being used by the same pair. However, the use of nests from non-consecutive years (1994 and 1996) located in different places from the Park reduced this bias.

The macrovariables were checked for statistical normality using Lilliefors test and variables were square root-transformed (distances) and arcsine-transformed (percentage circle area) as appropriate. Mean values for nest site and random site variables were compared using *t*-tests with a Bonferroni correction to reduce the chance of type I errors.

We used logistic regression, through a generalized linear model (GLM) procedure, to identify the set of variables that best separated nest sites from random sites (Jongman, ter Braak & Van Tongeren 1995). Using a forward stepwise procedure, each variable was tested for significance in turn, and the variable contributing to the largest significant change in deviance from the null model was then selected and fitted. At each step the significance of the variables included in the model was tested and any falling below the criterion level of $P = 0{\cdot}05$ was excluded. The final model was considered to have been identified when all the variables had a significant effect at $P < 0{\cdot}05$.

For GLM, the data were used without transformations for normality as this is not a requirement of logistic regression. Independent variables were analysed in three groups (macrovariables within the 530-m circle, those outside, and the microvariables). Model fit was assessed by examining the coefficient of sensitivity, residuals (deviance and Pearson chi-

Table 1. Variables used to characterize nest sites of the booted eagle compared with random sites

Code	Meaning
Macrovariables	
DELPOW	Distance (km) to nearest electric power lines
KELPOW	Km of electric power lines in circular sampling area
DBUILD	Distance (km) to nearest isolated building
DURBAN	Distance (km) to nearest urban centre
DPAVRO	Distance (km) to nearest paved road
KPAVRO	Km of paved roads in circular sampling area
DASPHRO	Distance (km) to nearest asphalt road
KASPHRO	Km of asphalt roads in circular sampling area
DPILGRIM	Distance (km) to nearest pilgrim trail (camino rociero)
KPILGRIM	Km of pilgrim trail (camino rociero) in circular sampling area
DFIRBRE	Distance (km) to nearest fire break
KFIRBRE	Km of fire breaks in circular sampling area
DUNMADRO	Distance (km) to nearest unmade road
KUNMADRO	Km of unmade roads (non-paved roads and tracks) in circular sampling area
DNIRCRO	Distance (km) to nearest non-irrigated crop
DIRCRO	Distance (km) to nearest irrigated crop
DRICRO	Distance (km) to nearest rice crop
DPASTU	Distance (km) to nearest pasture
DSCRUB	Distance (km) to nearest scrubland
DMARS	Distance (km) to the border of marsh
DWATER	Distance (km) to nearest open water
MARSH	% surface covered by marsh in the circular sampling area
PASTU	% pasture
SCRUB	% scrubland
EUCAL	% eucalyptus (*Eucaliptus* spp.)
PINE	% stone pines (*Pinus pinea*)
POPUL	% poplars (*Populus* spp.)
NIRRCRO	% non-irrigated crops
IRRCRO	% irrigated crops
OTHER	% other open lands (e.g. abandoned crops)
OAK	% cork oaks (*Quercus suber*)
SAND	% sand dunes
LAGOO	% lagoon
Microvariables	
SPECI	Tree species
HEIGHT	Height of tree (m)
NESHEIG	Height of nest in the tree (m)
DBH	Nest tree diameter (d.b.h.) (cm)
AZIMUT	Nest position in tree canopy (degrees)
OPEN	Nearest open land direction (degrees)
GROUP	Tree group size category (1, isolated tree; 2, < 10 trees; 3, row of trees; 4, small wood < 5 ha; 5, large wood > 5 ha)
APERT	Nest wood aperture angle (0° closed wood, 360° isolated wood)

square) and potential leverage (Nicholls 1989). Use of GLM with a logistic link function was considered more appropriate than the alternative of linear discriminant function analysis because the distributions of values were highly skewed (Green, Osborne & Sears 1994). We constructed similar models for the binary response variable nest productivity (two or more fledged chicks vs. one or fewer). All data were analysed using SYSTAT and SPSS (SPSS Inc., Chicago, IL, USA).

Results

NEST SITE SELECTION

Nest sites had significantly different habitat features from random points. Booted eagle nests were situated closer to marshes, pasture land, isolated buildings, the 'pilgrim trail' (camino rociero), rice fields and non-irrigated crops than random sites. Nests had fewer kilometres of dirt track and power lines in the immediate vicinity than random sites. Regarding vegetation structure, the eagles nested in places with a higher percentage of marsh than random sites, where only the proportion of stone pines was greater (Table 2).

Analysis of the microvariables showed that trees selected for nesting were taller (ANOVA, $F = 44{\cdot}37$, d.f. $= 1{\cdot}88$, $P < 0{\cdot}01$) and of greater girth (ANOVA, $F = 7{\cdot}51$, d.f. $= 1{\cdot}88$, $P < 0{\cdot}01$) than random trees. Trees with nests were 17·68 m tall (4·3–33 m, mean and range) while random trees were 10·56 m tall (6·3–23·8 m) ($t = -5{\cdot}840$, d.f. $= 61$, $P < 0{\cdot}001$). For nesting trees, d.b.h. averaged 240 cm (68–452 cm) and random trees averaged 188 cm (80–430 cm) ($t = -2{\cdot}630$, d.f. $= 87{\cdot}9$, $P = 0{\cdot}01$). Eucalyptus was the dominant nesting tree (44% of nests were located in this tree species) while stone pines were more prevalent at random sites (44% of random trees were stone pines) ($\chi^2 = 15{\cdot}95$, d.f. $= 5$, $P < 0{\cdot}01$; Table 3). Nests were found significantly more frequently in forests < 5 ha (33·3% of nest trees) or in groups of 10 trees or fewer (33·3% of nest trees), while 55·3% of random trees were found in forest > 5 ha ($\chi^2 = 26{\cdot}94$, d.f. $= 4$, $P < 0{\cdot}001$). Nests were placed more often in the eastern section of the tree top (mean orientation = 82·2°) than would be expected by chance (Rayleigh's test: $r = 13{\cdot}77$, $Z = 4{\cdot}51$, $n = 42$, $P < 0{\cdot}05$). The mean orientation of the nearest open area from the nesting tree was 29·8°, again significantly different from random (Rayleigh's test: $r = 13{\cdot}77$, $Z = 4{\cdot}21$, $n = 45$, $P < 0{\cdot}05$).

We built GLM for nest site selection from macrovariables, first using the variables measured inside the 530-m nest circle and then with the distance variables. Our final model combined all the variables selected by both models. Percentage of poplar trees was excluded from analysis because of its low variance. Distance to marsh was also excluded because of high colinearity with distance to pasture land. Taking into account only the variables measured inside the 530-m circle, four variables were significant in the model: length of non-paved roads and tracks; length of power lines; percentage of marsh; and percentage of cork oaks. This model classified correctly 72·4% sites according to whether they were used or not. Distance to isolated buildings and distance to pasture land was selected by the stepwise model on the distance variables and classified correctly 58·9% of the sites. From these variables we built the final model, which classified correctly

Table 2. Comparison (means and standard deviations) between 33 macrovariables quantifying the nesting habitat for 84 nest sites and 84 random sites. The table shows the significance of a Student's *t*-test, with Bonferroni correction, for the difference between the means with equal or different variances according to each case: $^*P < 0{\cdot}05$, $^{**}P < 0{\cdot}01$, $^{***}P < 0{\cdot}001$. See Table 1 for variable codes

	Random sites		Nest sites	
Variable	Mean	± SD	Mean	± SD
DELPOW	3·90	2·46	3·07	2·91
KELPOW*	0·24	0·44	0·06	0·23
DBUILD*	1·48	1·02	1·03	0·56
DURBAN	5·35	2·33	5·15	2·09
DPAVRO	1·61	1·40	2·25	1·58
KPAVRO	0·19	0·39	0·07	0·23
DASPHRO	3·79	2·56	4·38	2·22
KASPHRO	0·12	0·31	0·03	0·16
DPILGRIM***	3·71	3·37	1·69	2·25
KPILGRIM	0·20	0·42	0·19	0·35
DFIRBRE	0·52	0·80	0·40	0·79
KFIRBRE	1·08	0·94	0·86	0·75
KUNMADRO*	0·10	0·11	0·06	0·07
DUNMADRO	2·78	1·25	1·52	1·09
DNIRCRO*	8·54	6·86	5·80	3·68
DIRCRO	3·95	3·11	4·34	3·27
DRICRO*	14·38	6·01	10·98	4·84
DPASTU***	4·70	3·78	2·02	2·75
DSCRUB	2·57	2·90	2·80	3·14
DMARS***	4·66	3·75	1·95	2·67
DWATER	0·40	0·46	0·39	0·40
MARSH*	1·75	5·05	6·55	12·04
PASTU	4·09	11·83	9·95	16·78
SCRUB	14·60	29·47	24·76	35·17
EUCAL	15·50	32·44	16·95	30·05
PINE*	47·02	42·98	23·38	37·31
POPUL	0	–	0	–
NIRRCRO	1·5	7·71	0	–
IRRCRO	6·79	19·32	0·45	3·30
OTHER	2·80	11·03	2·24	8·70
OAK	3·63	15·09	14·74	29·92
SAND	0·67	3·23	0·21	1·13
LAGOO	1·61	4·49	1·20	4·60

Table 3. Comparison (percentages) among tree species occupied by nest and random trees

Tree species	Random site	Nest site
Quercus suber	22·2	31·1
Pinus pinea	44·4	8·9
Eucaliptus spp.	28·9	44·4
Fraxinus angustifolia	2·2	8·9
Populus spp.	2·2	4·4

Table 6. Comparison (means and standard deviations) between habitat variables for nest sites grouped according to success (group 1 ≥ two fledged chicks, group 2 ≤ one fledged chick). Significance of the Student's *t*-test with Bonferroni correction for the difference between the means, for equal or different variances according to each case: $^{**}P < 0.01$. See Table 1 for variable codes

Variable	Group 1, mean (SD)	Group 2, mean (SD)
DMARS**	0·68 (1·06)	2·38 (9·99)
PINE**	5·09 (38·1)	29·43 (40·83)

74·6% of the sites using five variables (length of non-paved roads and tracks; length of electric power lines; percentage marsh; percentage cork oaks in circular sampling area; distance to nearest isolated building; Table 4).

The model for microvariables selected two variables, tree height and the tree group-size category, correctly classifying 80·1% of nest sites (Table 5).

HABITAT FEATURES VERSUS BREEDING SUCCESS

Nests were separated into two groups to investigate habitat differences linked to nesting success. Nests where two or more chicks fledged were included in group 1 (more productive nests), the remainder in group 2 (less productive nests). This latter group also included territories where the pair was present or where eggs were laid, although no young were produced. Using *t*-tests, we found that more productive nests (group 1) were situated closer to marshland than nests from group 2. Of the habitat variables in the immediate vicinity of the nest, the percentage of stone pines was significantly different between the groups. Less productive nests had a greater percentage of pine trees nearby than more productive nests (Table 6).

Using logistic regression analysis of the data, we obtained a model with four variables (kilometres of pilgrim trail; percentage of stone pines; percentage of sand in the nesting circle; distance to nearest non-irrigated crop; Table 7). The classification accuracy of the model was 73·8%.

Discussion

NEST SITE SELECTION

In southern France, Carlon (1996) showed that human disturbance in some undisturbed forest areas caused a marked movement of breeding booted

Table 4. GLM model including the five macrovariables that best separated (accuracy of 74·6%) nest sites from random sites. This model was obtained using binomial error and logistic link function. See Table 1 for variable codes

Parameter	Estimate	SE	*t*-ratio	*P*-value
1 CONSTANT	3·912	0·739	5·293	< 0·001
2 KUNMADRO	−0·001	< 0·001	−5·727	< 0·001
3 KELPOW	−0·003	0·001	−3·359	0·001
4 DBUILD	−0·001	< 0·001	−3·369	0·001
5 MARSH	0·074	0·032	2·307	0·021

Table 5. GLM model for nest site selection (microvariables) using binomial error and logistic link function. Group 1 is an isolated tree; group 2 is a group < 10 trees; and group 4 is a small wood < 5 ha. See Table 1 for variable codes

Parameter	Estimate	SE	*t*-ratio	*P*-value
1 CONSTANT	−5·459	1·390	−3·927	0·000
2 HEIGHT	0·004	0·001	3·973	0·000
3 GROUP 1	−1·965	0·897	−2·190	0·029
4 GROUP 2	1·602	0·632	2·536	0·011
5 GROUP 4	2·901	0·831	3·492	0·000

Table 7. GLM model for nest site selection according to nest productivity, using binomial error and logistic link function. Four variables explained 73·8% of differences in habitat selection between less and more productive pairs. See Table 1 for variable codes

Parameter	Estimate	SE	*t*-ratio	*P*-value
1 CONSTANT	−0·978	0·691	−1·414	0·157
2 KPILGRIM	−0·002	0·001	−2·486	0·013
3 DNIRCRO	< 0·001	< 0·001	2·930	0·003
4 PINE	0·056	0·025	2·206	0·027
5 SAND	−1·129	0·501	−2·255	0·024

eagles away into other, less typical, habitats, with a change in hunting strategy to include urban areas and villages. Our results show that booted eagles in Doñana have tolerated some human disturbance. This is in contrast with other raptor species such as the spanish imperial eagle *Aquila adalberti* (González, Bustamante & Hiraldo 1990) and the bearded vulture *Gypaetus barbatus* L. (Donázar, Hiraldo & Bustamante 1993). Nests were placed in areas with lower densities of power lines and unmade roads, but significantly closer to buildings and other constructions than random points. This might be because these buildings were abandoned or unoccupied for part of the year and eagles obtain the advantage of nearby water or feeding sites. Like Ferrer (1995), who studied imperial eagles, we found a tendency for nests to be close to the pilgrim trail (camino rociero), probably because both species prefer open areas near their nests for vigilance or for hunting.

Booted eagles nested in small groups of trees (< 10 trees or small woods < 5 ha), typically of cork oaks, although nests were mostly placed in eucalyptus trees that were taller and of greater girth than trees at random points, which more often were dominated by stone pines. Ferrer (1995) observed a similar use of small groups of trees in imperial eagles, although stone pine was the preferred species. His results and ours show a preference for nest sites close to marshland and pasture, both in the immediate vicinity of the nest and further afield. These habitats are the most productive in the Park: they are richer in prey, especially rabbits (Delibes 1978; Moreno & Villafuerte 1995), and are used for hunting areas by adult eagles (as revealed by the study of 16 radiomonitored individuals; J. Balbontín & M. Ferrer, personal communication). However, we also found that booted eagle nests were located close to other feeding sites subject to some human disturbance, such as non-irrigated crops and rice fields.

Analysis with GLM showed that only five variables were needed to classify correctly 74·6% of sites used or avoided by booted eagles. Ferrer (1995) obtained a model explaining 93·3% of the variance with four variables for imperial eagles. Both models included variables for the distance to isolated buildings (although negative for booted eagles and positive for imperial eagles) and the proximity to pasture beside marshland. For booted eagles, our model also included the percentage of cork oaks, the length of power lines and the number of kilometres of unmade roads in the nest vicinity. In contrast, the model for imperial eagles included distance to irrigated crops and to roads.

HABITAT FEATURES VERSUS BREEDING SUCCESS

The more productive booted eagle nests (i.e. with two chicks, in contrast to the average of 1·5; De Juana 1989) were placed close to marshland and had fewer stone pines in the immediate vicinity. Marshland confers the advantage of an abundant food supply while the presence of stone pines might indicate marginal habitats associated with greater human disturbance and lower prey abundance. However, stone pines tend to be planted far from the marshlands and it was not possible to separate the effects of these two variables in our analysis.

MANAGEMENT IMPLICATIONS

Habitat protection is of prime importance for maintaining raptor populations (Newton 1979). In his review, De Juana (1989) concluded that booted eagles are one of the species affected least adversely by the planting of pine monocultures, and that problems such as overhead power lines, shooting, poisoning and the taking of chicks are of more importance in its conservation. However, our data do not support a preference for pine trees, but instead indicate that they were avoided for nesting, perhaps because the stone pine trees considered in this study were too young and small for nesting.

We make the following recommendations for improving the habitat available for booted eagles in the study area.

1. Replacing eucalyptus from Los Sotos with cork oaks, and planting them in groups of less than 10 individuals or in small woods < 5 ha. Eucalyptus trees were found to support most nests, so we propose leaving some small groups and large isolated trees taller than 605 cm (nests were found between 605 and 1830 cm) and larger than 68 cm d.b.h. (68–357 cm) that the birds could use for nesting.

2. Clearing some areas in stone pine plantations (especially young stone pines, close to RBD, that are rarely used for nesting) to allow some trees to grow to an adequate size for nesting (height = 770–1455; d.b.h. = 100–350 cm), maintaining small groups of trees and planting cork oaks as above.

3. Special protection of cork oaks close to marshland (mean distance 1·95 km, SD = 2·25), close to isolated buildings (mean distance = 1·03, SD = 0·56) and close to open land, but with a few kilometres of unmade roads in the vicinity (mean value = 0·06 in a circle with a radius = 530 m, SD = 0·07) (Table 2).

To protect optimal habitat for booted eagles in Doñana and to encourage breeding, we propose preserving large isolated trees (height = 430–1830 cm; d.b.h. = 68–452 cm), small groups of trees (< 10 trees) or woods < 5 ha close to open lands (mainly the pilgrim trail), crops and marshland (mean distance = 0·68 km, SD = 1·06; Table 6);

Wherever practicable, potentially dangerous overhead power lines should be buried (Ferrer, de la Riva & Castroviejo 1991; Janns & Ferrer 1998).

Other recommendations are:

1. clearing some areas of scrubland to increase populations of rabbits as prey (Moreno & Villafuerte 1995);

2. controlling forest activities (e.g. gathering of pinecones) to reduce disturbance to eagles in the breeding season.

Conclusion

The major increase in booted eagle populations in western Europe during recent decades may reflect the species' capacity to adapt to changes in its environment (Carlon 1996). Contrary to expectations, this study has shown that booted eagles are not a typical forest species. Rather than large woods, this species prefers to use small groups of trees or small woods as a nesting habitat, in the proximity of isolated human buildings, crops and open land. Sánchez-Zapata & Calvo (1999) reported that the proportion of forest cover was a good predictor of raptor distribution overall, but that the amount of edge habitat between forest and extensive agriculture was a very good predictor of booted eagle density, in particular. Taken together with our own results this may explain why populations of this raptor have not suffered any decline due to deforestation policies designed to favour agricultural use and implemented during the second half of the 20th century.

Acknowledgements

We wish to thank: Patrick E. Osborne for his help in preparing and correcting the manuscript; Luis García for his assistance in locating the nests and his comments; Hugo Le Franc (field assistant); and the University of León, the Monteleón Foundation and INRA-SAD of Rennes for help with travelling expenses.

References

Araújo, J. (1973) Falconiformes del Guadarrama surocci-dental. *Ardeola*, **19**, 257–278.

Bednarz, J.C. & Dinsmore, J.J. (1981) Status, habitat use and management of red-shouldered hawks in Iowa. *Journal of Wildlife Management*, **45**, 236–241.

Carlon, J. (1996) Response of booted eagles to human disturbance. *British Birds*, **89**, 267–274.

De Juana, F. (1989) Situación actual de las rapaces diurnas (Orden Falconiformes) en España. *Ecología*, **3**, 237–292.

Delibes, M. (1978) Ecología alimenticia del águila imperial ibérica (*Aquila adalberti*) en el Coto Doñana durante la crianza de los pollos. *Doñana Acta Vertebrata*, **5**, 35–60.

Donázar, J.A., Hiraldo, F. & Bustamante, J. (1993) Factors influencing nest site selection, breeding density and breeding success in the bearded vulture *Gypaetus barbatus*. *Journal of Applied Ecology*, **30**, 504–514.

Ferrer, M. (1995) *Análisis de los factores que determinan la productividad de la población de aguilas imperiales en el Parque Nacional de Doñana*. Convenio ICONA-CSIC, Sevilla, Spain.

Ferrer, M. & Harte, M. (1997) Habitat selection by immature imperial eagle during the dispersal period. *Journal of Applied Ecology*, **34**, 1359–1364.

Ferrer, M., De la Riva, M. & Castroviejo, J. (1991) Electrocution of raptors on power lines in southeastern Spain. *Journal of Field Ornithologist*, **62**, 181–190.

Fox, E. & Ulrich, C.G. (1995) *SygmaScan and SygmaScan Pro User's Manual*. Jandel Corporation, San Rafael, USA.

Gilmer, D.S. & Stewart, R.E. (1984) Swainson's hawk nesting ecology in North Dakota. *Condor*, **86**, 12–18.

González, L.M., Bustamante, J. & Hiraldo, F. (1990) Factors influencing present distribution of the spanish imperial eagle *Aquila adalberti*. *Biological Conservation*, **51**, 311–319.

González, L.M., Bustamante, J. & Hiraldo, F. (1992) Nesting habitat selection by the spanish imperial eagle *Aquila adalberti*. *Biological Conservation*, **59**, 45–50.

Green, R.E., Osborne, P.E. & Sears, E.J. (1994) The distribution of passerine birds in hedgerows during the breeding season in relation to characteristics of the hedgerow and adjacent farmland. *Journal of Applied Ecology*, **31**, 677–692.

Howell, J., Smith, B., Holt, J.B. & Osborne, D.R. (1978) Habitat structure and productivity in red-tailed hawks. *Bird Banding*, **49**, 162–171.

Iribarren, J.J. (1975) Biología del águila calzada *Hieraaetus pennatus* durante el período de nidificación en Navarra. *Ardeola*, **21**, 305–320.

Janns, G.F.E. & Ferrer, M. (1998) Rate of bird collision with power lines: effects of the conductor-marking and static wire-marking. *Journal of Field Ornithologist*, **69**, 8–17.

Jongman, R.H.G., ter Braak, C.J.F. & Van Tongeren, O.F.R. (1995) *Data Analysis in Community and Land-*

scape Ecology. Cambridge University Press, Wageningen, the Netherlands.

Moreno, S. & Villafuerte, R. (1995) Traditional management of scrubland for the conservation of rabbits *Oryctolagus cuniculus* and their predators in Doñana National Park, Spain. *Biological Conservation*, **73**, 81–85.

Nevado, J.C., García, L. & Oña, J.A. (1988) Sobre la alimentación del águila calzada *Hieraaetus pennatus* en las sierras del Norte de Almería en la época de reproducción. *Ardeola*, **35**, 147–150.

Newton, I. (1979) *Population Ecology of Raptors*. T.&A.D. Poyser, Berkhamsted, UK.

Newton, I., Davis, P.E. & Moss, D. (1981) Distribution and breeding of red kites in relation to land-use in Wales. *Journal of Applied Ecology*, **18**, 173–186.

Nicholls, A.O. (1989) How to make biological surveys go further with generalised linear models. *Biological Conservation*, **50**, 51–75.

Purroy, F.J. (1997) *Atlas de las aves de España (1975–1995)*. Lynx Edicions, Barcelona, Spain.

Rogers, P.M. & Myers, K. (1980) Animal distribution, landscape classification and wildlife management, Coto de Doñana, Spain. *Journal of Applied Ecology*, **17**, 545–565.

Sánchez-Zapata, J.A. & Calvo, J.F. (1999) Raptor distribution in relation to landscape composition in semi-arid Mediterranean habitats. *Journal of Applied Ecology*, **36**, 254–262.

Stein, P. & Grobler, J.H. (1980) Breeding biology of the booted eagle in South Africa. *Ostrich*, **52**, 108–117.

Valverde, J.A. (1967) *Estructura de Una Comunidad Mediterránea de Vertebrados Terrestres*. CSIC, Madrid, Spain.

Veiga, J.P. (1986) Food of booted eagle (*Hieraaetus pennatus*) in central Spain. *Raptor Research*, **20**, 120–123.