

ECOLOGY AND CONSERVATION OF EUROPEAN FOREST-DWELLING RAPTORS

IÑIGO ZUBEROGOITIA & JOSÉ ENRIQUE MARTÍNEZ (EDS.)

Estudios Medioambientales Icarus S.L.



Bizkaiko Foru Aldundia
Diputación Foral de Bizkaia

Published by:

Departamento de Agricultura de la Diputación Foral de Bizkaia

© Diputación Foral de Bizkaia

All rights reserved. No part of this publication may be reproduced in any form or by any means without the prior permission of the copyright owner.

Edited by:

Iñigo Zuberogoitia & José Enrique Martínez
Estudios Medioambientales Icarus S.L.

Project Supervision:

Antonio Galera Coleto, Director of the Department of Conservation, Natura 2000 Network and Biodiversity.

Graphic and maps Design:

Antonio Secilla

General Design:

ITZEL Digital, S.L.

Printer:

Berekintza, S.L.

Cover photo by:

Sparrowhawk. Juan Sagardía.

Translators:

Phillip Thomas
José Delgado
Maria Francia Iñiguez Puebla
Mikel John O'Rourke
Rally Haigh

I.S.B.N.: 978-84-7752-489-2

D.L.: 1730-2011

Ecology of the booted eagle in semiarid Mediterranean landscapes

José E. Martínez¹, Iluminada Pagán, María V. Jiménez-Franco & José F. Calvo

Departamento de Ecología e Hidrología. Universidad de Murcia. Campus de Espinardo, 30100 Murcia, España 'E-mail: ecoljemt@um.es

Introduction

The booted eagle (*Aquila pennata*) is a long lived, medium sized raptor and trans-Saharan migrant. Despite several studies carried out in recent years, mainly dedicated to the Spanish population (García-Dios, 2005), little is known of its biology. To fill this gap in our knowledge, a long term monitoring programme set out to look into several aspects of the ecology of one of the largest populations of the species in the Iberian Peninsula. This chapter presents a synthesis of the most results obtained during 12 years of field research (1998-2009).

We first describe the characteristics of the population studied, estimating its density and tendencies, and offering information relative to its conservation at both regional and national level. We then suggest determining factors in the territorial occupancy and reproductive output of breeding pairs. For this, we discuss habitat selection models that explain the probability of occupancy and the breeding performance of the species as a function of habitat type, competition and territorial fidelity. Thirdly, we describe general aspects of its reproductive ecology (phenology, reproductive parameters and non-natural causes of mortality), providing information on the influence of density and laying date on the reproductive parameters. Fourthly, we discuss the consequences of habitat selection on population regulation, looking at the temporal pattern of occupancy in relation with the ideal despotic distribution pattern and the theory of density-dependent regulation. In fifth place, we provide information on habitat use obtained by radio tracking during the breeding season, analysing home range and foraging habitat selection. Lastly, we describe the food habits, analysing the temporal variations in diet composition and the prey partitioning between mates in breeding booted eagles.

Study area

The study was conducted in a mountainous area located in the centre of the Region of Murcia (south-eastern Spain). The study area covers about 10,000 ha, with elevations ranging from 550 to 1234 m above sea-level. The climate is Mediterranean with a mean annual rainfall of c. 400 mm and insolation is high (more than 2800 hours per year). The landscape is characterized by mountain slopes covered by pine forests (*Pinus halepensis*) interspersed with traditional agroecosystems (cereals, vineyards, olive and almond groves). No tree felling takes place at present and forest management consists of regeneration and improvement of the pinewoods in both public and privately owned land. Agriculture, quarrying and hunting are other relevant land uses.

Discussion Density, population trend and conservation status

In the 12 years of the study, the number of pairs in the area varied between 21 and 29, with a mean density of 2.46 ± 0.10 pairs per 10 km², making it one of the areas in Europe with the highest number of pairs (Martínez *et al.*, 2006a). The population appears to be stable, contrasting with the expansion seen in populations in the north of the Iberian peninsula (García-Dios, 2005) and the regressive trend observed in other European populations (BirdLife International, 2004). In Spain, the booted eagle is classified as *Not Threatened* (Madróno *et al.*, 2004), but in the province of Murcia as *Vulnerable* (Martínez *et al.*, 2006c). However, in the study area the species shows no conservation problems, although badly planned forest management activities sometimes have an adverse effect, leading to habitat loss, desertions and reproductive failures.

Factors determining territorial occupancy and reproductive output

Raptors are among the most suitable species for analysing the factors that determine territorial occupancy, since they show strongly territorial behaviour, are long



Pine forests covering the mountain slopes and vineyards occupying valleys give rise to the typical landscape in the study area. José Enrique Martínez.

lived and show a high degree of fidelity to nest-sites (Krüger, 2002a). Several factors related with occupancy have been identified, including habitat characteristics, competition, age and sex of individuals, dispersion, pair fidelity and nesting area (Wiklund, 1996; Forero *et al.*, 1999; Krüger, 2002a, 2004). In our study, we found that the probability of territory occupancy is mainly determined by previous breeding success (Martínez *et al.*, 2006b; Fig. 55). This response seems to be related with territorial fidelity and the capacity of experienced individual to use the same territories in successive years (Switzer, 1997; Hoover, 2003). The variables competition and habitat are not so explicative as the variable previous breeding success in territorial reoccupation although they also condition the

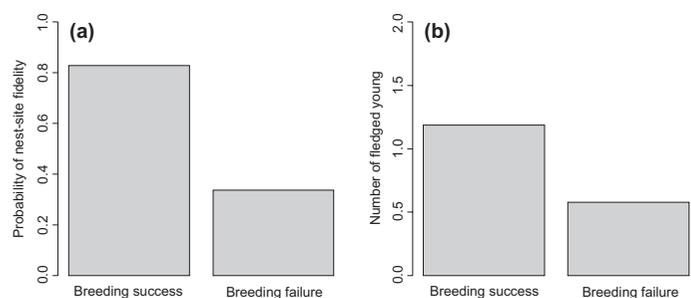


Figure 55. Probability of occupancy and expected success (number of fledglings) in booted eagle nesting territories according to best prediction models for the same (Martínez *et al.*, 2006b). Probabilities and estimated values are related with previous success (“reproductive success” and “reproductive failure”).

probability, especially the nest position in the upper third of the mountain slope and the distance to the nearest forest track (Fig. 56). This finding is probably related with the use of slope winds by the species, especially in Mediterranean areas where the meteorological conditions promote the formation of thermal currents, permitting gliding species like booted eagle to cover large distances (Martínez *et al.*, 2007). The selection of nesting territories far from forest tracks would seem to be the result of a preference for spaces free from human activity and corresponding disturbance (García-Dios & Viñuela, 2000).

As regards the factors determining the success of the species, previous breeding success was the most explicative variable in the best model (Fig. 55) and seems to be the consequence of the combined effect of two closely related factors but whose individual contribution is difficult to specify – the individual quality of the pair and the quality of the territory. In this respect, the habitat variables were less explicative than previous success in both models, suggesting that productivity is determined by the experience of reproductive individuals. However, the best additional model to explain success includes the variables trunk height (measured as distance from the ground to the first branch) and the nest plot's orientation (Martínez *et al.*, 2006b). The choice of the first could be a strategy to decrease the risk of exposure to terrestrial nest predators (carnivores and humans), while the second reflects the habit of the species to construct nests suited to the harsh conditions of insolation and high temperatures of the area. The scarce contribution of the variables related with competition in the best models contrasts with the findings of other authors where breeding success was strongly conditioned by inter and intraspecific competition (Hakkarainen *et al.*, 2004a; Krüger, 2004). In conclusion, the probability of occupancy

and its reproductive output is determined by previous breeding success (Fig. 55), which, together with the contribution of certain variables related with habitat and competition, will influence the selection of nesting territory, promoting the recruitment of new pairs to the population.

Reproduction

In the study area the pairs construct nests in Aleppo pines, in crowns offering intermediate cover. Both sexes contribute to nest building but the 1-2 (rarely 3) eggs are mostly incubated by the female for 38 days (Martínez, 2002). This species is considered a monogamous raptor, although one case of cooperative nesting by a trio of booted eagles was observed (Martínez *et al.*, 2005). This observation contrasts with the findings of a study by Díaz (2006), which mentioned at least 25% of territories are occupied by trios of booted eagle.

In our study area, booted eagle lays eggs around the middle of April (Table 46), which falls within the normal period mentioned for this species in the Iberian Peninsula (García-Dios, 2005). Rainfall has been identified as a potential limiting factor in many raptor species, especially in semiarid areas (Krüger *et al.*, 2002), so that unusually adverse weather conditions may lead to changes in laying date (Mearns & Newton, 1988; Steenhof *et al.*, 1999). In our study, we found no significant interannual variations in this respect, confirming the findings in other Mediterranean regions with a high number of sunny days (Bosch, 2003). However, the territories in which the mean laying date was early were more likely to witness reproductive success, although no significant relations with meteorological conditions were found during the pre-laying period (Pagán, 2008).

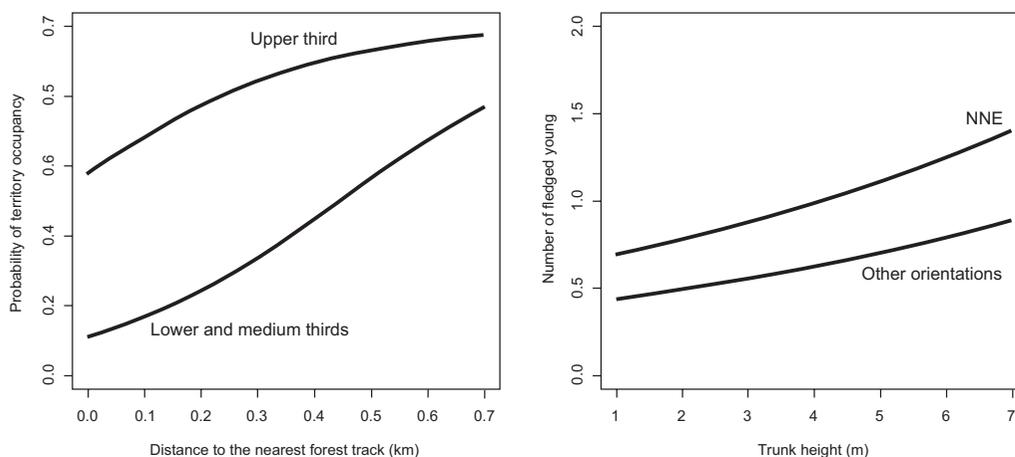


Figure 56. Probability of occupancy and expected success (number of fledglings) in booted eagle nesting territories according to best prediction models for the same (Martínez *et al.*, 2006b). Probabilities and estimated values are related with position of the nest on the valley slope and plot orientation.

In general, the reproductive parameters indicate that the population experiences no reproductive difficulties (Table 46), which is probably related with the long hours of sunlight in spring and summer that would facilitate hunting and the preys delivered to the nest by adults (Martínez *et al.*, 2006a). In other Spanish regions with high rainfall, nestling mortality in this species has been associated with adverse meteorological conditions which negatively affect hunting conditions (García-Dios & Viñuela, 2000).

The reproductive parameters of long-lived raptors are frequently density-dependent, that is, the highest reproductive success is associated with the lowest density (Newton, 1979). However, Martínez *et al.* (2006a) found that all the population breeding parameters analysed were density independent, suggesting that intra-specific competition is not a determining factor in the population regulation, unlike that observed for this and other species of forest raptors whose response was seen to be density dependent (Rodenhouse *et al.*, 1997; Sergio & Newton, 2003; Casado *et al.*, 2008).

The main cause of nestling mortality was predation by carnivores and eagle owls (Martínez *et al.*, 2006a). Genet (*Genetta genetta*) and stone marten (*Martes foina*) mainly killed fledglings. The eagle owl was the main predator of chicks and adult birds (females), a role that is well known in zones where other raptors compete for resources (Sergio & Hiraldo, 2008). How-

ever, in our study area the eagle owl is very scarce (no more than 4-5 pairs) so that we are inclined to think that the mortality observed was an isolated episode, perhaps the predation of one specialized individual. Unlike in other populations of booted eagle, in which a substantial number of reproductive failures were observed as the result of disturbance associated with forest management (Carlon, 1996; García-Dios & Viñuela, 2000), in our area the losses of eggs and nestling due to this factor were exceptionally low, basically due to the fact that any forest management activity was confined to improvement and regeneration tasks.

Distribution, territorial quality and density-dependent regulation

Previous studies on nest-site selection in a large number of raptor species have shown that the territory occupancy patterns differ from randomness, a circumstance usually attributed to differences in habitat quality among territories (Marchesi *et al.*, 2002; Sergio & Newton, 2003), and that territorial species may show a site-dependent mechanism of population regulation (Krüger & Lindström, 2001a; Rodenhouse *et al.*, 2003; Casado *et al.*, 2008). In the context of a given population, the occupancy of territories of higher quality reflects a pattern that has been described as ideal despotic distribution (IDD). In this model, the high-quality individuals (e.g. more experienced)

Table 46. Densities, laying dates and reproductive parameters of a population of booted eagle in the Sierras of Burete, Lavia and Cambrón (SE Spain).

Year	N° of birds monitored	N° of reproductive pairs	Mean laying date ¹ ± SD (range)	N° of eggs hatched	N° of successful birds ²	Mean number of fledglings ± SD	
						Productivity	Reproductive success
1998	27	23 (85%)	113.5 ± 8.5 (90-128)	38 (84%)	20 (87%)	1.22 ± 0.85	1.65 ± 0.49
1999	26	21 (81%)	113.9 ± 9.4 (103-135)	33 (83%)	17 (81%)	1.04 ± 0.87	1.59 ± 0.51
2000	21	12 (57%)	111.7 ± 8.8 (92-123)	21 (91%)	11 (92%)	0.90 ± 0.94	1.73 ± 0.47
2001	23	15 (65%)	111.4 ± 7.3 (98-125)	28 (96%)	14 (93%)	1.13 ± 0.97	1.86 ± 0.36
2002	26	13 (50%)	119.3 ± 9.9 (103-131)	20 (83%)	12 (92%)	0.73 ± 0.87	1.58 ± 0.51
2003	22	15 (68%)	118.2 ± 8.3 (103-135)	22 (81%)	11 (73%)	0.82 ± 0.91	1.64 ± 0.50
2004	25	17 (68%)	121.5 ± 9.6 (109-147)	24 (73%)	9 (53%)	0.52 ± 0.77	1.44 ± 0.53
2005	21	11 (52%)	120.1 ± 7.2 (112-132)	10 (48%)	6 (55%)	0.43 ± 0.75	1.50 ± 0.55
2006	21	12 (57%)	111.8 ± 12.0 (99-146)	23 (100%)	10 (83%)	0.67 ± 0.80	1.40 ± 0.52
2007	22	10 (45%)	119.9 ± 5.7 (114-132)	18 (90%)	9 (90%)	0.68 ± 0.89	1.67 ± 0.50
2008	21	14 (67%)	107.8 ± 8.6 (101-128)	17 (68%)	12 (86%)	0.81 ± 0.81	1.42 ± 0.51
2009	21	18 (86%)	111.6 ± 6.4 (106-125)	24 (73%)	15 (83%)	1.05 ± 0.80	1.47 ± 0.52
Total	276	181 (66%)	114.7 ± 9.3 (90-147)	278 (81%)	146 (81%)	0.84 ± 0.87	1.47 ± 0.52

¹ Day 90 is 31st March.

² Estimated percentages with respect to number of reproductive pairs.



Javier Coll.

tend to occupy the higher-quality territories, followed by young or subordinate individuals which will take the lower quality sites (Newton, 1998). However, unlike that observed for most raptors (Sergio & Newton, 2003), the distribution of our population of booted eagle did not fit the IDD pattern (Pagán *et al.*, 2009). This conclusion was based on the fact that: first, the pattern of temporal occupancy did not differ from the randomness, suggesting the absence of preferences for specific territories and, secondly, in the absence of significant correlation between the occupancy rate and reproductive parameters, it would be plausible that lower quality individuals could occupy high quality sites and vice versa. All this seems to suggest that in the studied population the occupancy rate is not a good measure of territory quality, the quality and experience of the individuals being the determining factors in productivity (Nielsen & Drachman, 2003).

As regards the hypotheses related with site-dependent population regulation, our study found no relation between reproductive parameters and density (Pagán *et al.*, 2009). At the same time, no relation was observed

between density and the variance of productivity, which, according to density-dependent population regulation, should be positive, which reinforces the idea that booted eagle does not fit the IDD pattern.

These findings point to possible difficulties for a species to evaluate the quality of territories in an area of heterogeneous environmental characteristics, and explain the absence of relations between habitat characteristics and variations in productivity and occupancy rate. This could have important implications for the conservation of the booted eagle, since species that exhibit random distribution and no site-dependent population regulation are more prone to extinction (McPeck *et al.*, 2001).

Habitat use

Figure 57 shows the home ranges corresponding to six booted eagles obtained by the minimum convex polygon method (MCP). The marked individuals had large home ranges that varied in size from 5,130 to 13,484 hectares (5,130-14,266 ha for two males and 4,542-13,484 ha for the four females), which is greater than

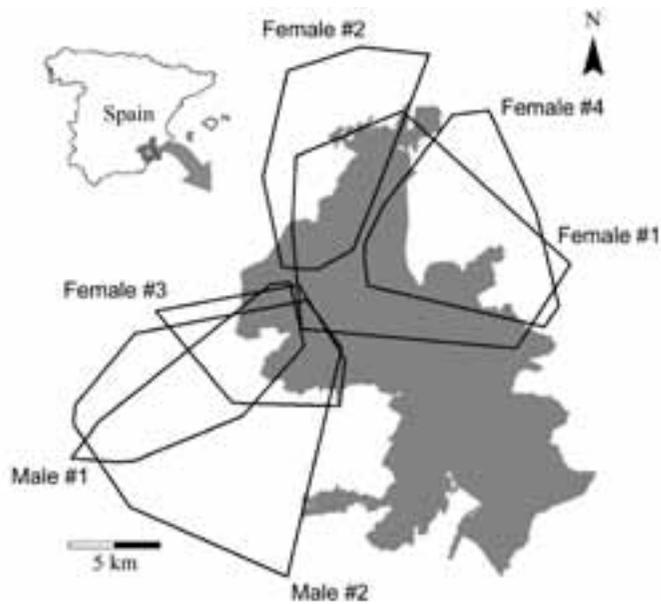


Figure 57. Home ranges of six booted eagle individuals fitted with radio transmitter in SE Spain (F, females; M, males). Area in grey corresponds to limits of Special Protection Area.

that recorded for the goshawk (Mañosa, 1991), one of its potential competitors in the Mediterranean region. From a methodological point of view, the estimations of home ranges by MCP were similar to those obtained using Kernel's method (Martínez *et al.*, 2007).

Assuming that the home range is determined, at least in part, by the food availability (Fernández *et al.*, 2009), in agreement with Peery (2000), the use of such large home ranges by the booted eagle individuals monitored may reflect the need to cover large areas in order to find sufficient individuals of its preferred prey birds in our study area (Martínez & Calvo, 2005). Previous studies have shown that avian prey generally are less abundant than other prey groups for a given body size (Maurer & Brown, 1988; Greenwood *et al.*, 1996; Silva *et al.*, 1997; Peery, 2000).

A compositional analysis (Aebischer *et al.*, 1993) indicated that the types of habitat preferred by booted eagle were (in this order): forests, edges and scrubs (Table 47). However, simulated randomness tests pointed to no significant differences in the preference for the positively selected habitat types. This presumed lack of difference probably reflects the low number of individuals analysed and radio localisations received.

This result might also be determined by the quality of the habitat used by the different types of prey present and which form part of their diet. The choice of edge and scrub habitats probably reflects the search for prey that themselves forage in soils covered by vegetation with an open structure, especially rabbits, ocellated lizards and red-legged partridges, which make up almost half of the biomass taken to the chicks during breeding season (Martínez, 2002). At the same time, the positive selection of forest may have been determined by the search for forest birds, adults, nestlings and fledglings, which form a substantial part of the booted eagle diet (Martínez, 2002). The preference for natural environments that provide better quality prey as opposed to those which provide prey of a worse quality – agricultural, semi-urbanised – agrees with the avoidance behaviour shown by birds of prey towards ranges of poor quality (Marzluff *et al.*, 1997; Burgess *et al.*, 2009). The large tracts of irrigated and not irrigated crops are poor in prey and offer little to satisfy the energy requirements of adult birds (Martínez, 2002). This avoidance of cropland contrasts with observations made about the short-toed eagle in northern Greece, where this species' preference for this kind of habitat is associated with an abundance of snakes (Bakaloudis *et al.*, 1998). Since forested areas, edges and scrubs play such a key role in the hunting habits of booted eagle, it is to be recommended

Table 47. Compositional analysis of habitat selection. Simplified matrix based on comparison of the proportions of radio localisations in each habitat type with respect to the proportion of each habitat type within the home ranges of booted eagle. The last column shows the order of preference. Triple signs indicate significant differences ($P < 0.05$) between habitat types.

Habitat type	Habitat type						Ranking
	Forest	Scrub	Dryland	Irrigated	Urban	Ecotone	
Forest		+	+	+	+++	+	1
Scrub	-		+	+	-	-	3
Dryland	-	-		+	+++	-	4
Irrigated	-	-	-		---	-	6
Urban	---	+	---	+++		-	5
Ecotone	-	+	+	+	+		2



Light morph of booted eagle. Carlos González.

that management strategies should have as a major objective their good functioning, conservation and profitability since many of them are privately owned (Tisdell, 2004). Many authors have shown the need to protect hunting areas and nesting sites to ensure the long term conservation of raptor species (Kenward & Widén, 1989; Sánchez-Zapata & Calvo, 1999).

Diet

The booted eagle consumes a wide variety of prey ranging in size from small rodents weighing less than 100 grams to adult rabbits that weigh around 1,000 g. Medium sized birds, mainly pigeons, and ocellated lizards make up the bulk of the diet, while the above mentioned rabbits and medium sized birds are the main source of biomass (Martínez, 2002). The diet,

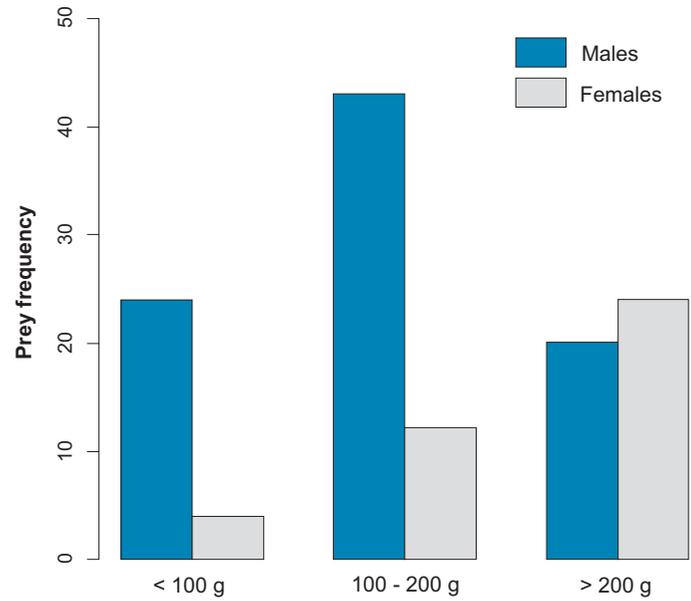


Figure 58. Proportion of prey delivered by booted eagle males and females to the nest according to biomass (weight categories: <100 g; 100-200 g and >200 g).

In another study, we analysed the prey items delivered to the nest by male and female booted eagles (Martínez & Calvo, 2005). Through the direct observation of nests, we found that females contributed prey of greater biomass and did so more frequently than males, which brought a greater quantity of small prey, such as ocellated lizard (Fig. 58). Such differences would probably be related with the sexual dimorphism of the species (del Hoyo *et al.*, 1994).

however, varies during reproduction, and in a study of pellets and the remains of prey collected from nests showed that the consumption of mid-sized birds increases as the reproduction period progresses, while the importance of small prey decreases (Martínez *et al.*, 2004). In contrast, during incubation and in terms of biomass, small prey (mainly passerines) increased in importance (Martínez *et al.*, 2004).