

NON-BREEDING FEEDING ECOLOGY OF TERRITORIAL BONELLI'S EAGLES *HIERAAETUS FASCIATUS* IN THE IBERIAN PENINSULA

ECOLOGÍA TRÓFICA DE LAS ÁGUILAS-AZOR PERDICERAS *HIERAAETUS FASCIATUS* TERRITORIALES DURANTE EL PERIODO NO REPRODUCTOR EN LA PENÍNSULA IBÉRICA

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The feeding ecology of many species of raptors remains largely unknown since most of diet studies are usually restricted to a half of the year, the breeding season, probably due to the easiness for recovering food data related to the association of individuals to nesting sites. Contrary, during the non-breeding season birds are difficult to locate and information on diet is scarce, causing lack in overall knowledge and comprehension of feeding habits (Cramp and Simmons, 1980; del Hoyo *et al.*, 1994; Ferguson-Lees and Christie, 2001). Because of food is one of the main limiting factors for birds of prey (Newton, 1979), this shortage in basic information during a long life-period of such species should be urgently addressed. In this sense, the diet of non-breeding period have proved to influence the healthy of birds, body condition and the reproductive output in the subsequent breeding attempt (Newton, 1979; González, 1991), final-

ly leading to a strong limitation of both density and survival of a number of bird species (see a review in Newton, 1998). Hence the study on non-breeding diet in raptors, a group of species usually threatened (del Hoyo *et al.*, 1994; Tucker and Heath, 1994), is not only an important aspect to promote the ecology knowledge but also a necessary tool to plan adequately conservation measures.

The Bonelli's eagle *Hieraaetus fasciatus* is an endangered bird of prey (Tucker and Heath, 1994; Real, 2004) inhabiting the Mediterranean coast, Middle East and southern Asia (del Hoyo *et al.*, 1994; Ferguson-Lees and Christie, 2001). Dietary studies on this species are frequently related to the breeding season and restricted around European continent (Jordano, 1981; Palma *et al.*, 1984; Fernández and Insausti, 1986; Real, 1987; Salvo, 1988; Simeon and Wilhelm, 1988; Rico *et al.*, 1990; Real, 1991; Gil-Sánchez *et al.*, 1994; Leiva *et al.*, 1994;

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Martínez *et al.*, 1994; Gil-Sánchez, 1998; Gil-Sánchez *et al.*, 2000; 2004; Iezekiel *et al.*, 2004; Palma *et al.*, 2006). Only few works exist facing the non-breeding period (France: Cheylan, 1977; Simeon and Wilhelm, 1988; Cyprus: Iezekiel *et al.*, 2004), but these studies were made using heterogeneous collecting methods (Cheylan, 1977; Simeon and Wilhelm, 1988), or were focused on non continental Bonelli's populations (Iezekiel *et al.*, 2004).

The main goals of this paper were: 1) to describe the diet of territorial Bonelli's eagles during the non-breeding season in two representative areas of the Iberian Peninsula, 2) to study seasonal differences related to breeding behaviour and 3) to discuss the profitability of the main prey and prey preferences for Bonelli's eagles under the light of classic predator-prey theories.

Our research were focused in two different areas representing very distinct ecological and demographical patterns in the European species distribution (Real and Mañosa, 1997; Real *et al.*, 2001; Muñoz *et al.*, 2005; Carrascal, in press), one in the south (Granada province; 37°20'N, 03°45'E) and other in the northeast (Catalonia region; 41°34'N, 01°25'E) of Spain. Granada, with ca. 52 Bonelli's breeding pairs and showing a slight increased tendency, supports the most productive population of this species in Europe (Gil-Sánchez *et al.*, 2004; Moleón and Gil-Sánchez, 2006), while Catalonia sustains a decreasing population of ca. 66 pairs, even though during the last years reached some stability (Real and Mañosa, 1997; Real, 2004). The habitat of the Bonelli's eagle in Granada is mainly characterised by a mixture of non-irrigated crops and Mediterranean shrubs, while the Catalanian habitat is more forested.

In relation to the known trophic ecology (in the breeding season), both areas are also clearly differentiated, since Bonelli's eagles in Granada consume mainly rabbits *Oryctolagus cuniculus* and red-legged partridges *Alectoris rufa* (both prey meaning ca. 70 % of the total

diet; Gil-Sánchez *et al.*, 2000, 2004) while in Catalonia pigeons and rabbits are the more frequent prey (both meaning ca. 50 % of the total diet), existing a broader trophic spectrum (Real, 1987, 1991).

We collected diet data searching for food regurgitated pellets and freshly captured prey in roosting sites in the breeding areas from the end of dependence period of juveniles until egg laying (October-January; Arroyo *et al.*, 1995; Real *et al.*, 1998; Gil-Sánchez, 2000; Mínguez *et al.*, 2001). These two methods offer the most reliable results for the diet composition in this species (Real, 1996). The study period was comprised between 1981-2002 for Catalonia and 1998-2007 for Granada, corresponding to 14 and 9 breeding territories respectively.

Firstly, we contrasted the overall non-breeding food habits from Granada and Catalonia, and then we compared by territory the diet between breeding and non-breeding periods only using territories with sufficient sample size (> 20 prey items) coinciding for the same years (Granada: $n = 4$; Catalonia: $n = 3$). Breeding samples were collected from February to June (see Gil-Sánchez *et al.*, 2000, 2004; Real, 1996; for more methodological details).

Prey species were grouped in seven categories: rabbit, other mammals, red-legged partridge, pigeons *Columba* spp., corvids, other birds and eyed lizard *Lacerta lepida*. All diet analyses were tested by means of a chi square and assumed $P < 0.05$.

At a global level we obtained 519 prey items for the non-breeding season, 412 from Granada and 107 from Catalonia. By regions, in southern Spain the rabbit was the staple prey (52 %), followed by partridge (18 %) and pigeons (16 %); the other prey categories were of minor importance. In Catalonia the main prey was pigeons (49 %), followed by other birds (25 %); rabbit reached only 10 % (Table 1).

The non-breeding diet composition differed between Granada and Catalonia ($\chi^2 = 40.2$; $df = 6$; $P < 0.001$), as rabbits and partridges were more frequently consumed in the south ($\chi^2 =$

TABLE 1

Average food habits of the Bonelli's eagle in southern (Granada province) and northeastern (Catalonia region) Spain during the non-breeding season. Data are referred to frequencies of occurrence, and values providing differences ($P < 0.05$) are given in bold.

[*Alimentación del águila-azor perdicera en el sur (provincia de Granada) y el noreste (región de Cataluña) de España en época no reproductora. Los datos se refieren a frecuencias de ocurrencia. Los valores que aportan las diferencias ($P < 0,05$) se señalan en negrita.*]

Geographic area	Rabbit	Other mammals	Partridge	Pigeons	Corvids	Other birds	Lizard	<i>n</i>
Southern Spain	51.7	3.9	17.7	16.0	1.5	7.8	1.5	412
Northeastern Spain	9.8	3.9	4.9	49.0	7.8	24.5	0	107

10.2-60.5; $df = 1$; $P < 0.001$ for both cases) while pigeons and other birds being more numerous in the north ($\chi^2 = 21.6-51.0$; $df = 1$; $P < 0.001$ for both cases; Table 1).

We also found differences between breeding and non-breeding diet in five of the seven territories ("Granada 3-4" and "Catalonia 1-3"; $\chi^2 = 18.8-68.6$; $df = 6$; $P < 0.01$ for all cases; Table 2; Fig. 1). Overall, in Granada the consumption of pigeons were higher in the non-breeding season ($\chi^2 = 7.3$; $df = 1$; $P < 0.01$), while partridges fell off at half ($\chi^2 = 20.6$; $df = 1$; $P < 0.001$); the other prey groups did not suffer seasonal changes ($P > 0.05$ for all cases; Table 2; Fig. 1). In Catalonia there was a higher ingest of pigeons and other birds ($\chi^2 = 7.0-17.2$; $df = 1$; $P < 0.01$ for both cases), and a lower consumption of rabbit, other mammals and lizards in the non-breeding period ($\chi^2 = 5.7-10.2$; $df = 1$; $P < 0.05$ for all cases); partridges and corvids were equally consumed in both periods ($P > 0.05$ for both cases; Table 2; Fig. 1).

Independently of the season, rabbit was the main prey of the Bonelli's eagle in southern Spain. Taking into account that rabbit abundance decreases over ca. 50–80% in the eagle non-breeding season in relation to the breeding period (Villafuerte *et al.*, 1997; Gil-Sánchez

et al., 1999; Calzada, 2000; Mínguez *et al.*, 2001; Palomares, 2001), the absence of seasonal changes in the rabbit consumption rate suggests a functional response and an active selection by Bonelli's eagle to this prey in Granada (Stephens and Krebs, 1986), as other studies had previously described (Gil-Sánchez, 1998; Palma *et al.*, 2006). Then, the higher mobility of eagles during the non-breeding season (Consejería de Medio Ambiente, 2006; J. Real and M. Moleón, *unpubl. data* of radiotracking) due to the lack of parental care could favour the displacements and staying in rabbit high density patches, although being these areas far away from the nests, so giving a plausible explanation to our results.

The scenery in Catalonia is different, since in this region the rabbit is on average much less abundant than in southern Spain (Real, 1991; Blanco and Villafuerte, 1993; Villafuerte *et al.*, 1998; Gil-Sánchez *et al.*, 2004), consequently being less frequent in the eagle diet than in Granada. In fact the winter rabbit scarcity is so low that functional response could remain hidden. So it is likely that rabbits lost their profitability for eagles in these very low rabbit density areas and seasons, and they were permuted by other prey like pigeons and other birds.

TABLE 2

Comparative diet of the Bonelli's eagle during the breeding and non-breeding seasons in four territories of Granada (southern Spain) and three territories of Catalonia (northeastern Spain). Frequency of occurrence of each prey group is shown.

[*Dieta comparada del águila-azor perdicera en los periodos reproductor y no reproductor en cuatro territorios de Granada (sur de España) y tres de Cataluña (noreste de España). Se muestra la frecuencia de ocurrencia de cada grupo-presa.*]

Territory	Period	Other			Other			Lizard	n
		Rabbit	mammals	Partridge	Pigeons	Corvids	birds		
Granada 1	Non breed.	36.2	10.3	15.5	19.0	5.2	10.3	3.4	58
	Breeding	39.6	2.1	24.7	16.6	4.2	5.6	7.1	889
Granada 2	Non breed.	64.7	2.5	19.6	4.5	1.6	6.7	0.5	231
	Breeding	47.7	7.5	29.0	5.5	1.4	6.7	2.3	656
Granada 3	Non breed.	40.9	6.8	20.5	22.7	0	6.8	2.3	44
	Breeding	22.3	1.5	39.3	18.0	1.0	5.3	12.6	206
Granada 4	Non breed.	30.3	0	6.1	48.5	0	9.1	6.1	33
	Breeding	43.3	3.3	13.3	30.0	0	10.0	0	30
Catalonia 1	Non breed.	15.0	0	10.0	10.0	15.0	40.0	0	20
	Breeding	23.5	15.9	6	27.2	6	10.1	11.3	455
Catalonia 2	Non breed.	10.7	3.6	3.6	50.0	7.1	25.0	0	28
	Breeding	17.6	19.0	1.4	33.1	3.5	7.0	18.3	142
Catalonia 3	Non breed.	4.5	0	0	68.2	9.1	18.2	0	22
	Breeding	25.3	21.3	6.7	29.3	6.7	6.7	4.0	75

The Bonelli's eagle is the Iberian predator consuming more red-legged partridge (see a review in Moleón, 2007), which is an expected result taking into consideration that this species belongs to the hawk eagles, a group of raptors including a high number of galliforms in their diet (Brown, 1952, 1955; Smeenk, 1974; Steyn, 1975; Debus, 1984; Nevado *et al.*, 1988; Martínez, 2002; García-Dios, 2006); besides, some authors have suggested certain ornithophagical specialization (Clouet and Goar, 1984; Parellada *et al.*, 1984). Surprisingly we did not find evidences of any functional response to this prey, so that the proportion of partridges in the Granada diet diminished when increased their abundance in the field (Braza *et al.*, 1985; Duarte and Vargas, 2001; Mínguez *et al.*, 2001). The lower

consumption of partridge during the non-breeding period could be related to seasonal differences in its vulnerability to predators. In this respect, the exhibition calls by males of partridges in spring (Cramp and Simmons, 1980) could make themselves easier to catch by eagles in the breeding season (*pers. obs.*), as it has already been suggested in the case of another Iberian raptor (Donazar and Castián, 1989). For its part, the seasonal stability of red-legged partridges in the diet of Bonelli's eagle in Catalonia could be a functional response to the non-breeding scarcity of a more profitable prey such as rabbit. The lower availability of rabbits in this area should therefore force eagles to prey on partridges in the non-breeding period, so compensating for their lower vulnerability.

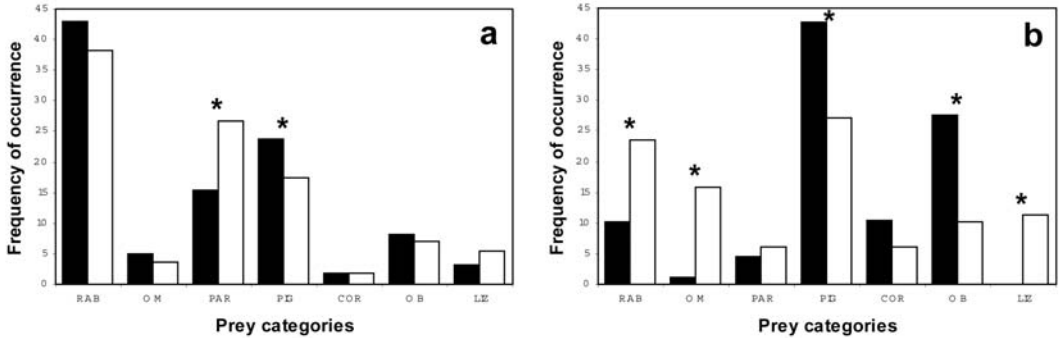


FIG. 1.—Average food habits of the Bonelli's eagle in four territories of southern Spain (a) and three territories of northeastern Spain (b) having data from both breeding and non-breeding periods. Black bars: non-breeding period; white bars: breeding period; RAB: rabbit; O M: other mammals; PAR: red-legged partridge; PIG: pigeons; COR: corvids; O B: other birds; LIZ: eyed lizard. Asterisks indicate prey groups providing the statistical differences ($P < 0.05$).

[Dieta del águila-azor perdicera en cuatro territorios del sur (a) y tres territorios del noreste de España (b) que cuentan con datos para las épocas reproductora y no reproductora. Barras negras: periodo no reproductor; barras blancas: periodo reproductor. RAB: conejo; O M: otros mamíferos; PAR: perdiz roja; PIG: palomas; COR: córvidos; O B: otras aves; LIZ: lagarto ocelado. Los asteriscos señalan los grupos de presa que aportan las diferencias ($P < 0,05$).]

The overall relative scarcity of rabbits and partridges in Catalonia (Real, 1991; Villafuerte *et al.*, 1993; Villafuerte *et al.*, 1998; Gil-Sánchez *et al.*, 2004) could be the cause of the differences observed between areas, so that northern eagles were forced to capture alternative prey (Angelstam *et al.*, 1985), namely pigeons, other birds, other mammals and lizards. In relation to the non-breeding season, the lack in rabbits in northern Spain is probably accentuated by the lower availability of cold-sensitive species like lizards (Pérez-Mellado, 1998) and certain other mammals (e.g., *Sciurus vulgaris*; Blanco, 1998), leading to a higher consumption of pigeons (mainly domestic) and species included into the other birds' category, which are more abundant in this season due to the arrival of wintering birds (Díaz *et al.*, 1996; Tellería *et al.*, 1999).

To conclude, non-breeding diet suggested that rabbits are a key prey for Bonelli's eagles in the Iberian Peninsula, although rather than a true trophic specialist, the Bonelli's ea-

gle can be considered as a facultative specialist (Glasser, 1982), preferring the rabbit when it is relatively abundant but shifting to other prey when the rabbit is too scarce, which is neither a surprise nor an exception for the Mediterranean community of vertebrate predators (Fedriani *et al.*, 1998; Calzada, 2000; Lozano *et al.*, 2006). This situation would fit with the sigmoidal Type III functional response (Holling, 1959), and is therefore not consistent with the specialist Type II found in southern Portugal by Palma *et al.* (2006). Two hypotheses can provide a suitable explanation at this respect. Firstly, it might be that rabbit population density in southern Portugal is not under the profitability threshold, as it seems to be the case of Granada. Secondly, it is possible that differential food requirements and availability among seasons lead to differential strategies of resource exploitation by Bonelli's eagles. Consequently, further research is needed taking into account different ecological scenar-

ies and seasons where both the eagle diet and the rabbit densities are known.

Nonetheless, the searching for the richer non-breeding prey patches can be a concern for the eagle conservation. In this sense eagles with lower trophic resources as rabbits have bigger home ranges and have to move long distances outside the breeding season (*pers. obs.*) that implies a supplementary energy expense. Moreover, high rabbit density areas support a strong game activity during the non-breeding season, and illegal persecution by hunters is one of the two main mortality causes for Bonelli's eagles (Real *et al.*, 2001). On the other hand, pigeons and other birds like gulls, thushes and corvids are usually associated to humans, which increase the mortality risk by direct persecution, power lines casualties, parasite diseases and poisoning. Hence, Bonelli's eagle conservation planning should take into account this prey-mediated vulnerability, even more because this raptor frequently breeds and disperses in human-influenced habitats (Gil-Sánchez *et al.*, 1996; Bautista *et al.*, 2004; Gil-Sánchez *et al.*, 2004; Balbontín, 2005).

RESUMEN.—*Presentamos los primeros datos sobre la dieta de las águilas-azor perdiceras Hieraaetus fasciatus territoriales durante el periodo no reproductor en la península Ibérica. El estudio, realizado en dos áreas, una del sur (Granada) y otra del noreste (Cataluña) de España, mostró que existen diferencias alimenticias tanto geográficas como estacionales. El águila parece comportarse como un especialista facultativo sobre el conejo, de manera que prefiere esta presa cuando es relativamente abundante pero desvía su atención hacia presas alternativas cuando el conejo es demasiado escaso. El consumo de perdices rojas parece estar condicionado por la abundancia de conejo y el conspicuo comportamiento de los machos de perdiz durante el celo. En los lugares y épocas donde los conejos y, en menor medida, las perdices están menos disponibles para las águilas, presas como las pa-*

lomas y otras aves adquieren especial relevancia. Las preferencias alimenticias y las restricciones impuestas por la disponibilidad de las presas incrementan la vulnerabilidad de las águilas-azor perdiceras hacia amenazas de origen antrópico, circunstancia que se ve acentuada en época no reproductora.

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