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# Factors influencing the decline of a Bonelli's eagle *Hieraaetus fasciatus* population in southeastern Spain: demography, habitat or competition?

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**Abstract.** We investigated three possible causes of territory desertion among Bonelli's eagles *Hieraaetus fasciatus* in Murcia (southeastern Spain): low demographic parameters, low habitat quality and competition with Golden eagles *Aquila chrysaetos*. From 1983 to 1997, we surveyed a Bonelli's eagle population. Abandoned and occupied territories were compared to find differences in demographic parameters (flight rate, productivity and mortality) or habitat characteristics. Mortality was significantly higher in abandoned territories. Abandoned territories also had larger areas of forest and extensive agriculture, while occupied territories had more shrublands. Competition with Golden eagles was not a determinant of territorial abandonement but interacted with human persecution of the species. Management implications are discussed.

## Introduction

Bonelli's eagle is a cliff-nesting raptor mainly distributed over the Mediterranean coastal provinces (Cramp and Simmons 1980; del Hoyo et al. 1994). During recent decades and all over its range, this eagle has experienced one of the most severe population declines recorded among birds of prey in Europe (Arroyo and Garza 1995; Real and Mañosa 1996) so it has been listed as an Endangered European Raptor (Rocamora 1994). The main European breeding population, located in Spain, has been reduced by 25% and the species has been included in the Spanish Red Data Book as Vulnerable (Blanco and González 1992). International, national and regional legislation include it as a prioritary species target of special conservation measures (Council Directive 79/409/EEC, Real Decreto 439/1990, Ley 4/1992). Causes proposed to explain its population decline are habitat destruction, demographic unbalance (such as a high mortality rate or a low productivity), low prey availability and competition with other species (such as Golden eagle *Aquila chrysaetos*) (Garza and Arroyo 1996; Real and Mañosa 1997).

Although in the 1970s the Murcia region (SE Spain) held one of the highest

densities of the species (0.37 pairs/100 km$^2$), today this density is much lower (0.15 pairs/100 km$^2$) (Sánchez-Zapata 1997). This decline seems to be steeper than that in other populations because of particularly low adult survival values due to high human persecution (Real and Mañosa 1996, 1997; Sánchez-Zapata 1997). Like this, many territories that were occupied by Bonelli's eagle in the past have not been recolonized. To implement conservation planning, it is important to know why these areas remain unoccupied. For many species, individuals may change territory following a poor or unsuccessful reproductive attempt or mate loss (Nager et al. 1996; Wiklund 1996; Forero et al. 1999) or after occupying a poor quality territory (Korpimäki 1993). Competition with similar sympatric species may also limit the local breeding density of certain species (Bourski and Forsmeier 2000) and in some cases it could be expected that the stronger species reduces the breeding density of the weaker one or merely restricts it to inferior sites (Newton 1979; Gil-Sánchez 1999). The aim of this paper is to discuss three hypotheses that may explain territory desertion: (a) high territorial mortality rates that impede breeding pairs to stand or reestablish; (b) low productivities and low quality habitats that promote breeding pairs to move to other areas and (c) pairs displacement by a stronger competitor. To do that, we compared demographic parameters (territorial mortality and productivity) and habitat variables between occupied and abandoned territories of Bonelli's eagle, considering the breeding distribution of Golden eagle.

## Methods

### *Study area*

The study area covered the Murcia region (SE Spain), a 11317 km$^2$ area that experiences a semi-arid Mediterranean climate with a mean annual rainfall of 300 mm and annual temperature averaging 17 °C. The region, from the southeast to the northeast, is crossed by mountains that reached 2000 masl. The vegetation used to be typically shrubs, grasslands and mixed forest, but human activity has transformed it into a mosaic by introducing cultivated lands.

In the 1970s, Bonelli's eagle distributed over a high surface of the region. Now, only a few pairs breed in mountains near the Segura river and the species occupies mainly the southern part, where the climate is hotter and drier (Figure 1).

### *Territorial occupancy and demographic parameters*

We studied the long-term change of a Bonelli's eagle population from 1983 to 1997. Known territories and potential breeding habitat for the species ($n = 50$) were visited during the breeding season. We considered a territory to be occupied when we observed birds, territorial activity, courtship, brood rearing activity, young or any conspicuous field sign in an area (Fuller and Mosher 1987). As abandoned territories, we included those areas where the species reproduced at least once, but no birds were recorded during the rest of the monitoring time.

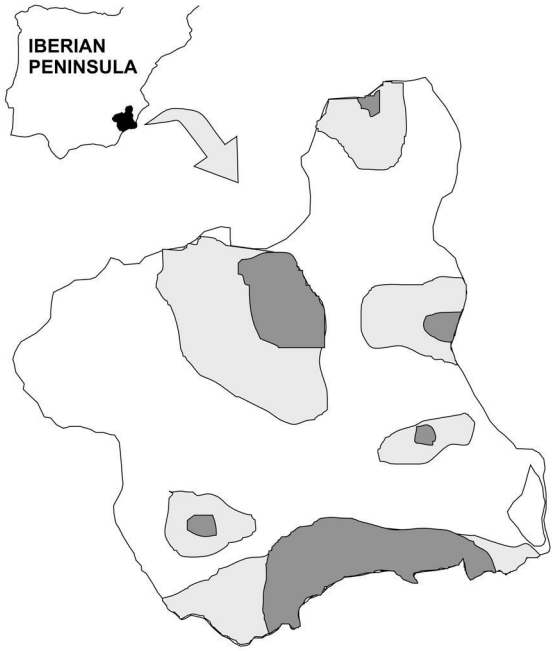


*Figure 1.* Map of the study area showing past (light shadow) and present (dark shadow) Bonelli's eagle.

A pair was classified as successful if it produced one or more young that reached 80% of normal fledging age (i.e. around 50 days) (Real et al. 1997). To evaluate breeding success, we used the average rate of young fledged (for laying pairs, number of young fledged per number of years that the territory was occupied and monitored) and the average productivity (for territorial pairs, number of young fledged per number of years that the territory was occupied and monitored) of each territory (Sánchez-Zapata et al. 2000). To compare reproductive fitness between adults and subadults we aged eagles depending on plumage patterns (Parellada 1984).

Mortality was estimated for territorial birds and was calculated as the proportion of birds present in the population at the start of the breeding season that were not still present at the start of the following breeding season. A bird was considered dead if it disappeared from its breeding site from one year to the next or if it was replaced by another bird. Because they were not marked, the movement of one bird to a vacant territory would have been counted as a death (Real and Mañosa 1997). The lack of bird observations and the absence of arranged nests and drooping on perches revealed the disappearance of a pair. When only one bird was observed in a breeding territory, the loss of half a pair was recorded. When a pair was not recorded in its traditional site, we searched within a radius of several kilometers for suitable breeding habitats in order to exclude the possibility of a pair having moved to a new breeding site (Real and Mañosa 1997).

*Habitat parameters*

The location of breeding territories (occupied and abandoned) was incorporated into a Geographic Information System (GIS) (IDRISI, Eastman 1992). For each one we quantified land-uses and human disturbances in a 3 km radius around the most frequently used nest-site (Table 1). Different land-use classes were obtained from maps of the Ministerio de Agricultura (1:200 000) (MAPA 1985). New categories were formed by combining related land-use cover categories (e.g., lemon, orange and other fruit trees were combined to give a single arboreous intensive agriculture category). Human disturbance variables were obtained from maps of the Instituto Geográfico Nacional (1:50 000) (Table 1). In both cases, information was corroborated with field data.

The study population has one of the highest productivities recorded in the literature (Real and Mañosa 1997; Sánchez-Zapata 1997), so food abundance could be considered as above the minimum required by the species. Like this, we did not measure food supply as a habitat parameter. However, in the Levante region, racing pigeons are common and many disappeared breeding pairs included them in their diet (Sánchez-Zapata 1997). The behaviour of those pigeons made them easy to catch, moreover during competitions. Bets are important and a good racing pigeon could cost a lot of money (Sánchez-Zapata 1997). To evaluate its importance, and considering the same territory size (28.27 $km^2$), pigeon lofts were counted and classified as occupied by racing or domestic pigeons.

*Table 1.* Variables used to characterize breeding areas.

| | |
|---|---|
| *Land use* (ha) | |
| IRRIG | Irrigated lands (i.e. lemon and orange trees, vegetables, ...) |
| EXTA | Extensive agriculture (i.e. olive and almond trees, cereals, ...) |
| SHRUB | Shrubland |
| FOREST | Forest (mainly *Pinus halepensis*) |
| URBAN | Urbanizations |
| *Human disturbance* | |
| SR | Number of houses |
| NIRRIG | Number of new irrigated lands |
| QUARRY | Number of quarries |
| INFRA | Number of other infrastructures (industries, ...) |
| SPARE | Number of places for outdoor activities (bike, climbing, scaling, ...) |
| MTPL | Medium tension electric power lines (km) |
| HTPL | High tension electric power lines (km) |
| TPL | Medium and high tension electric power lines (km) |
| VILLA | Distance to the nearest inhabited village |
| *Food availability* | |
| RPL | Number of racing pigeon lofts |
| DPL | Number of domestic pigeon lofts |

*Competition*

Competition with Peregrine falcon *Falco peregrinus*, Griffon vulture *Gyps fulvus* and Golden eagle has been recorded in the literature (Jordano 1981; Fernández and Insausti 1990; Fernández and Donázar 1991; Gil-Sánchez 1999; Rico et al. 1999). As all known territories of Bonelli's eagle were visited during the breeding season, we registered any entry of individuals of other raptor species. As complement and because the most important competitor for Bonelli's eagle in Murcia seems to be the Golden eagle, during 1997 we censused its population incorporating breeding territories in the same GIS (Carrete et al. 2000).

*Data analysis*

To test for differences between pairs with and without subadults, we pooled all data across years. In those analyses, we excluded those pairs for which some reproductive stage could not be confirmed. We used non-parametric (Kruskal–Wallis) and percentage uniformity $t$ tests (Sokal and Rolhf 1969) to compare reproductive parameters between pairs with and without subadults and between territories occupied and abandoned. For the last case only adult pairs were considered, to avoid potential differences between adults and subadults (Forslund and Pärt 1995; Sánchez-Zapata et al. 2000). Mean values of habitat variables for occupied and abandoned territories and nearest neighbour distances were compared with non-parametric tests (Kruskal–Wallis) as well. Spearman rank correlations were used to relate demographic parameters (mortality and productivity) and habitat variables. We chose a 5% level of significance for all tests.

## Results

*Territorial occupancy and demographic parameters*

During 1983–1997, the Bonelli's eagle population of Murcia changed from 35 to 17 breeding pairs (Figure 2). Rate of young fledged was $1.35 \pm 0.70$ ($n = 171$) and productivity $1.13 \pm 0.81$ ($n = 218$). Reproductive rates of adult pairs were lower in abandoned territories but differences were not significant (rate of young fledged: $1.44 \pm 0.65$ ($n = 114$) vs. $1.24 \pm 0.78$ ($n = 34$), $H = 1.57$, $P = 0.21$; productivity: $1.30 \pm 0.75$ ($n = 126$) vs. $1.08 \pm 0.84$ ($n = 39$), $H = 2.08$, $P = 0.15$, for occupied and abandoned territories, respectively).

Mortality was significantly higher in abandoned territories than in occupied territories (0.24 ($n = 46$) vs. 0.07 ($n = 196$), respectively; $t = 2.97$, $P = 0.003$). When both members of a pair died, territories became deserted more frequently than when only one bird disappeared (0.71 ($n = 7$) and 0.00 ($n = 15$), respectively; $t = 4.38$, $P = 0.00001$). Recruitment was more frequent with subadult birds than with adults (0.76 ($n = 17$) vs. 0.24 ($n = 17$), respectively; $t = 3.25$, $P < 0.01$). This has

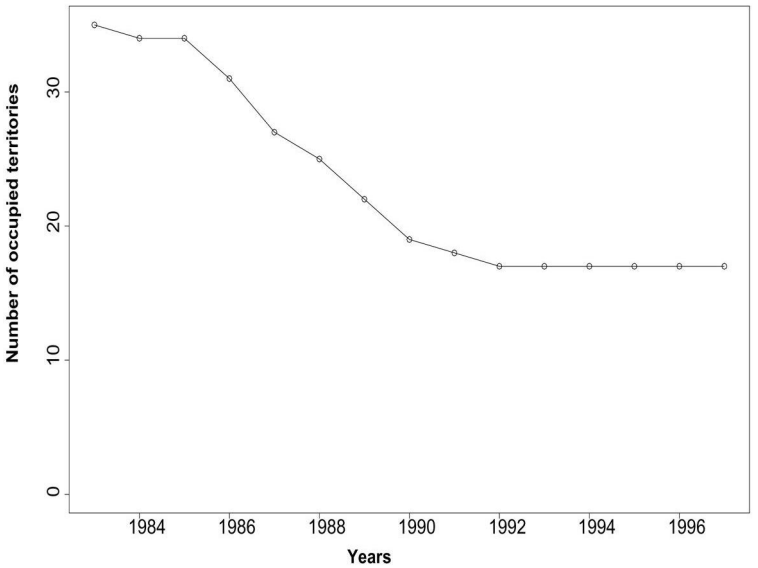


*Figure 2.* Bonelli's eagle population trend from 1983 to 1997 in SE Spain.

important influences on reproductive parameters, because territories held by adult pairs had significantly higher flight rate and productivity than those that included at least one subadult bird (Rate of young fledged: 1.37 ± 0.71 ($n = 150$) vs. 0.71 ± 0.76 ($n = 150$), $H = 4.95$, $P < 0.05$; Productivity: 1.22 ± 0.79 ($n = 168$) vs 0.33 ± 0.62 ($n = 15$), $H = 15.54$, $P < 0.001$).

*Nest-site habitat*

There were some significant differences in land-uses between occupied and abandoned territories. Those still occupied by eagles had more shrub, less forest and less extensive agriculture lands than abandoned territories (Table 2). Considering pigeon availability, territories occupied by Bonelli's eagles had more domestic pigeons than those abandoned, although differences were not significant (Table 2). Occupied and abandoned territories do not have differences in the abundance of racing pigeons. Correlations between habitat variables and demographic parameters were not significant. However, relationships between surface of irrigated lands and productivity ($r_s = -0.28$, $P > 0.05$, $n = 21$) and mortality ($r_s = 0.17$, $P > 0.05$, $n = 21$) should be mentioned.

*Competition*

In 1997, Golden eagle was more densely distributed than Bonelli's eagle (0.45 pairs/100 km$^2$ and 0.15 pairs/100 km$^2$, respectively). Nearest neighbour distances for Bonelli's eagle were larger than those for Golden eagle (15.57 ± 12.06 ($n = 17$)

*Table 2.* Mean (±SD) of the variables characterizing occupied and abandoned territories.

| Variable | Occupied territories ($n = 17$) | Abandoned territories ($n = 14$) | $H$, $P$ |
|---|---|---|---|
| IRRIG | 138.88 (±223) | 257.98 (±349) | 0.93, 0.33 |
| EXTA | 647.78 (±582.16) | 1244.5 (±596.18) | 6.66, 0.03 |
| SHRUB | 1241.1 (±604.16) | 562 (±311.77) | 8.86, 0.03 |
| FOREST | 278.4 (±391.96) | 514.97 (±453.21) | 4.61, 0.03 |
| URBAN | 32.03 (±71.29) | 24.65 (±51.68) | 0.01, 0.91 |
| SR | 0.35 (±0.86) | 0.35 (±0.84) | 0.04, 0.84 |
| NIRRIG | 0.88 (±2.47) | 0.42 (±0.93) | 0.02, 0.87 |
| QUARRY | 0.17 (±0.39) | 0.14 (±0.36) | 0.06, 0.80 |
| INFRA | 0.47 (±0.94) | 0.07 (±0.26) | 1.69, 0.19 |
| SPARCE | 0.35 (±0.60) | 0.14 (±0.36) | 1.07, 0.30 |
| MTPL | 4.29 (±3.8) | 3.38 (±4.76) | 1.00, 0.31 |
| HTPL | 2.37 (±3.1) | 2.4 (±3.89) | 0.20, 0.65 |
| TPL | 6.66 (±4.53) | 5.78 (±4 6.12) | 0.73, 0.39 |
| VILLA | 4.13 (±3.66) | 2.94 (±1.63) | 0.57, 0.45 |
| RPL | 0.59 (±1.5) | 0.64 (±0.84) | 1.60, 0.20 |
| DPL | 1.35 (±1.54) | 0.07 (±0.27) | 7.71, 0.06 |

and 8.90 ± 4.75 ($n = 51$), respectively; $H = 9.45$, $P = 0.002$). When occupied and abandoned territories of the former were considered together, this difference disappeared ($H = 0.63$, $P = 0.43$).

Seven territories of Bonelli's eagle were occupied by the Golden eagle, but any territory occupied by Bonelli's eagle was colonized by Golden eagle. In a few cases, when only one bird remained in a territory, a Golden eagle pair established themselves in the vicinity without expelling Bonelli's eagle. The *vice versa* was never registered during the study.

## Discussion

Long-term productivity of Bonelli's eagles in Murcia was high compared with other European populations (range = 0–1.09) (Garza and Arroyo 1996; Real and Mañosa 1997), although a proportion of territories was occupied by subadult birds which are 'low quality' breeders (Forslund and Pärt 1995). Subadult birds hold breeding territories either when prey numbers are very high and the population is increasing or when adult numbers become depleted, through persecution for example (Newton 1979). Considering that, since 1983, Bonelli's eagle population in Murcia declined from 35 to 17 pairs, the latter hypothesis is more likely.

The various territories occupied by a species could not be of the same quality and it could be expected to find breeding differences between them (Ferrer and Donázar 1996), with a higher probability of territory change after poor or unsuccessful breeding attempts or mate death (Forero et al. 1999). In Murcia, flight rate and productivity were not different when occupied and abandoned territories were compared, while mortality was significantly higher in abandoned breeding areas. Like this, territory abandonment may be associated with high mortality rates rather

than low reproductive success. Furthermore, the simpatric Golden eagle population has a high turnover rate and one of the highest numbers of breeding subadults compared with other populations, perhaps because it showed a high territorial mortality rate too (Sánchez-Zapata et al. 2000).

High mortality rates could be related with Bonelli's eagle diet. The species preys mainly on rabbits *Oryctolagus cuniculus*, very common in shrublands in Mediterranean areas (Moreno and Villafuerte 1995; Palomares and Delibes 1997). In those open lands, vegetation structure favours prey detection and hunting success for eagles. Small surfaces of shrubland may signify small areas to hunt rabbits, so alternative prey may increase its importance. Abandoned territories had less shrubland surface, so there pigeons would become an important prey. Where densities of domestic pigeons were high, they may produce a buffer effect on the predation on racing pigeons. In those territories where domestic pigeons were less abundant, conflicts between pigeon fanciers and Bonelli's eagle appeared. Direct persecution by pigeon fanciers resulted in the loss of numerous breeding pairs, not only Bonelli's eagles but also Peregrine falcons (personal data). Since 1990, after 'problematic pairs' disappeared, the population 'stabilized' (Figure 2) and territorial mortality reduced (Carrete et al. 2002). In this way, mortality in breeding areas seemed to be the most important factor in determining its occupancy.

As in other studies, our results suggest that Bonelli's eagle can tolerate a certain degree of human presence (Arroyo and Garza 1995; Gil-Sánchez et al. 1996). However, previous studies that model the species abundance found that it changed its response to slope, i.e. those territories with steepest cliffs remained occupied (Sánchez-Zapata 1997). This last factor could be related with nest accessibility and with direct persecution. Areas with high surfaces of irrigated crops were negatively related with productivity and survival, too, perhaps because of the higher number of people working in those fields and its negative impact on prey populations or due to the increase in power lines that irrigated cultivation needs. This last factor has been cited as an important cause of mortality for different raptors (González et al. 1990; Ferrer 1992; Ferrer and Hiraldo 1992; Janss 2000). Like this, the quality of territories could be determined by variables related with bird mortality.

In Murcia, the most important competitor for Bonelli's eagle seems to be the Golden eagle. Both species have similar habitat and food requirements, the second one higher and more abundant than the former, but no direct displacement of Bonelli's eagles was registered. Only when a member of a pair died and territorial defense relaxed, did the Golden eagle occupy the surroundings. When both members of a pair died, the existence of a nest site on an abandoned cliff may attract eagles to recolonize it and, as the Golden eagle is more abundant than Bonelli's eagle, it is more likely that a dispersing Golden eagle would occupy abandoned territories where no significant alteration exists. Competition with other species such as vultures (*Gyps fulvus*) did not seem to be important in this region.

As seems to be happening in other regions, mortality is the most important cause of territory abandonment among Bonelli's eagle in Murcia (Garza and Arroyo 1996). The situation appears to be complex, as all three factors (direct persecution, prey availability and competition with Golden eagles) have some implication. Our

results suggest that habitat has a role because a lower abundance of rabbits brings the Bonelli's eagles into conflict with pigeon fanciers, leading to the persecution of breeding pairs. This absence is then exploited by Golden eagles moving into the territory, and whilst Golden eagle may not be responsible for displacement, they may be preventing recolonization. But, why don't Bonelli's eagles re-occupy abandoned areas that remain vacant? Some hypothesis could be proposed. At first, surplus numbers in eastern Spain could be low due to a high mortality rate of non-breeding birds (Real and Mañosa 1997; Real et al. 2001). Dispersal areas rich in rabbits and partridges overlap with hunting areas, where people shoot and trap eagles. Moreover, electrocution is an important non-natural mortality factor in those places, so dangerous lines should be identified and corrected. Second, four territories recolonized by Golden eagles in 1997 have been abandoned in the following years, so recolonization could be discouraged by continued active persecution. Control and actions should be performed to avoid conflicts between eagles and people.

Charismatic and representative of Mediterranean ecosystems, this eagle could be considered as a *flagship* species (Esteve and Calvo 2000). Management actions and establishment of protected areas for Bonelli's eagle may promote biodiversity conservation in these areas where tourism and intensive agriculture threaten to destroy all natural patches and traditional uses. At present, life programmes, nature conservation actions financed by the European Union, are demanded for the species in many parts of its distribution range.

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