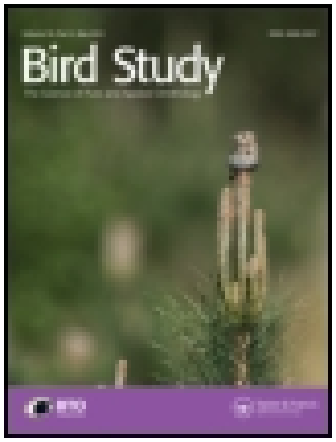

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Causes of death in different areas for Bonelli's Eagle *Hieraaetus fasciatus* in Spain

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The Spanish Bonelli's Eagle populations have decreased markedly because of high mortality. We recorded 424 cases of dead eagles between 1990 and 1998 in Spain which after cross-comparison corresponded to 377 individuals. Electrocution (55% of deaths), followed by direct persecution (26%) were the main causes of death. No differences in the cause of death were found between sexes. Non-adult eagles mostly died of electrocution whereas adults were mainly the victims of persecution. A log-linear model showed that these differences were associated with a difference in the spatial distribution of age classes, rather than to age or experience per se. *Persecution was the main cause of death in breeding areas and electrocution in non-breeding areas. There were differences between regions: electrocution was the main cause in Catalonia and Central Spain (50% and 86% respectively) whereas direct persecution was the main cause in Levant and Northern Spain (52% and 43% respectively). We recommend that steps are taken in order to reduce eagle mortality, taking into account the differences between regions and areas.*

The Bonelli's Eagle *Hieraaetus fasciatus* is an endangered bird of prey, populations of which are declining in number and range (Rocamora 1994). The Spanish population accounts for 80% of the European breeding population (Real *et al.* 1997) but this has decreased by 20% in the last two decades as a result of high adult and pre-adult mortality (Real & Mañosa 1997). However, the only data available on the causes of death for this species date from the 1980s (Arroyo *et al.* 1995). The identification of the main causes of mortality of Bonelli's Eagle is essential in order to undertake the appropriate conservation measures.

In birds of prey, unbiased quantitative information on the causes of mortality can be obtained by radiotracking studies (Kenward 1993), but these are extremely costly and time consuming, and often beyond the spatial scope and urgency of conservation needs. Radiotracking studies on Bonelli's Eagle are scarce and involve only the tagging of a few fledglings (Arroyo & Garza 1996, Real *et al.* 1998). Compilation studies on dead birds can be a useful alternative to radiotracking studies for identifying the main causes of mortality of a species, as long as any potential biases are taken into account (Elliot & Avery 1991, Franson & Little 1996, Franson *et al.* 1996, Newton *et al.* 1999).

Here we describe the main causes of death of Bonelli's Eagles in Spain and describe an analysis of the variation in mortality causes according to age, sex and geographic area on the basis of a compilation of Bonelli's Eagles recovered dead during the period 1990–1998.

MATERIAL AND METHODS

We carried out an investigation to collect data on Bonelli's Eagles found dead or fatally

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injured in Spain between 1990 and 1998. We sent questionnaires to the Banding Office of the Environment Ministry, to 54 bird of prey rehabilitation centres, to 28 biologists or research groups working on Bonelli's Eagle, and to the Wildlife Management Services of several Autonomous Communities in Spain. We requested date of death, locality, cause of death and eagle age and sex. Unpublished reports on the species were also compiled (see Acknowledgements).

The data were analysed considering the following factors: *Cause of death* (power line casualties, direct persecution, and other causes); *Area* where the eagle had died (*breeding area,* if within a 10 km radius of any breeding site of the distribution map by Arroyo *et al*. (1995), or *non-breeding area* if not); *Regions* (Levant, including Murcia and Comunitat Valenciana; Catalonia; Central Spain, including Castilla-La Mancha and Madrid; Andalucía; Northern Spain, including Castilla-León and Navarra; and Aragón); *Age* (adult, non-adult or unknown), and *Sex* (male, female or unknown), both determined according to plumage and size criteria (Parellada 1984 and pers. obs). Where only bird skeletons were examined, the humerus length was measured and a bimodal curve was obtained. Birds with a humerus length greater than 142 mm were considered to be females and those with humerus shorter than 140 mm were considered to be males (n = 53) (Cramp & Simmons 1980). Deviations from the 1:1 sex ratio were tested by means of goodness-of-fit test. Interactions between causes of mortality, sex, age, area and region were analysed by a log-linear model and contingency tables including only the above-mentioned cases. Aragon and Northern Spain were excluded from this analysis because of the few data available. The most suitable log-linear model was selected using the backward stepwise method (Bisquerra 1989). Since sex did not interact with any other variable, we repeated the model selection process excluding this variable, so that the unknown sex cases could be included in the analysis to increase the sample size. Likelihood ratio χ^2 was used to determine whether to retain or discard factors. The interactions selected by the model were further analysed by contingency tables and χ^2 tests. Observed cell frequencies were considered to be significantly different from the expected frequencies when the absolute value of the standardized residual was greater than $Z_{\alpha/2}$ (α = 0.05). Cases including missing values for some of the variables were discarded from the analysis. Statistics were performed on the SPSS/PC package (SPSS-INC 1996).

RESULTS

We obtained data on 15 cases from the Banding Office, 77 from raptor rehabilitation centres, 24 from Wildlife Management Services and 308 from researchers on this species and from published or unpublished reports (Arroyo & Garza 1996, Fernández-León 1994, Guzmán & Castaño 1998) (Table 1). Information obtained from the Banding Office and Wildlife Management Services (3.5% and 5.7% of the data respectively) emphasize the impact of power lines over human persecution. However, research studies and rehabilitation centres that provided most of the information to our

Table 1. Causes of death of Bonelli's Eagle according to the source of information.

	Banding office		Wildlife services		Rehab. centres		Research[a]		Research[b]	
Cause of death	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Power line	10	66.7	11	45.8	18	23.4	204	66.2	41	28.3
Persecution	3	20	8	33.3	34	44.2	73	23.7	73	50.3
Others	0	0	4	16.7	19	24.7	8	2.6	8	5.5
Unknown	2	13.3	1	4.2	6	7.8	23	7.5	23	15.9
Total	15		24		77		308		145	

The data were from researchers, reports and files of the authors. Some cases are duplicated, because they were obtained simultaneously from several sources.

[a]Including underline searches; [b]Excluding underline searches.

Table 2. Causes of death of Bonelli's Eagle in various regions of Spain between 1990 and 1998.

	Catalonia	Levant	Andalucía	Aragon	Northern Spain	Central Spain	Total
Power line casualty							
Electrocution	17	26	10	6	0	150	209
Collision	2	4	3	0	1	2	12
Total	19	30	13	6	1	152	221
Direct persecution							
Shooting	9	40	11	7	3	11	81
Trapping	0	5	0	0	0	1	6
Poisoning	0	10	0	0	0	1	11
Total	9	55	11	7	3	13	98
Other							
Starvation	1	0	4	0	1	1	7
Disease	0	0	1	0	0	0	1
Predation	0	0	1	0	0	0	1
Other collisions	0	5	6	0	0	4	15
Drowning	1	0	3	1	0	0	5
Total	2	5	15	1	1	5	29
Unknown	4	15	2	1	2	5	29
Total	34	105	41	15	7	175	377

enquiry (72.6% and 18.2% respectively) revealed a higher impact of human persecution over power lines, especially if intensive underline searches, which are obviously biased, are removed (Table 1).

All cases from all sources were cross-referenced to avoid duplication; this resulted in 377 cases of eagles which were found dead or fatally injured during the nine-year period being considered (Table 2). The main cause of death was interaction with power lines (58%): either electrocution (55%) or collision (3%). Direct persecution was the second most important cause of death (26%) and included shooting (21%), poisoning (3%) and trapping (2%). Other deaths (8%) were attributed to starvation (2%), disease (0.3%), predation (0.3%), other collisions (including two collisions with game fences) (4%) and drowning (1%). The cause of death for 29 (8%) eagles was unknown. In Catalonia and Central Spain, the main causes of death were power line casualties (56% and 87% respectively), followed by direct persecution (27% and 7%), whereas direct persecution was the main cause of death in Levant and Northern Spain (52% and 43% respectively), followed by power line casualties (29% and 14%). In Aragon, power line casualties and direct persecution showed similar frequencies (40% and 47%). In Andalucía, power lines (32%) and direct persecution (27%) were less prevalent, and most deaths were the consequence of other causes (37%).

Of 182 birds of known sex, 96 (53%) were males and 86 (47%) females, which did not deviate from the expected 1:1 sex ratio (χ^2_1 = 0.5, ns). The causes of death were similar in both sexes (χ^2_2 = 1.6, ns), but different between age classes (χ^2_2 = 33.7, $P < 0.0001$) and breeding/dispersal areas (χ^2_2 = 79.9, $P < 0.0001$) (Table 3).

Further analysis of the interaction between these variables was obtained by means of a log-linear model conducted on the 216 cases with complete information (excluding sex, see Methods). This revealed interactions between cause–region, area–cause, area–region, area–age and region–age (Table 4). Independent contingency tables including only the cases used to build the log-linear model showed that the cause–region interaction was due to high direct persecution and low frequencies of power line casualties in Levant, high

Table 3. Causes of death of Bonelli's Eagle according to sex, age and area.

	Sex				Age				Area			
	Male		Female		Non-adult		Adult		Non-breeding		Breeding	
Cause	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Power line	48	52.2	43	56.6	99*	66.0	26*	28.6	149*	86.1	64*	41.6
Persecution	33	37.9	24	31.6	38*	25.3	55*	60.4	22*	12.7	65*	42.2
Other	6	6.9	9	11.8	13	8.7	10	11.0	2*	1.2	25*	16.2
Total	87		76		150		91		173		154	

*Standardized residuals > $Z_{\alpha/2}$.

Table 4. Marginal association χ^2 values of the log-linear four-factorial independence test between the variables area (dispersal or breeding), cause of death (power line casualty, direct persecution or others), region (Catalonia, Levant, Andalucía or central Spain) and age (non-adult or adult) (*n* = 216).

Factor	df	Partial χ^2	*P*
Area × cause × region	6	5.53	0.4770
Area × cause × age	2	1.18	0.5522
Area × region × age	3	0.37	0.9449
Cause × region × age	6	9.88	0.1296
Area × cause	2	10.07	0.0065
Area × region	3	12.04	0.0072
Cause × region	6	67.05	0.000
Area × age	1	55.55	0.000
Cause × age	2	3.88	0.1437
Region × age	3	7.50	0.0575

Log-linear model: constant + area–age + area–cause + area–region + cause–region + region–age.
Goodness-of-fit test statistics: likelihood ratio $\chi^2 = 25.68$ (df = 25, $P = 0.425$); Pearson's $\chi^2 = 26.12$ (df = 25, $P = 0.401$).

frequencies of power line casualties and low persecution in Central Spain, and high frequency of other causes in Andalucía ($\chi^2_6 = 103.8$, $P < 0.0001$; Table 5). The area–cause interaction can be explained by the high frequencies of persecution and other causes in breeding areas and by the high mortality associated with power lines in non-breeding areas ($\chi^2_2 = 34.2$, $P < 0.0001$, Table 5).

Adult eagles were more affected by direct persecution than non-adults, which died more often by electrocution (Table 3). However, the log-linear analysis indicated that there was no interaction between cause and age and so the differences in mortality found between adults and non-adults were not connected with age but with the region and area of death, as revealed by significant interactions between area–age, region–age and region–area (Table 4).

DISCUSSION

In quantitative terms, we recorded information of age and cause of death of 91 adult and 150 non-adult eagles (Table 3). This entails 7.5% and 3.4% of the 1210 adult and 4463 non-adult birds which are thought to have died in Spain (excluding Extremadura, because no mortality data were available) between 1990 and 1998, following the estimated number of pairs in the study area (Arroyo *et al.* 1995), the average survival rates for each age class (Real & Mañosa 1997) and the average annual production of young (Arroyo *et al*. 1995).

In qualitative terms, it is obvious that compilation studies on the causes of death of birds may be biased by the source of information (Newton 1986, Elliot & Avery 1991). In Central Spain, power line monitoring was the main data source (78%) and there was potential bias

Table 5. Contingency table connecting cause of death with region and area.

	Region								Area			
	Catalonia		Levant		Andalucía		Central Spain		Non-breeding		Breeding	
Cause	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Power line	19	63.3	10*	16.1	9	33.3	79*	81.4	69*	76.7	48*	38.1
Direct persecution	9	30	49*	79	8	29.6	13*	13.4	20*	22.2	59*	46.8
Other	2	6.7	3	4.9	10*	37.1	5	5.2	1*	1.1	19*	15.1
Total	30		62		27		97		90		126	

Only the 216 cases with complete information were considered.
*Standardized residuals > $Z_{\alpha/2}$

towards power line casualties, but these results reflect the great impact of power lines on non-adult birds in these areas. In Andalucía, although much of the data comes from rehabilitation centres (59%), and this could bias the information, the low observed frequencies of causes of death related to man (power lines or persecution) agree with the stable trend of the population in this area (Leiva 1987, Gil *et al.* 1994), as reported in other raptor species (Newton *et al*.1999).

Female biased mortality by electrocution has been found in several birds of prey and has been related to the larger female wingspan (Ferrer & Hiraldo 1992, Dawson & Mannan 1994). Although the Bonelli's Eagle has a clear reversed sized dimorphism (Cramp & Simmons 1980), we found no sex bias in the causes of mortality, which agrees with Arroyo *et al.* (1995).

Moreover, several studies have reported age-related differences in causes of mortality (González 1991, Ferrer & Hiraldo 1992, Bevanger 1998). In contrast, in our study differences were associated with different distribution and habitat use between age classes rather than to age. Non-adult Bonelli's Eagles concentrated in dispersal areas in Southern and Central Spain (Real *et al.* 1997) and, as well as other species, they occupy habitats other than those of adults (Steenhof *et al*. 1983, Ferrer & Harthe 1997, Bustamante *et al.* 1997, Mañosa *et al.* 1998). In these areas, the flat or undulating agricultural landscapes, which lack natural perching sites, favour the use of electric pylons, making eagles especially vulnerable to electrocution (Arroyo *et al.* 1995, Watson 1997).

The frequency of power line casualties reported here, mainly as a result of electrocution, is greater than that reported by Arroyo *et al.* (1995). This may be associated with an increase in the length of power lines, as reported in France (Cheylan *et al*. 1996), an increase in power line monitoring, a real or relative decrease in direct persecution, or a combination of these factors. In Spain, the length of power lines has increased considerably during the last decade (Ferrer & Janss 1999), especially in rural areas, which may affect key habitats for birds (Bignal & McCracken 1996, Ferrer & Harthe 1997, Pain & Pienkowski 1997, Sánchez-Zapata & Calvo 1999). Incidence of electrocution is higher in Catalonia, Central Spain and Levant, where adult and pre-adult mortality seem to be greater than in other regions (Real & Mañosa 1997 and pers. obs.). These areas are an important sink for Spanish and French populations (Arroyo & Garza 1996, Cheylan & Ravayrol 1996, Real & Mañosa 1997). In Andalucía, where measures to prevent electrocution were introduced during the 1980s (Ferrer & Hiraldo 1992, Negro & Ferrer 1995), the incidence of power line casualties was low, and was also low in Northern Spain, where Bonelli's Eagle pairs breed in remote and unpopulated areas (Fernández *et al.* 1998) with few power lines.

Shooting, trapping and poisoning are major problems for raptors even in European countries (Watson *et al.* 1989, González 1991, Tucker & Heath 1994, Green 1996, Watson 1997). Direct persecution was the second cause of mortality for Bonelli's Eagle in Spain, especially in Levant. The apparent reduction of the impact

of persecution compared with the previous decade is probably due to an increase in power line casualties rather than to a reduction in persecution. Most cases of direct persecution of Bonelli's Eagles may be associated with game shooting activities (Fig. 1). In Levant, direct persecution is also related to pigeon competition activities (Sánchez-Zapata *et al.* 1995). Direct persecution may limit raptor number and distribution in game areas (Gibbons *et al.* 1994, Etheridge *et al.* 1997) or even over large areas (Newton 1979, 1998, González *et al.* 1989). The persecution of eagles persists in some areas (Levant, Central Spain and Catalonia) (Sánchez-Zapata *et al.* 1995, Ramia-Blasco & GER 1996, Arroyo *et al.* 1995), which is supported by the fact that poisoning of Bonelli's Eagles has been recorded for the first time.

In conclusion, Bonelli's Eagles die mainly by power line casualties (29% for dead adults and 66% for dead non-adults) and direct persecution (60% for dead adults and 25% for dead non-adults) in Spain. The annual mortality rate, which results from all these causes of death, can be estimated by considering the average annual mortality rates for Bonelli's Eagle in Spain, which are 0.1 for adult and 0.41 for pre-adult birds (Real & Mañosa 1997). In this context, direct persecution yielded an annual mortality rate of 0.06 among adults, and of 0.10 among non-adult eagles, whereas the mortality rates resulting from power lines were 0.03 and 0.27 respectively.

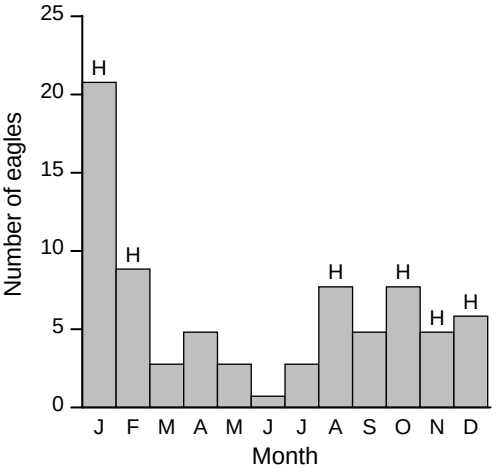

Figure 1. Monthly distribution of Bonelli's Eagle deaths due to persecution. H = months with hunting activity.

Management and conservation implications

Research on birds and power lines in Spain, as well as co-operation between scientists and power line companies, has proved useful on a regional scale (Ferrer & Janss 1999). Safe pylon designs and mitigation measures that avoid electrocution and collisions have been described (Bevanger 1994, Negro & Ferrer 1995, APLIC 1996, Janss & Ferrer 1999). Nevertheless, the regions that maintain the bulk of the Bonelli's Eagle population in Spain lack specific legislation regulating the safety of power lines.

In eastern Spain, where direct persecution is of concern, educational campaigns aimed at hunters and rural population are urgently needed. In areas where eagles conflict with game shooting interests, specific research on the relationship between game and predators should be carried out in order to reconcile the conservation of birds of prey with viable game shooting activities.

Although the conservation of Bonelli's Eagle requires local and regional conservation actions, a relationship between different populations has been demonstrated (Cheylan & Ravayrol 1996 and pers. obs.). Therefore, a global European conservation programme is needed. Besides, regular monitoring of mortality causes is required to detect whether regional or temporal changes affect management strategies.

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