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Sources of variation in mortality of the Bearded Vulture *Gypaetus barbatus* in Europe

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Summary

We analyse the causes of mortality for the Bearded Vulture in Europe. Shooting (31%), intentional poisoning (26%), collision (18%) and unintentional poisoning (12%) were the most important causes of mortality. No differences were found between sexes or age classes (non-adults and adults) for any of the causes of death. When the four main categories of mortality were grouped in periods of 3 years from 1986 (coinciding with the species' reintroduction to the Alps) to 2006, mortality showed significant temporal variation. The results suggest that while the number of collision/electrocution deaths has remained stable or increased slightly, the number of cases of shooting has declined during the last 6 years, while at the same time intentional and unintentional poisonings have increased. We found substantial differences between causes of mortality recorded for birds located by chance (75% related to shootings and collisions with powerlines) and radio-tagged birds (86% related to intentional and unintentional poisoning), suggesting biases in methodology for monitoring mortality. The results suggest that human persecution continues to be the main factor contributing to unnatural mortality for European Bearded Vultures. Future management actions should concentrate on the creation of protocols for the collection of carcasses and detailed analyses to determine and mitigate anthropogenic sources of mortality.

Introduction

Direct persecution has been one of the most important factors in the extinction or reduction of populations of many species of birds of prey (e.g. Etheridge *et al.* 1997, Holmes *et al.* 2003, Whitfield *et al.* 2003). In the case of the Bearded Vulture *Gypaetus barbatus*, human persecution at the end of the nineteenth and beginning of the twentieth centuries caused a reduction in numbers or extinction of the species across most of Europe (see review in Hiraldo *et al.* 1979, Terrasse 2001). After its extirpation from the Alps at the beginning of the twentieth century (Coton and Estève 1990, Mingozzi and Estève 1997) and in other regions such as Andalucía (Simón *et al.* 2005), the former Yugoslavia (Grubac 2002), Bulgaria (Marin *et al.* 2002) and Sardinia (Schenk *et al.* 2004) throughout the second half of the same century, the distribution of this species in Europe was reduced to the mountains of the Pyrenees (France and Spain), Greece, Crete and Corsica. In 1986, birds bred in captivity were reintroduced into the Alps (Switzerland, Austria, Italy and France) and a new population became established as a consequence of annual releases (Terrasse 2001). The Alpine population, with 17 territories, is now the second largest population in Europe (Heredia 2005).

The Bearded Vulture is endangered in Europe (Annex I, EU Wild Birds Directive 79/409/EEC, Appendix II of the Bern Convention, Bonn Convention and CITES), with 150 breeding territories in the European Union in 2006. Knowledge of the causes of mortality and their variation in both space and time can help interpret demographic trends. Moreover, it can facilitate the application of management measures to improve conservation of this endangered bird.

An increase in the causes of unnatural death can have important effects on population dynamics, especially in endangered species (see Cooper 2004, Green *et al.* 2004, Whitfield *et al.* 2004, González *et al.* 2007, Mee *et al.* 2007). Vultures are at the extreme of the trophic chain, but are different from other large raptors such as eagles in that they are not as often directly persecuted by humans. However, indirect effects can be important. For example, Asian vultures have suffered indirectly from human activity by dying after ingesting diclofenac (e.g. Green *et al.* 2004, 2006, Oaks *et al.* 2004). The ingestion of foreign anthropogenic material has been the primary cause of nest failure in the reintroduced California Condor *Gymnogyps californianus* population and threatens the re-establishment of a viable breeding population in southern California (Mee *et al.* 2007). In addition, avian scavengers are susceptible to lead poisoning when they ingest pellets or fragments in the tissues of animals (see Hunt *et al.* 2006), lead ingestion being the principal recorded cause of death in wild California Condors (Wiemeyer *et al.* 1988, Cade *et al.* 2004).

No published work exists on the spatial and temporal variations in the causes of mortality of Bearded Vultures in Europe. The critical state of its population and the difficulty of access to its habitat have probably limited the collection of information. The aims of this paper are to analyse: (1) causes of mortality of the Bearded Vulture in Europe, (2) how causes vary in space and over time, and (3) variation associated with the birds' age and sex.

Materials and methods

In total, 106 Bearded Vultures were found dead or injured between 1955 and 2006. Most cases were examined by a pathologist to determine the cause of death, at official wildlife rehabilitation centres and veterinary facilities in Spain and France, by private practitioners in France, and a national sanitation network (SAGIR), the Vetereninärmedizinische Universität of Wien in the Alps, and the Natural History Museum in Crete (NHMC). In addition, we used information in the literature (Terrasse 2001) and the intensive monitoring of 105 individuals radio-tagged in Spain with VHF or satellite transmitters between 1987 and 2006, and of the Alpine international programme (R. Zink, pers. comm.), the data of the Corsican programme (J. F. Seguin, pers. comm.) and of the Greek programme (S. Xirouchakis, pers. comm.). For each recorded case we used, whenever possible, the information contained in the necropsy reports. The latter consisted of data on the place, date of capture (if injured) or death, age class, on whether the bird was radio-tagged or not, and cause of injury or death.

Following standard necropsy procedures, samples from most birds were submitted for further analytical procedures. These included determination of post-mortem interval, routine bacteriology and histopathology, and toxicological investigations. Because examinations were done over an extended period, methods varied somewhat. However, nearly all cases from the Pyrenees from 1992 to 2004 were examined at the Laboratorio Forense de Vida Silvestre at Madrid, except one individual injured in France in 1993.

The diagnostic results and conclusions by the pathologists were used to categorize incidents. Diagnosis of *shooting* was reached when lead shot pellets or fragments were found to be life-threatening, or when wounds caused by another kind of ammunition suggested it to be the main cause of death or injury. *Electrocution* or *collision* with powerlines was diagnosed when specific wounds (i.e. electric burns or fractures) were found in the absence of other evidence of disease. *Poisoning* was recorded when intentional exposure to a toxic substance was confirmed. All cases of strychnine toxicosis and of organophosphate and carbamate pesticides in association with suspected bait in the gastrointestinal tract, regardless of concentration, were considered to be poisonings. Cases yielding a toxicological result suggestive of toxicosis, but where intentional exposure could not be ascertained, were considered as *unintentional poisoning*. These include cases of secondary poisoning, unintentional primary poisoning, as well as incidents in which the toxic substance was responsible for the mortality, even in cases when the proximate cause of death was from other processes (collision, electrocution, shooting, etc.). Lastly, *contamination* was considered in all those cases where a toxic substance, usually one that was accumulative and resulted in chronic exposure, was present and contributed to mortality. In circumstances where the presence of the toxin could not be ascertained, the cases were identified as *exposure*. Given that only two cases of contamination were identified, these were grouped with those considered as *unintentional poisoning*. Cause of death was categorized as *unknown* if it was either considered as unknown or not investigated.

Causes of mortality were further classified according to whether humans or any tools or infrastructures of human origin were linked to the birds' death, whether they were related to any type of productive human activity (e.g. game rearing and hunting, livestock rearing, transport and industry), or whether the cause was related to natural factors. We identified three classes of causes of human origin: *power infrastructures*, including electrocution and collision with powerlines or ski lifts; *hunting and agricultural practices*, including direct persecution such as shooting, the illegal use of poisoned bait and the presence of lead after ingesting contaminated carcasses; and *others*, in which the causes of death related to handling (transmitter attachment, ringing and wing-tagging accidents causing injury or death) and interaction with humans (e.g. collision with vehicles, individuals injured by humans).

Among the *natural causes* are those related to natural processes such as avalanches, diseases and interactions with other species such as breeding Golden Eagle (*Aquila chrysaetos*). For human-related mortality we also considered *indirect* causes to be those for which the death of the bird was not an objective (e.g. collisions, handling, unintentional poisonings), while *direct* causes were those where humans deliberately intended to kill Bearded Vultures or other animals (e.g. shooting, poisoning).

To study variation due to age, individuals were divided into two categories: (1) *adults*, defined as birds with definitive or almost complete adult plumage and generally corresponding to an age of >5 calendar years, and (2) *non-adults*, corresponding to an age of less than 4 calendar years (see Heredia and Margalida 2005).

In evaluating geographic variation, birds fell into one of four main regional subpopulations: Pyrenees (including Spain, France and Andorra), Alps (including France, Italy, Austria and Switzerland), Corsica and Crete.

Temporal variation was assessed using three periods: (1) Pre-1986, corresponding to when the species was distributed only in the Pyrenees (north and south sides), Corsica and Crete. This period was characterized by an increase in the population in the Pyrenees and stabilization in Corsica and Crete. (2) From 1986 to 1996, when reintroduction into the Alps commenced, the population increase in the Pyrenees was obvious, and numbers decreased and stabilized in Crete and Corsica, respectively. In addition, in the Spanish Pyrenees in 1987, Bearded Vultures were equipped with radio-transmitters (Heredia and Sunyer 1989). (3) From 1997 to 2006, a period during which Bearded Vultures were established as breeders in the Alps (Heuret and Rouillon 1998), the population was increasing in the Pyrenees, stabilized in Corsica and decreased in Crete. Although differences in breeding phenology may exist between subpopulations, causal factors of mortality were separated into seasons (winter, spring, summer and autumn) and between deaths occurring in the *breeding season* including the incubation (December, January, February) and chick-rearing periods (March, April, May, June, July), and the *non-breeding season* (August, September, October, November). In addition, we compared data obtained from birds with and without radio-transmitters.

We used 2×2 contingency tables and χ^2 tests to analyse the dependency between pairs of factors. Observed cell frequencies were considered to be significantly different from the expected frequencies when the absolute value of the standardized residual was greater than $Z_{\alpha/2}$ ($\alpha = 0.05$). Statistical analyses were carried out using SPSS/PC software (SPSS, 1996).

Results

Of the 106 cases of mortality, it was possible to determine the cause of death in 82% of the individuals (Table 1), with shooting (31%) and poisoning (26%) predominating. Of the remaining causes, only collision (18%) and unintentional poisoning (12%) occurred at rates greater than 10%. The causes of mortality in most of the cases (97%) were of human origin. The most common causes of mortality were powerlines (collision and electrocution) (22%), and hunting and agricultural practices (69%). Taking into account intentionality, of the 87 cases documented, 58% were direct persecution (shooting and poisoning) while the remaining 42% were of an indirect or accidental nature.

Variation associated with sex and age

Of the 59 birds that were sexed, 47% were males and 53% females, and the cause of death was known for 24 males and 25 females (Table 2). Considering all known causes in the three main categories (power infrastructures, hunting and agricultural practices, and other), we could not detect a statistically significant difference between sexes ($\chi^2_2 = 1.26$, $P = 0.54$; Table 2). Similarly, we could not detect a difference in the causes of death between the two age classes ($\chi^2_2 = 3.54$, $P = 0.17$; Table 2).

Seasonal, inter-annual and spatial variation

The number of birds collected did not vary between seasons ($\chi^2_3 = 0.33$, $P = 0.95$; Table 3). In addition, the causes of mortality varied little between breeding and non-breeding seasons, with no significant differences ($\chi^2_2 = 2.64$, $P = 0.27$; Table 4).

In none of the populations we studied did the frequencies of the causes of death vary over the different time periods (i.e. pre-1986, 1986–1997, 1997–2006) ($\chi^2_2 = 1.18$, $P = 0.56$; Table 4). In addition, the causes of mortality did not vary geographically ($\chi^2_3 = 5.95$, $P = 0.11$; Table 4). When the four main causes of mortality (collision/electrocution, poisoning, shooting and unintentional poisoning) were grouped into periods of 3 years between 1986 (reintroduction to the Alps) and 2006, there were significant differences in causal factors of mortality ($\chi^2_{18} = 48.4$, $P < 0.001$; Figure 1). While collision/electrocution has remained stable or increased slightly, shooting deaths have declined over the last 6 years and at the same time mortalities related to the use of illegal poisons and unintentional poisonings have increased. However, detection of

Table 1. Causes of Bearded Vulture mortality in the European Union.

	Pyrenees	Alps	Corsica	Crete	Total
Human origin					
Power infrastructures					
Collision	12	4	0	0	**16**
Electrocution	3	0	0	0	**3**
Hunting and agricultural practices					
Shooting	12	4	3	8	**27**
Intentional poisoning	22	0	0	1	**23**
Unintentional poisoning	9	1	0	0	**10**
Other	5	0	0	0	**5**
Non-human origin					
Snow avalanche	0	2	0	0	**2**
Interspecific interaction	0	1	0	0	**1**
Unknown	14	2	3	0	**19**
Total	**77**	**14**	**6**	**9**	**106**

Table 2. Causes of Bearded Vulture mortality in relation to sex and age (percentages in parentheses).

	Power infrastructures	Hunting and agricultural practices	Other	Total
Sex				
Male	7 (29)	13 (54)	4 (17)	**24**
Female	6 (24)	17 (68)	2 (8)	**25**
Age				
Non-adult	3 (12)	20 (77)	3 (12)	**26**
Adult	16 (29)	36 (65.5)	3 (5.5)	**55**

Table 3. Causes of Bearded Vulture mortality in relation to the time of the year, according to different age classes (percentages in parentheses).

	Winter	Spring	Summer	Autumn
Adult	10 (63)	10 (63)	8 (67)	9 (56)
Non-adult	6 (38)	6 (38)	4 (33)	7 (44)
Total	**16**	**16**	**12**	**16**

Table 4. Variation in the frequency of the causes of Bearded Vulture deaths during the breeding cycle, periods and different regional subpopulations (percentages in parentheses).

	Power infrastructures	Hunting and agricultural practices	Total
Breeding cycle			
Incubation	5 (31)	11 (69)	**16**
Chick-rearing	5 (29)	12 (71)	**17**
Non-breeding	1 (8)	12 (92)	**13**
Period			
Pre-1986	5 (33)	10 (67)	**15**
1986–1996	5 (21)	19 (79)	**24**
1997–2006	8 (20)	32 (80)	**40**
Subpopulation			
Pyrenees	15 (25)	43 (75)	**58**
Alps	4 (44)	5 (56)	**9**
Corsica	0	3 (100)	**3**
Crete	0	9 (100)	**9**

mortality may not be unbiased. Analysing the data of the four main causes of death separately starting from 1987 (start of radio-tracking) and differentiating between birds with (n = 21) and without a radio-transmitter (n = 40), there was a significant difference in cause of death (χ^2_3 = 24.8, P < 0.0001; Table 5). More radio-tagged individuals were found to be poisoned intentionally (57%) or unintentionally (29%), while the non-tagged individuals were typically found to be shot (53%) and or suffered collisions (23%), indicating a higher chance of carcass recovery of the radio-marked birds in the cases of poisoning and unintentional poisoning. To separate the effect associated with region, only data from the Pyrenees were analysed between radio-tagged birds (n = 20) and non-radio-tagged birds (n = 22), with the differences being significant (χ^2_3 = 15.6, P = 0.0014). In the radio-tagged individuals the most important causes of mortality were poisoning (60%) and unintentional poisoning (30%), while in the non-radio-tagged birds they were shooting (36%) and collisions with powerlines (32%) and to a lesser degree poisoning (23%).

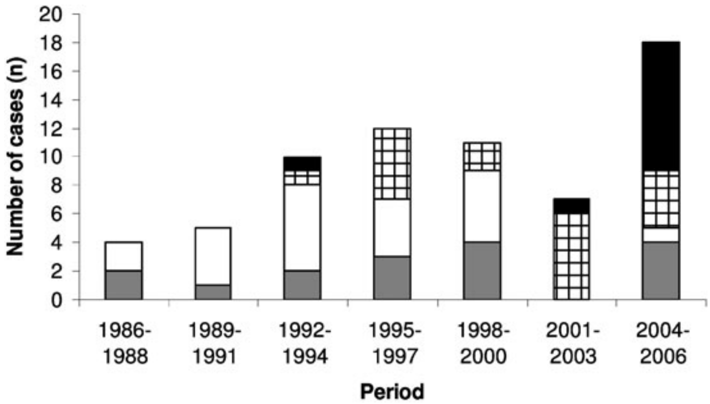

Figure 1. Temporal variation in the cases of Bearded Vulture mortality in the European Union. Black columns, unintentional poisoning; white columns, shooting; grey columns, collision/electrocution; hatched columns, poisoning.

Table 5. Differences in the causes of mortality between radio-monitored and non-radio-monitored Bearded Vultures.

	Radio-monitored	Non-radio-monitored
Power infrastructures	2	11
Poisoning	12	5
Unintentional poisoning	6	3
Shooting	1	21
	21	**40**

Discussion

Our results show that the causes of mortality in the European population of Bearded Vultures are still very much related to direct persecution, as has been documented in other birds of prey (Real *et al.* 2001, Whitfield *et al.* 2003, Martínez *et al.* 2006, González *et al.* 2007). Despite the effort and money invested (partially funded by European Union in its conservation: three Life Nature projects in Spain, one in the French Pyrenees, three in the Alps, one in Corsica, three in Greece-Crete, totalling more than 95 million euros) and the still precarious nature of some of subpopulations and their geographic isolation (6 territories in Crete, 10 in Corsica, 17 in the Alps after the species' reintroduction and 133 in the Pyrenees), the Bearded Vulture continues to suffer cases of unnatural mortality that could have negative repercussions on the overall population (Etheridge *et al.* 1997, Whitfield *et al.* 2004).

The causes of mortality of vultures found by chance that were attributable to shootings and collisions with powerlines (75%) were significantly different from the causes of mortality assigned to vultures located by radio-tracking (86% related to poisoning and unintentional poisoning). These differences were consistent when we analysed all documented cases in all subpopulations or when we used only the information from the Pyrenees. The large proportion of poisoning and unintentional poisoning cases among the radio-tagged individuals indicates that detection of poisoned birds is lower for untagged birds (Pain 1991, Kosteck *et al.* 2001). The reason for the detection bias may be the rugged habitat occupied by the species. In addition, records from birds found only by chance could lead to deaths related to electricity powerlines and shooting being overestimated, because birds killed in these ways may be more easily found or more people may frequent the areas where these mortality factors are at work (Kosteck *et al.* 2001). In the case of the Pyrenees, although five radio-marked individuals had previously been found by chance, it is evident that radio-tracking offers the most information since 76% of these individuals ($n = 21$) were located by radio-tracking. These results suggest the likely underestimation of the cases related to unintentional and intentional poisoning in the rest of the subpopulations (Xirouchakis 2004, H. Frey pers. comm.). The difficulty of accurately determining some cases of exposure to toxic substances and the lack of specific laboratory analyses, probably also explains this bias.

The results show temporal variation in the causes of mortality. From midway through the 1980s through the early 1990s the causes of mortality were mostly collisions with powerlines and shootings, whereas from halfway through the 1990s and mainly since 2001, intentional and unintentional poisoning has become the main source of mortality (in particular in the Pyrenees). Because vultures are at the top of the food chain, a higher risk of pesticide accumulation from agriculture may exist (Houston 2001). Although an increase in the use of illegal poisons has been documented, it is possible that an increased presence of contaminated products, and increase in the use of poisons against birds in mountain habitats and better and wider use of toxicological analyses has contributed to an increase in the number of cases in which poisoning is identified as the cause of mortality.

We found no differences in the causes of mortality according to sex, age or period of the breeding cycle. The low degree of sexual dimorphism in the Bearded Vulture may explain why males and females showed similar patterns (principally with mortality causes related to electricity powerlines and shooting). In addition, the similarity of parental roles of the sexes in the Bearded Vulture (Margalida and Bertran 2000) may explain the absence of sex differences in the causes of mortality during the breeding season. In other species where distinct parental roles are evident (e.g. Collopy 1984, Margalida *et al.* 2007) may result in differences in mortality between sexes, although in populations of some dimorphic raptors such sex differences have not been found either (Real *et al.* 2001, González *et al.* 2007).

Finally, the lack of a difference in the number of mortality cases between the breeding and non-breeding portions of the population could be a consequence of spatial segregation. In other territorial raptors, the availability of food means that the pre-adult fraction of the population is dispersed to zones far from the nesting sectors and they settle in areas rich in food, where the differences in habitat (and probably no protected areas) seems to be what may favour a higher level of mortality rather than the age of the individuals (Real *et al.* 2001). In the case of the Bearded Vulture, at least in the Pyrenees, Corsica and Crete, a spatial segregation between age classes does not exist, probably as a result of the availability of food and the presence of feeding stations near territories. This means that young birds remain settled in areas close to breeding places (see Carrete *et al.* 2006) and, therefore, mortality factors operate equally in both age classes.

Management implications

The results suggest that human persecution continues to be a significant cause of mortality for European Bearded Vultures. Despite the limitations of the data and differences between subpopulations, there has been an increase in cases of intentional and unintentional poisoning, and currently this is the most important problem for Bearded Vulture conservation in Europe. Similarly, toxicosis has been documented in other species of raptors in Europe (Watson 1997, Real *et al.* 2001, Holmes *et al.* 2003, Barnett *et al.* 2002, González *et al.* 2007) and especially in vultures in Asia, where some species have suffered dramatic declines (Prakash *et al.* 2003, Shultz *et al.* 2004). Because poisoning was one of the main factors in the steep decline in the populations of European Bearded Vultures (Hiraldo *et al.* 1979, Terrasse 2001), its reappearance and apparent increased frequency of use is worrying, especially when one takes into account the already fragile population status of the species.

Future management activities should concentrate on the creation of protocols for collecting carcasses, and detailed necropsies and laboratory analyses to determine causal factors. By doing this the human and financial resources aimed at mitigating and eliminating unnecessary mortality and promote Bearded Vulture conservation can be used most effectively.

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