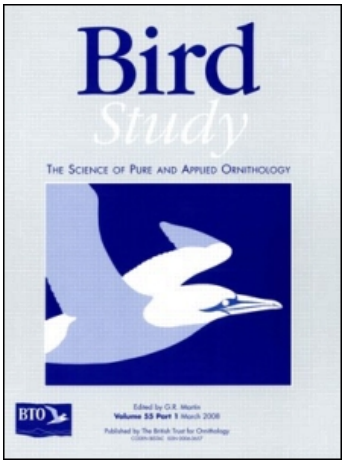

Bird Study
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t904369352

Distribution, population size and breeding parameters in the insular population of Bearded Vultures *Gypaetus barbatus* of Corsica over 28 years

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Online publication date: 30 July 2010

To cite this Article Seguin, Jean-Francois , Torre, Jose and Bretagnolle, Vincent(2010) 'Distribution, population size and breeding parameters in the insular population of Bearded Vultures *Gypaetus barbatus* of Corsica over 28 years', Bird Study, 57: 3, 361 — 368
To link to this Article: DOI: 10.1080/00063651003716754
URL: http://dx.doi.org/10.1080/00063651003716754

Bird Study (2010) **57,** 361–368

Distribution, population size and breeding parameters in the insular population of Bearded Vultures *Gypaetus barbatus* of Corsica over 28 years

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Capsule Between 1981 and 2008 population size was stable, but there were negative trends in breeding parameters.
Aims To determine the current status and long-term population trend of an isolated breeding population of Bearded Vultures *Gypaetus barbatus* (Corsica, Mediterranean).
Methods The total Bearded Vulture population was monitored between 1981 and 2008.
Results The current effective breeding population size of Bearded Vultures in Corsica is ten pairs/trios with a slight increase of one to two pairs since 1983. The population is currently estimated at 25 individuals. Breeding parameters (laying rate, breeding success and productivity) have decreased significantly over the full 28-year study period, although the decrease was not significant when the data set was restricted to 1988–2008. A mean of 60.3% (n = 204) of pairs have laid, but this proportion is highly variable between years. Productivity has been very low (0.16 young/pair/year, n = 233). Breeding parameters of the Corsican population of Bearded Vultures are very low compared with those of other western European populations in the Pyrenees.
Conclusions This isolated insular population is of small size (eight to ten pairs/trios) but shows a stability of distribution and numbers, but low (and decreasing) breeding rates, making this insular population one the most threatened in Europe.

Bearded Vultures *Gypaetus barbatus* are long-lived scavenging raptors which specialize in the consumption of bones and carcasses of medium-sized wild and domestic ungulates (Cramp & Simmons 1980). Its numbers and breeding range in Western Europe have dramatically declined over the last century (leading to its current listing as vulnerable in Europe [BirdLife International 2004]). Main reasons for decline include shooting, toxic substances in the diet, habitat loss and decrease in pastoral activities (for regional accounts, see Mingozzi & Estève [1997], Heredia & Heredia [1991], Donazar [1993], Razin *et al.* [2004] and Xirouchakis *et al.* [2001]). Although a reintroduction programme is in progress in the Alps (Frey & Zink 2000), the Corsican population of Bearded Vulture is currently extremely isolated and one of only two remaining island populations for the species in the World. The other island population is on Crete. Here we provide accurate data on population monitoring (including distribution, population size, territory occupancy and breeding parameters) over a recent 28-year period for the population on Corsica.

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METHODS

Study area and species

Bearded Vultures (body weight 4.5–7.2 kg, wingspan 231–283 cm [Ferguson-Lees & Christie 2001]) have a very long breeding cycle (nest-building in November; laying in January–February; incubation period about two months; rearing period about four months) and a low fecundity (clutch size of one to two eggs, one fledgling/pair/year). They forage on open ground, usually above 1000 m asl in Corsica. Corsica is a Mediterranean

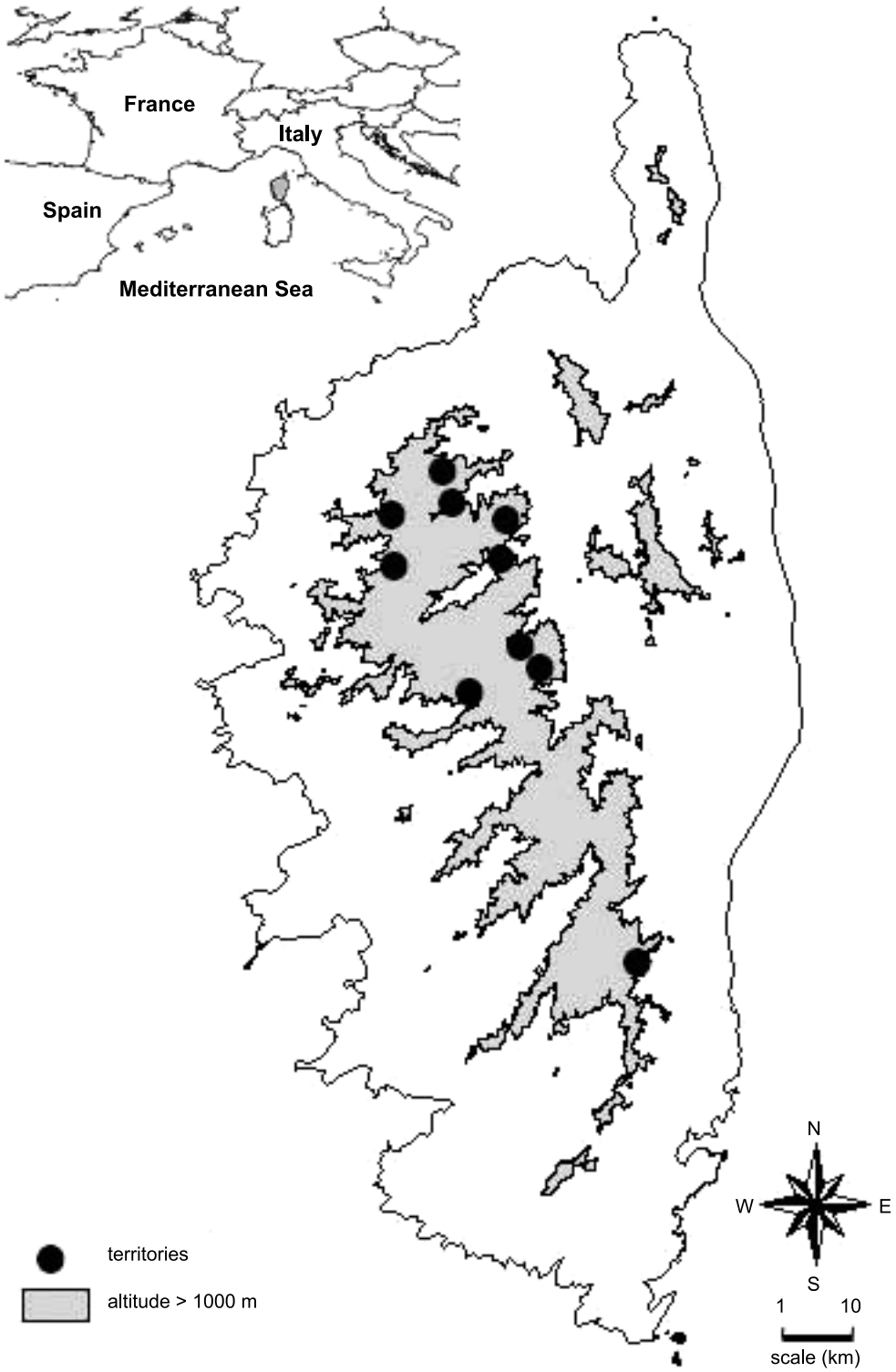

Figure 1. The location of Corsica and the approximate distribution of Bearded Vulture territories in the island.

island of 8750 km^2 located at 42° N and 9° E with mountain areas higher than 1000 m covering 18.7% of its total surface (Fig. 1). Diet in Corsica mainly consists of carcasses of large mammals, both domestic and wild ungulates (Sheep *Ovis aries*, Goat *Capra hircus*, Cattle *Bos taurus* and Mouflon *Ovis gmelini* [Thibault *et al.* 1993]), with preference for younger animals, especially for Cattle (Robert *et al.* 2002).

Distribution, numbers and territory occupancy

Between 1976 and 1985, all mountain areas with available cliffs and potential nest-sites were systematically searched in order to locate Bearded Vulture territorial pairs. Prospecting was achieved mainly in autumn–winter (and sometimes in spring). More recently (since 1999), additional simultaneous censuses were conducted, mainly in November–December, a period at which observers were more likely to contact individuals together due to the pre-breeding behaviours of pairs (nest-building, courtship, copulation), as well as territorial defence around the nest involving both intra- and inter-specific interactions. Simultaneous censuses were also conducted in March 2004, 2005 and 2007, covering all mountain areas occupied by Bearded Vultures in order to estimate the total population size, including floaters and immature birds. These censuses have been completed by observations carried out during territory surveys, breeding monitoring, and the checking of artificial feeding stations located in the same area (in addition, occasional observations were also included).

Territory occupancy has been monitored partially between 1976 and 1982, then fully (i.e. every territory) since 1983. For each surveyed territory, the presence of a pair, a trio or a single individual was established. Age determination, from juvenile to adult, was based on plumage characteristics and stage of moult (Adam & Llpopis Dell 2003).

Breeding parameters

Each pair was surveyed (i.e. an observer checked pair presence, activity, and breeding status) a minimum of four times by direct observation between December and August (see details on methods in Seguin *et al.* [2005]), in order to estimate annual breeding parameters. The proportion of breeders (hereafter, proportion breeding) was estimated as the ratio of the number of pairs that laid eggs and the number of checked pairs; breeding success was estimated as the number of young fledged out of the number of pairs that laid eggs; and productivity estimated as the total number of young fledged out of the total number of checked pairs (Heredia & Margalida 2001, Margalida *et al.* 2003).

Analysis of data

Trends in breeding parameters were analysed using linear regression or Spearman correlation between year and each breeding parameter. For the analysis of productivity at the territory level, we averaged data of each territory from 1983 to 2008.

RESULTS

Distribution, numbers, and territory occupancy

The Bearded Vulture population was distributed strictly over the main mountain axial ridge, but its distribution was not uniform (Fig. 1): nine pairs were located in the northern part, while the last one, in the south of the island, was approximately 43 km from the nearest occupied territory. However, other massifs and valleys, though currently unoccupied by breeding pairs, were sometimes used by individuals (pers. obs.).

Since 2003, territories were occupied by nine pairs and a polyandrous trio (except in 2008). In addition, in 2008, observations of floaters (showing immature plumage) suggested that four different pre-adult individuals were present. No confirmed adult floater was detected, though several were suspected in isolated massifs during simultaneous surveys in 2004, 2005 and 2007. In total, the Bearded Vulture population of Corsica is estimated at a minimum of 25 individuals (9 pairs + 1 trio + 4 pre-adults floaters), and may not exceed 27–28 individuals.

Every single territory has been occupied every year for the last 28 years (1981–2006; Fig. 2a), except in 2002 when one territory was occupied by a lone adult. Between 1983 and 1994, the eight territories were occupied by seven pairs and a polyandrous trio. Between 1995 and 1997, six pairs and two polyandrous trios were present. Since 2000, two additional pairs have been located, but we suspect that only one of them was new (the other was not located precisely, but was actually suspected since 1983). Mate replacement has been detected by mixed-age breeding pairs in recent years (six cases since 1994 [Fasce & Fasce 2002]), but was not detected before 1994.

Breeding parameters

Overall, 60.3% (n = 204) of checked pairs laid eggs, but this proportion varied over time (Fig. 2b). The

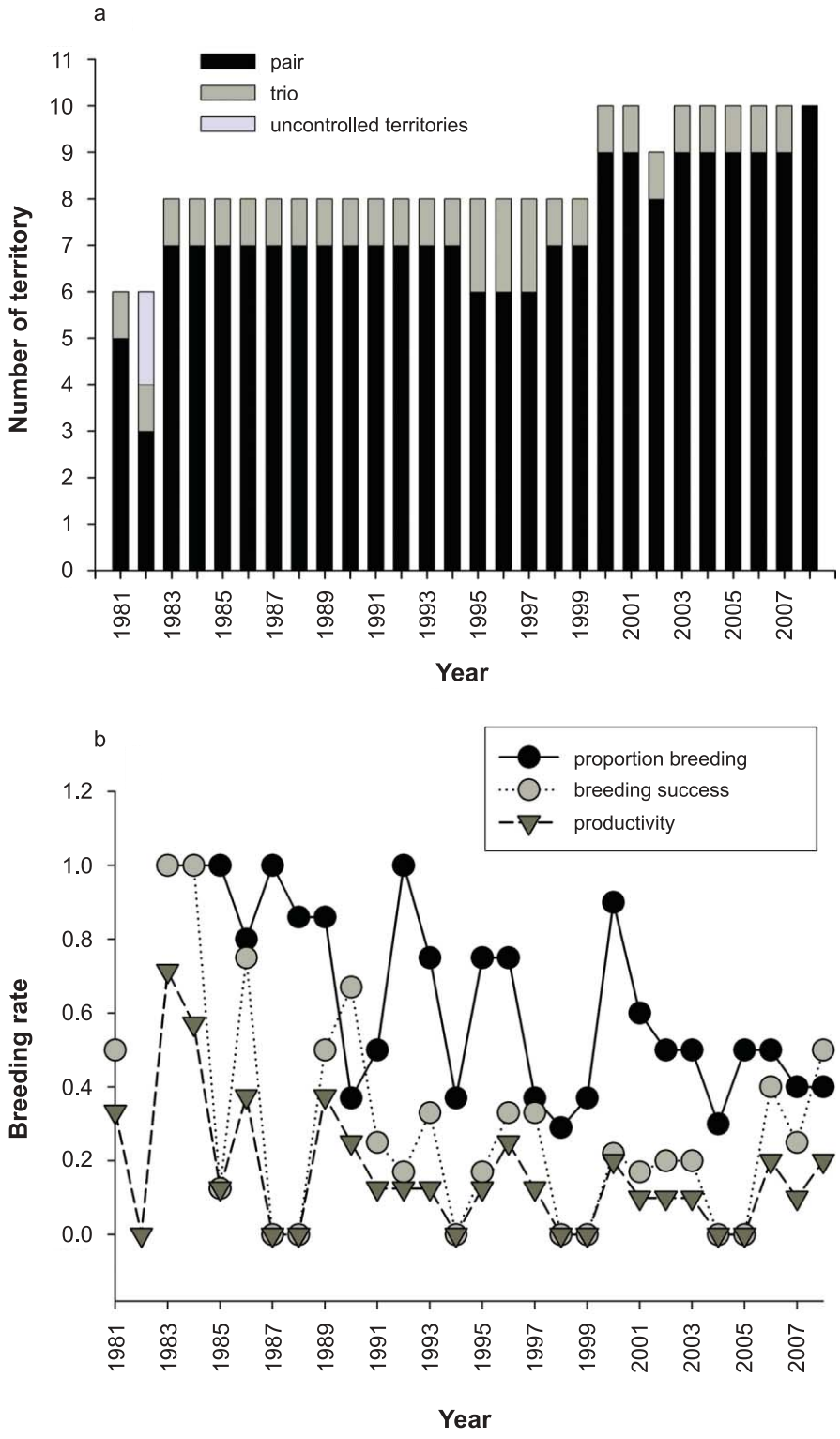

Figure 2. Trends of the Bearded Vulture population in Corsica, 1981–2008. (a) Territory occupancy; (b) breeding parameters. Breeding success, young fledged out of pairs that laid eggs; productivity, young fledged per checked pairs.

proportion of pairs breeding significantly decreased over the study period (F = 22.33, P < 0.0001, 1983–2008; Fig. 2b). However, the searching effort for pairs increased between 1981 and 1988: 68% of pair × year (n = 40) were checked before 1988, compared with 96% (n = 186) after 1988. We repeated this analysis a number of times, deleting early years successively (starting with 1983), and found that there was no longer a significant relationship for years after 1988 (F = 3.5, P = 0.08), showing that the decline in breeding pairs was probably caused by the inclusion after 1988 of a larger number of low quality territories where breeding was less likely.

Similarly, breeding success decreased significantly during the study period (F = 5.79, P = 0.02, 1983–2008; Fig. 2b), but again, no significant trend was found when restricting the analysis to 1986–2008 (F = 0.77, P = 0.39) or afterwards. The same results were found for productivity (negative trend for 1983–2008, F = 5.9, P = 0.02, and no significant trend after 1986, F = 1.2, P = 0.28; see Fig. 2b). Productivity for this population appears to be quite low (0.16 young/pair/year, n = 233 territorial pair × year), especially over the last years (0.1 young/pair/year, n = 90, 2001–08 period).

The proportion of birds breeding (Rate) varied between territories from 0.33 to 0.89, and productivity from 0 to 0.38 (Fig. 3a). These two parameters were correlated (r_s = 0.88, P = 0.01, n = 10), i.e. territories with higher productivity were also those with highest proportion breeding. As expected, breeding success and productivity were correlated with each other (r_s = 0.85, P = 0.004; Fig. 3a). Total productivity per territory between 1988 and 2008 was very uneven for the eight pairs that were monitored every year (Fig. 3b): one of the territories contributed 37% of the total productivity (i.e. it produced 7 of 19 fledglings after 1988), while three territories never produced any fledglings over this period. Among the latter, one territory never raised any fledgling despite a rather high laying rate (0.54). However, there were gradual changes over the study period: one territory accounted for nearly half of fledglings before 1998 (40% of 25 fledglings produced in total), but since then has not contributed anymore. Two other territories showed high productivity in the 1980s but not later (Fig. 3b), while another territory, which had produced no fledglings since 1983, then bred successfully in 2000–01 and again in 2007–08.

DISCUSSION

Past and present distribution and numbers of Bearded Vultures in Corsica

Archaeological investigations have shown that Bearded Vultures were present in Corsica 14 000 years ago, i.e. long before human arrival on the island (Robert & Vigne 2002). Whitehead (1885) considered Bearded Vultures rare in Corsica. Giglioli (1907) and Jourdain (1912a, b) noted a few pairs and/or individuals located in mountainous massifs. However, we have only poor historical knowledge of Bearded Vultures in Corsica, and do not know if this population has suffered a decline, in number and breeding range, as is known to have occurred in other continental and insular populations. In the second half of the century, the population was initially estimated at two to three pairs (Terrasse 1965), six pairs (Thiollay 1968), and finally seven to ten pairs (Thibault 1978). More careful surveys carried out in the 1980s have increased the number of pairs: 14–16 pairs estimated (but only 7 of them identified [Bouvet 1985]) and 8–9 pairs known (Thibault 1983, Fasce *et al.* 1989, Fasce & Fasce 1992, Thibault & Bonaccorsi 1999).

The population size has been stable (or slightly increasing) for the last 28 years. One or maybe two pairs have been found in addition to the eight already known since 1983. Among the two pairs identified very recently (in 2000), one occupies a territory whose existence has been suspected for a long time, and the other established one or a few years before 2000 in the high density area in the northern part of the island (Fasce *et al.* 1989, Thibault & Bonaccorsi 1999). It occupies a previous Golden Eagle *Aquila chrysaetos* nest, again indicating a recent colonization (Seguin *et al.* 2001). The fact that current density is higher in the northern part of the island (nine out of ten territories) results from higher availability of nest-sites and the geography of Corsica. Owing to intensive surveying effort since 1999–2000, we are confident that there are no other pairs in Corsica currently. The first known territories (dating back to the 1970s) have always been occupied since their discovery. No loss of territory has ever been observed. The proportion of trios has varied from 12.5% (1983–94 and 1998–99), to 25% (1995–97) and 10% (2000–07). In recent times (after 2000), it is notable that very few (or even perhaps none) adult floaters are present in the population, thus predisposing the Corsican population to be impacted by demographic

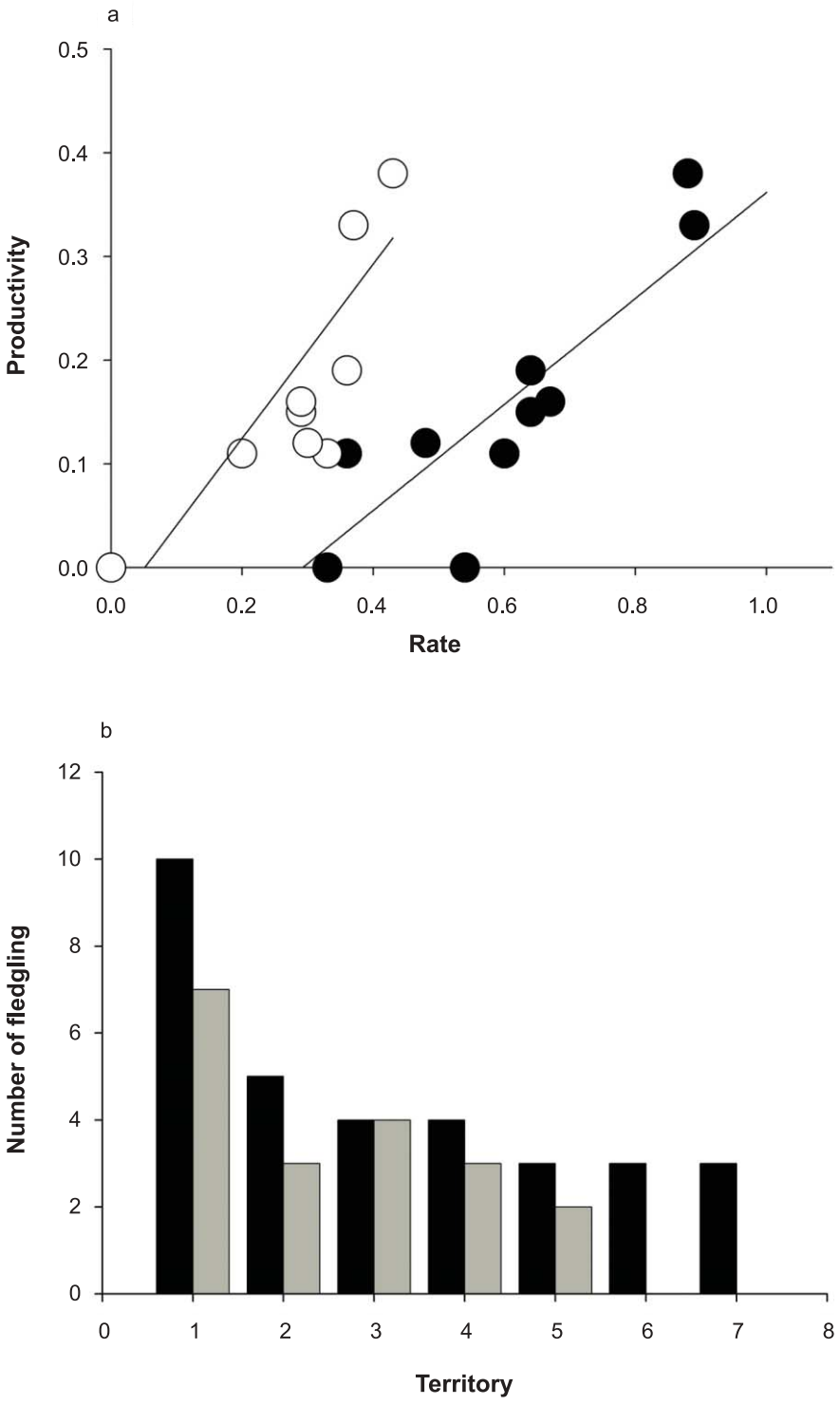

Figure 3. (a) Relationship between the breeding parameters. *x*-axis, proportion breeding (•), or breeding success (□; young fledged out of pairs that laid eggs); *y*-axis, productivity (young fledged per checked pairs). (b) Number of fledglings per territory from a sample of eight territories of Bearded Vultures in Corsica over two periods. Black bars, 1983–2008; Grey bars, 1988–2008.

stochasticity and consequently to have a rather high extinction risk (Bretagnolle *et al.* 2004).

Recent trends in breeding parameters

In contrast to the observed stability of the population size, all breeding parameters decreased, significantly or not according to the time lag considered, and are currently very low. The significant decline in laying rate, breeding success and productivity, which was found over the whole study period, but which is no longer apparent if the data set is restricted to only after 1986, may be because of better monitoring rather than a real biological effect. Proportion breeding is quite variable, but productivity has now stabilized to a very low average. Together, the ten Bearded Vulture territories have produced ten fledglings between 2000 and 2008. Several identified cases of chick mortality at the nest were related to starvation (unpubl. data). The current decrease of feeding resources, both wild and domestic ungulates, appears to be the main limiting factor of the population (Seguin *et al.* 2005). Artificial feeding stations have not proved very efficient in Corsica, in contrast to other populations (but see Oro *et al.* [2008] and Margalida *et al.* [2009]). An alternative explanation of the breeding parameters decline is a possible inbreeding depression owing to the isolation of this population.

Comparison with other western European Bearded Vulture populations

The main western European Bearded Vulture population is located in the Pyrenees. Although its numbers and breeding range have dramatically declined in the recent past (Heredia & Heredia 1991, Razin *et al.* 2004), this population is currently sharply increasing, both in numbers and breeding range, with establishment of new pairs in vacant territories being observed yearly (Heredia & Margalida 2002, Razin & Bretagnolle 2002). Therefore, Corsican and Pyrenean populations show opposite trends, and comparison of their respective demographic parameters may be useful. Polyandrous trios occur in both Corsica and the Pyrenees, with apparently similar rates: 10–25% in Corsica, 11.5% (1988: Heredia & Donazar [1990]), 14.3% (2002: Margalida & Garcia-Ferré [2002]) and 20.5% (1996: Margalida *et al.* [1997]) in the Pyrenees, and 33% (Razin *et al.* 2004) in the French Alps. However, breeding parameters vary strongly between the two areas: proportion breeding is lower in Corsica (60.3%, n = 204 this study) than in the French (76%, n = 386 [Razin *et al.* 2004]) or Spanish Pyrenees (75.6%, n = 119 [Margalida *et al.* 2003]); breeding success (29%, n = 123, Corsica) is half that in the Spanish Pyrenees (56%, n = 115 [Margalida *et al.* 2003]); and productivity (0.16 fledgling/pair/year, n = 233, Corsica) is two to three times lower than in the French and Spanish Pyrenees: 0.35 (1994–2003: Arroyo & Razin [2006]), 0.59 (1994–2000: Heredia [2000]) and 0.43 (n = 115 [Margalida *et al.* 2003]), respectively. We suggest that these differences in breeding parameters result from resource availability and whether the population is close to carrying capacity: in Corsica, domestic feeding resources are decreasing (Thibault *et al.* 1993, Seguin *et al.* 2005), natural feeding resources are very scarce (Seguin *et al.* 2005), and the population is at carrying capacity. Conversely in the Pyrenees, domestic feeding resources appear stable, while natural feeding resources have increased (Razin & Bretagnolle 2002). It is noteworthy that the Spanish population currently shows a slower increase rate, as well as a decreasing productivity (Margalida *et al.* 2003, Carrete *et al.* 2006), suggesting that the Bearded Vulture population may be approaching carrying capacity there.

ACKNOWLEDGEMENTS

We are extremely grateful to Jean-Claude Thibault (Parc Naturel Régional de la Corse, PNRC) for his support and the coordination of this programme. Special thanks also to Paolo and Laura Fasce (Foundation for the Conservation of the Bearded Vulture) for their high contribution to the Bearded Vulture population monitoring since the beginning, and to the staff of the PNRC, and all other professionals (Office National des Forêts, Office National de la Chasse et de la Faune Sauvage, Direction Régionale de l'Environnement de Corse) and volunteers for their help to the 'Altore' programme (Conservation of the Bearded Vulture and restoration of its habitat in Corsica). P. Inchausti kindly read and improved the manuscript, as did G. Siriwardena and two anonymous referees. This study has been co-financed by the DIREN-Corse (Ministry of Environment), the OEC-Corse (Territorial Collectivity of Corsica) and the European Commission (LIFE-Nature 98 project).

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(MS received 13 June 2009; revised MS accepted 19 February 2010)