Long-term monitoring of an insular population of Barbary Falcon 
*Falco peregrinus pelegrinoides*

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Territory spacing and breeding rates of an insular population (north-western Tenerife, Canary Islands) of Barbary Falcon *Falco peregrinus pelegrinoides* was studied from 1993 to 2008. The population increased constantly since the outset, from two pairs in 1993 to 12 in 2008. Mean density was 5.48 pairs per 100 km² and mean nearest neighbour distance was 3 119 m. The regularity of the spatial distribution pattern of the nests, observed in most years, may be maintained in the future despite the expectation that new pairs may occupy still-vacant territories. Considering the 79 breeding attempts analysed, the mean number of fledged young per territorial pair was 1.92, per laying pair was 2.0 (*n* = 76), and per successful pair was 2.24 (*n* = 68). No significant variations were observed between the annual mean number of fledged young per laying pair, nor between the number of fledged young of pairs according to density in a 5 km radius. All fledglings (brood size one to four) left the nest in the month of May. In order to avoid affecting breeding success, sporting activities practised in the breeding areas must be correctly managed by the appropriate authorities.

Introduction

The taxonomic status of the Barbary Falcon is still not entirely clear, since it has been regarded both as a subspecies of Peregrine Falcon (*Falco peregrinus pelegrinoides*; Del Hoyo et al. 1994) and as a distinct species (*F. pelegrinoides*; Cramp and Simmons 1980, Ferguson-Lees and Christie 2001). With few exceptions, resident falcons in the Canary Islands show Barbary phenotypes (Delgado et al. 1999, Rodríguez et al. 2011). A preliminary genetic study, in which three falcons from the Canary Islands with Barbary phenotypes were used, showed hybridisation with Peregrine Falcon *F. p. brookei*, as two of these bird samples had identical haplotypes to the latter (Amengual et al. 1996). Other preliminary studies show a very close genetic relationship between Barbary Falcon and Peregrine Falcon, which indicates that the former ‘represents a subspecies rather than a true species’ (Wink and Seibold 1996, Wink et al. 2000).

Mainly as a consequence of the use of dichlorodiphenyl-trichloroethane (DDT) and derivatives, populations of Peregrine Falcon from different geographical areas decreased dramatically during the 1950s and 1960s (Cade et al. 1988, Ratcliffe 1993). After the prohibition of organochlorated pesticides and with increased legal protection, the greater part of those populations has gradually recovered naturally or by means of reintroduction programmes (Castellanos et al. 1997, Horne and Fielding 2002, Powell et al. 2002, Dzialak et al. 2005, Sielicki and Mizera 2009). Although the precise causes are unknown, the falcons in the Canary Islands were rarely seen at least from the 1950s to mid-1990s (Rodríguez et al. 2009). Indeed, in a census carried out in 1987 and 1988 only seven pairs were observed, and their distribution was limited to the eastern islands and islets of this archipelago: Fuerteventura, Lanzarote, Alegranza and Montaña Clara (Hernández et al. 1991). Falcons are currently present on all the islands and the number of pairs has been estimated to be about 144 (Siverio et al. 2009). Their presence on the island of Tenerife has been known since the beginning of the twentieth century (Thanner 1909), but the uncertainty surrounding subsequent sightings led to their being considered extinct for many years (Hernández et al. 1991). Once nesting was confirmed in 1991 (Hernández et al. 1992), their numbers have increased until the present day, and 35 pairs is the latest population estimate for the entire area of the island (Rodríguez et al. 2009).

In general, the density and breeding parameters of many subspecies of Peregrine Falcon have been studied in depth (Mearns and Newton 1988, Mendelsohn 1988, Ratcliffe 1993, Zubero-gotía et al. 2002, Rizzolli et al. 2005, Verdejo and López-López 2008). With the exception of the Canaries, where their biology and ecology have received some attention (Delgado et al. 1999, Rodríguez and Siverio 2006, Rodríguez et al. 2007), the acquired knowledge of the Barbary Falcon throughout its distribution range is still scant (Ferguson-Lees and Christie 2001). In this regard, many of the data available regarding Morocco, its area of occupation closest to the Canaries, are confusing since they could also pertain to other sympatric races of Peregrine Falcon.
(Thévenot et al. 2003). In the present study we assess the evolution of demographic and reproductive parameters in an increasing Barbary Falcon population during 16 years. Our main goals are to describe annual variation in density, nest spacing and breeding rates, and evaluate the effect of density on breeding performance.

**Study area**

Our study area is situated in the north-west sector of Tenerife, the highest (3 718 m) and largest (2 034 km²) island of the Canarian archipelago, located some 100 km off the north-west coast of Africa (Figure 1). This zone is a very steep massif known as Teno, of which around 105 km² have been studied (taking into account its coastal platforms) within an altitude range of 0–1 350 m. The south-west flank is characterised by the presence of a great sea cliff (c. 12 km long and with several sectors almost 500 m high) cut by a succession of perpendicular deep ravines. One of the best-preserved laurel forests in Tenerife is to be found in the middle altitude zones of the northern flanks. The human population of the area is estimated at 10 770 inhabitants (http://www.ine.es), distributed in villages (inland valleys) and towns (particularly on the coastal platforms). A good part of this surface area is included in the Canarian Network of Protected Natural Areas (Government of the Canary Islands): Parque Rural de Teno (80.63 km²) and Sitio de Interés Científico de Interián (1.01 km²).

**Methods**

During the breeding season (February–May) from 1993 to 2008 the previously occupied territories of Barbary Falcon were visited, in addition to potential breeding sites (all the cliffs of the Teno massif, both coastal and inland, were inspected). It was assumed that a territory was being occupied when the birds frequently used perching sites, courting behaviour was observed, or, in the majority of cases, when the nest was located. In order to assess breeding rates, nest surveillance was performed with telescopes (20–60×) and binoculars at distances ranging from 250 to 600 m. In order to estimate the distances to the nearest neighbours a global positioning system receptor and a geographic information system (ArcView 3.2) were used. On those occasions when their position could not be established, because of the difficult orographic conditions, the point on the breeding cliff where the behaviour of the birds pointed clearly to the existence of a nest (nestlings calling, adults bringing prey and newly fledged young) was taken into account. The age of breeding birds (adults or young of 2 cy) and the sex of the fledglings were determined by means of the coloration patterns and size, respectively (Ferguson-Lees and Christie 2001).

In order to avoid bias in the reproductive parameters, breeding pairs were closely monitored from an early date (February), to determine which pairs laid eggs (taking turns during incubation) or which failed. To define the reproductive parameters we consulted Steenhof and Newton (2007).

The population growth rate was calculated by means of the formula $r = \ln (N_f - N_i) / t$, where $N_f$ is the final number of pairs, $N_i$ the initial number of pairs, and $t$ is the number of years elapsed. The annual rate of multiplication was estimated with the formula $\lambda = e^r$, affording the annual growth rate (%) as $(\lambda - 1) \times 100$. The regularity of the spatial distribution of the nesting sites was analysed by mean of the G-statistic (based on the geometric mean/arithmetical mean ratio of the squared distances between nearest nests), whose range of values varies between 0 and 1, and would indicate a regular nest spacing if it is greater than 0.65 (Brown 1975). To assess the possible repercussion of pair density on reproduction, we have examined annually the size of the broods as a function of the number of neighbour pairs (0, 1, 2, 3 and 4–5) in a radius of 5 km. The said surface area was chosen after weighing up the mean distances and ranges between neighbouring nests, both of Peregrine Falcon (Ratcliffe 1993, Gainzarain et al. 2000, Zuberojigota et al. 2002) and Barbary Falcon in our study area. The data were analysed by means of the Kruskal-Wallis non-parametric test and the chi-squared test (Sokal and Rohlf 1981). The mean values are followed by the standard error (±SE).

**Results**

**Density**

The population increased from two pairs in 1993 to 12 in 2008 ($r = 0.119$, $\lambda = 12.7\%$; Figure 2a). Four out of 10
new territories were occupied by young females. Their subsequent mating, once adulthood was reached, involved one adult and three young males. In another territory, also occupied for the first time, the pair consisted of an adult female and a young male. Birds of the remaining territories (63.6%) were adults. Moreover, a paired adult male was replaced by a young male approximately one year after disappearing from the territory.

Mean density for the entire study period was $5.48 \pm 0.64$ pairs per 100 km$^2$ (range 1.90–11.43). Mean distance between nearest-neighbour nests varied significantly between years ($H_{15} = 50.81, p < 0.001$; Figure 2b) and the overall mean was $3 119 \pm 332$ m ($n = 16$). In most years ($n = 12$) the spatial distribution pattern was regular (Figure 2c). The number of nests recorded per territory fluctuated between one and five (mean $2.27 \pm 0.38$). In those territories with more than one nest, these were always very closely placed on the same rock face (<200 m), with the exceptions of six over 1 000 m distant from the last nest used.

Reproductive parameters
Reproductive parameters were analysed using 79 breeding attempts. Taken together, 152 chicks fledged the nest, the mean number of fledged young per territorial pair was $1.92 \pm 0.12$, that per laying pair was $2.0 \pm 0.12$ ($n = 76$), and that per successful pair was $2.24 \pm 0.10$ ($n = 68$). The nesting success (proportion of laying pairs that raise at least one young) was 89.5%. Mean annual productivity (number of fledged young/laying pairs) did not vary significantly between years ($H_{15} = 20.55, p > 0.05$; Figure 2d), and no differences were observed between productivity of pairs with 0, 1, 2, 3 and 4–5 neighbouring territories in a radius of 5 km ($H_4 = 5.792, p > 0.05$). Two breeding attempts by the mixed pairs (adult–young) proved successful, while the remainder of these pairs ($n = 3$) did not lay eggs judging by their behaviour. The breeding success observed in 74 breeding attempts of adult pairs was 89.2% ($n = 66$). All the fledglings that left the nest did so during the month of May, and the brood size varied between one and four: 14 (20.6%) had one fledging, 27 (39.7%) had two, 24 (35.3%) had three, and three (4.4%) had four. Fledging sex could be determined in 49 individuals belonging to 22 broods, of which 61.2% were male ($\chi^2 = 12, p < 0.01$).

Discussion

Density
In the mid-1980s, none of the present territories of the study area was occupied (FS and MS pers. obs.), and the scant sightings of falcons both in the remainder of Tenerife and in other western islands of the Canarian archipelago were sketchy (Hernández et al. 1991). After the lack of information since the beginning of the last century (see Introduction), the first reliable observations of Barbary Falcons in Tenerife took place relatively frequently during 1989/90 at Teno (Rodríguez et al. 2009), where two pairs were confirmed to have bred one year later (Hernández et al. 1992). All the above points to a recolonisation of Teno (and, by extension, of Tenerife also), beginning in the years immediately preceding the study period, probably from the eastern Canaries (Siverio and Concepción 2004) or from north-west Africa. This apparent expansion, which began likewise to be observed in the remaining central and western islands (Delgado et al. 1999), might have also taken place
from North Africa towards the Sahel, where observations of the birds have continued to increase (Brouwer and Mullié 2000). The huge population increase in our study area, as in the Canary Islands in general (Siverio et al. 2009), could be because of coincidence of several factors including, among others, legal protection of the species and high availability of food resources (nowadays, feral pigeons constitute a plague in many natural sites of the islands; MS pers. obs.).

If population dynamics during the Teno study are taken into account, the cases of young territorial females and mixed pairs (adult–young) detected can not be taken to indicate a negative tendency (e.g. replacement of birds induced by human persecution), as reported for stable populations of falcons and other birds of prey (Ferrer et al. 2003, Pandolfi et al. 2004). On the contrary, our examples (sighted throughout the monitoring period) appear to be more related to population growth in an enclave with a high load capacity, where the young produced occupied optimal vacant sites, at times on an individual basis (females). On the other hand, the use of new nests within a territory could not be attributed to substitutions of breeding females (see Zuberogotía et al. 2002 for the Peregrine Falcon) owing to the fact that the birds were unmarked.

For the entire island of Tenerife, Rodríguez et al. (2007) found a density of 1.27 pairs 100 km² and a mean distance between neighbouring nests of 5 868 m. In this study, the importance of Teno is already noteworthy (given the high availability of suitable cliffs and other factors) as being one of the areas of the island with a greater density of Barbary Falcon. Thus, the availability of these cliffs favours the abundance of falcons and other rupicolous species, both here (Rodríguez et al. 2007, Siverio et al. 2007, Rodríguez et al. 2010, present study) and in continental environments (Newton 1988, Gainzarraín et al. 2000, Jenkins and van Zyl 2005, Rizzoli et al. 2005). On the other hand, annual differences in distances between neighbouring nests detected in Teno are because they were greater when there were fewer pairs at the beginning of the study. When their number subsequently increased, the abundance of trophic resources may have minimised intraspecific conflicts and, consequently, favoured the regularity of the spatial distribution pattern recorded in most years (see e.g. Solonen 1993). On the other hand, the irregularity of the spatial distribution pattern observed between 2005 and 2007 (Figure 2c) was caused by a new pair established at a much greater than average distance (~5 000 m). Considering that Teno still offers potential nesting territories, it is foreseeable that the population will continue to increase and when it stabilises (c. 15 pairs) spatial regularity will be maintained. Indeed, in the Italian Alps, the spacing of a stable population of Peregrine Falcon was always regular in each of the six years studied (Rizzoli et al. 2005), although in the Cape Peninsula (South Africa) observed spacing was irregular, probably because of the equally irregular distribution of cliff sites (Jenkins and van Zyl 2005).

**Breeding parameters**

The values of the breeding parameters of our study are within the range of those recorded in populations of Peregrine Falcon (see reviews in Zuberogotía et al. 2002, Rizzoli et al. 2005). For *F. p. babylonicus*, a very similar race to that dealt with here, the scant data published give the most usual brood size as two (Dementiev 1957). According to the available information on the few populations of Barbary Falcon monitored, particularly in the Canaries, no disparity is observed between the mean values found in the islands and those of the study area (Table 1). The sole exception is the considerably higher value of the Teno fledging rate (fledged young/successful pairs) versus that of the island of Tenerife (Teno included), which may well be caused by a greater sample in the former case (Table 1).

It is highly probable that the very scant rainfall in our study area (mean values for March–April, 2000–2008: 37.68 ± 6.5 mm, range 11.2–74.8; http://www.agrocabildo.com) does not limit productivity, as occurs in other regions where rainfall is abundant (Mearns and Newton 1988, Olsen and Olsen 1989, Zuberogotía et al. 2002). Moreover, if we consider that a great number of nest sites in Teno are on cliff ledges under an overhang and in cavities (MS pers. obs.), the absence of differences between years is not surprising. A further factor limiting productivity in birds of prey is the availability of prey species (Newton 1979). In our study area, both wild and feral pigeons *Columba livia* are abundant and may represent a substantial contribution to the diet during chick rearing (93.3%, n = 45 nest prey delivery observations). It is noteworthy that in some populations of Peregrine Falcon the continuous availability of large prey, such as pigeons, implies high productivity (López-López et al. 2009).

In birds of prey, population increase can also involve decreased productivity, as the new pairs occupy lower-quality territories (presence and absence of floating populations, trophic resources, etc.), and narrowing of territories (Ferrer and Donázar 1996, Carrete et al. 2006). However, in Teno, even taking into account the gradual decrease in distance between neighbour territories (Figure 2c), the good quality of territories could minimise the density-dependent effect on productivity. The causes of breeding failure (10.5%) may have been related to the disappearance of a male during incubation, the apparent nest robbing or depredation of a brood at early-stage and the probable infertility of the eggs of six clutches (incubation was verified, but no chicks were subsequently observed).

**Conservation**

Both the information contained in the present study and that provided by Rodríguez et al. (2007) and Delgado et al. (1999) for all of Tenerife and the archipelago, respectively, provide evidence that Teno is one of the best areas for Barbary Falcon in the Canaries. Despite the fact that its population has, in general, increased in the Canarian archipelago (Rodríguez et al. 2009), its conservation status (IUCN criteria) remains Endangered (Siverio and Concepción 2004). The greater part of the territories are located in Protected Natural Areas of the Canary Islands, and it is thus improbable that its nesting habitat will be significantly modified, at least in the short and medium term. Despite all the above, many people practise outdoor sports such as rock climbing, abseiling, and hang-gliding in Teno and other sites, implying a potential risk for the falcons, as well as other birds of prey, during the breeding season. Indeed, it is known that the productivity of the
Peregrine Falcon is lower in nests situated on rock faces where climbing is practised, unlike sites that remain undisturbed by such activity (Brambilla et al. 2004). On the other hand, since the Barbary Falcon population began to increase in Teno and in the Canaries in general, problems have arisen between certain pigeon fanciers (because of pigeon capture) and hunters (for alleged disloyal competition) on the one hand, and the appropriate authorities on the other. Although such conflicts should be resolved, the most pressing issue at present is the efficient management by the relevant authorities of the above-mentioned sporting activities where necessary. Likewise, before implementation of conservation measures such as modifying the legal conservation status of the species, we recommend a census be undertaken of the entire Canarian archipelago in order to assess the current status correctly.

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References


Table 1: Productivity estimates for populations of the Barbary Falcon across its distribution range. Sample size is shown in brackets followed by the number of years monitored

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<tr>
<th>Region</th>
<th>Mean number of fledging young per pair</th>
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<td></td>
<td>Territorial pair</td>
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<td>Morocco</td>
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<td>Lanzarote</td>
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<tr>
<td>Tenerife</td>
<td>1.55 (37; 2)</td>
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<tr>
<td>Teno</td>
<td>1.92 (79; 16)</td>
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