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LONG-TERM MONITORING OF A PEREGRINE FALCON POPULATION: SIZE, BREEDING PERFORMANCE AND NEST-SITE CHARACTERISTICS

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SUMMARY.—*Long-term monitoring of a peregrine falcon population: size, breeding performance and nest-site characteristics.*

Aims: We report a twenty-one year monitoring study of peregrine falcon *Falco peregrinus brookei* in the southwest of the Castellón province, a Mediterranean area of the East of Spain.

Methods: We systematically monitored a small population occupying 5 - 10 different territories, from 1982 to 2002, over a 1500km^2 study area.

Results: A total of 120 breeding attempts were counted. The average breeding density in the study area was 0.41 ± 0.09 pairs / 100km^2. The number of breeding pairs increased from 5 in 1982 to 9 in 2002. No differences in breeding performance were detected, neither between territories nor between years. Nests were placed in caves, cracks and holes, and peregrines even used nests originally built by corvids and large eagles for breeding. Territory alternation with other cliff-nesting birds was frequent, with cliffs occupied by common ravens, Eurasian kestrels and Bonelli's eagles.

Conclusions: The population has doubled since the beginning of the monitoring, twenty-one years ago. Breeding parameters are of the highest reported in the world, although it could be caused by a low sample size. Notwithstanding, it suggests an optimum state of the population in the study area.

Key words: conservation, *Falco peregrinus*, population ecology, raptors, reproductive parameters, Spain.

RESUMEN.—*Seguimiento a largo plazo de una población de halcón peregrino: tamaño poblacional, parámetros reproductores y características de los nidos.*

Objetivos: Se muestra el resultado de veintiún años de seguimiento de una población de halcón peregrino *Falco peregrinus brookei* localizada en el Suroeste de la provincia de Castellón, un área mediterránea al Este de España.

Métodos: Desde el año 1982 hasta el 2002, se ha llevado a cabo un muestreo sistemático de una pequeña población que ocupa entre cinco y diez territorios de cría diferentes, en un área de estudio que abarca 1500 km^2.

Resultados: Se han contabilizado un total de 120 intentos de cría. La densidad media de parejas reproductoras en el área de estudio fue de 0.41 ± 0.09 parejas / 100km^2. El número de parejas reproductoras aumentó de cinco en 1982 a nueve en 2002. No se detectaron diferencias en cuanto a parámetros reproductores, ni entre territorios ni entre años. Los nidos fueron emplazados ocupando cuevas, grietas y agujeros, así como nidos originalmente construidos por córvidos y grandes águilas. Asimismo observa-

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mos la alternancia en los territorios con otras especies rupícolas como el cuervo, cernícalo vulgar y águila-azor perdicera.

Conclusiones: La población de halcón peregrino se ha duplicado desde el inicio del seguimiento, hace veintiún años. Los parámetros reproductores son de los más elevados que se conocen en el mundo, aunque esto pudiera ser debido al bajo número de parejas monitorizadas. No obstante, esto podría indicar un óptimo estado de la población en nuestro área de estudio.

Palabras clave: conservación, *Falco peregrinus*, ecología de poblaciones, rapaces, parámetros reproductores, España.

Introduction

The peregrine falcon *Falco peregrinus* is a cosmopolitan species distributed throughout all continents apart from the Antarctic (Cramp and Simmons, 1980; Del Hoyo *et al*., 1994). In the Iberian Peninsula the subspecies *F.p. brookei* is present, representing approximately 25 - 31 % of the European population (calculated from BirdLife International / EBCC, 2000). The species is considered as "Not Threatened" in Spain according to IUCN categories and its main threats are the plundering of nests (Gainzarain *et al*., 2003) and especially, in the Mediterranean region, the direct persecution by pigeon fanciers (Urios *et al*., 1991; Sánchez-Zapata *et al*., 1995; López-López *et al*., in press). Despite the lack of accurate data of the species' population trend in Spain, from the last part of the XX century onwards, the population size seems to have increased along its distribution range, especially in high-density areas (Gainzarain *et al*., 2002). Population size is estimated at 2435 - 2743 breeding pairs (Gainzarain *et al*., 2002), 50 % more than the previous estimate (Heredia *et al*., 1988).

Several studies have been published in the last three decades about the biology, ecology and conservation of peregrine falcons both in the European range (Terrasse and Terrasse, 1969; Ratcliffe, 1993; Quinn and Kokorev, 2000; Horne and Fielding, 2002; Pandolfi *et al*., 2004; Rizzolli *et al*., 2005; among others) and in Spain (Garzón, 1977; Verdejo, 1991; Gainzarain *et al*., 2000, 2002; for a complete revision see Zuberogoitia *et al*., 2002). Except some of them, with ten year monitoring data (*e.g.* Fasce and Fasce, 1982; Schenk *et al*., 1985), most papers report reproductive performance in the short-term. In this sense, long-term monitoring studies which to compare results are scarce. The aim of this paper is to show a summary report of a twenty-one year monitoring programme regarding population size, breeding performance, and nest site characteristics of peregrine falcons in an small area in the East of Spain.

Material and methods

Study area

The study area was located in eastern Spain, in the southwest of the Castellón province (40°08'N, 39°43' S, 0°26'E, 0°50'W, Fig. 1) and encompasses 1500 km^2 ranging from 300 to 1400 m a.s.l. The climate is Mediterranean, with annual mean temperatures varying from 8 ºC in winter to 23 ºC in summer. At heights lower than 800 m.a.s.l. there exists a large amount of dry-farmed crops, mainly olive and almond trees, mixed with irrigated crops near the riversides. Above 800 m.a.s.l. there is a cereal-producing area. These areas are also dotted around forest areas and isolated groups of trees, generally pines, conforming small woods. The area is also crossed by two main rivers, several ravines and dry watercourses, shaping a much folded peak line with several cliffs suitable for breeding.

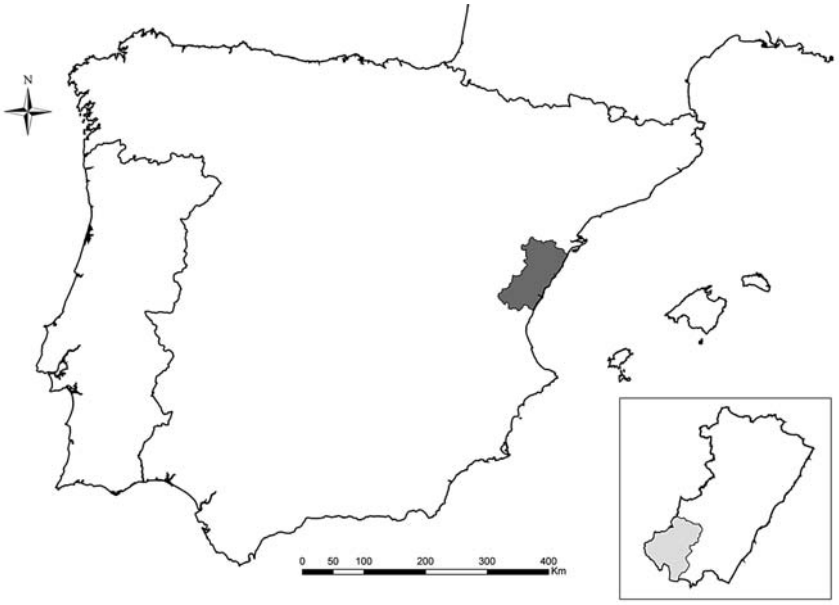

FIG. 1.—Iberian Peninsula with the Castellón province shaded. In box: Castellón province. The study area shaded in grey.
[Se muestra la península Ibérica con la provincial de Castellón sombreada. En el cuadro: provincia de Castellón con el área de estudio sombreada en gris.]

Census

We monitored peregrine falcons in the study area during a twenty-one year period (from 1982 to 2002). During each breeding season (from early February to the end of July) all known breeding places and potential ones were visited. For the detection of breeding pairs, direct searches for nesting places were conducted (Ratcliffe, 1993). Observations were made ~ 300 m from cliff nest sites with a 20-60 x spotting-scope during clear days to avoid disturbance to falcons. A territory was considered occupied if we observed nests with hollows, typical pair behaviour, courtship, brood rearing activity or young (Newton, 1979; Steenhof and Kochert, 1982). We considered as the same pair those that occupied the same breeding place during all years or at least one part of the study period, although presumably, some individuals conforming breeding pairs could have changed. Unfortunately, no individual identification by rings or wing-tags was possible, thus preventing us from calculating the turnover rates.

At least three visits were made to each territory. A first visit was performed at the beginning of the breeding season to confirm the presence of breeding pairs; a second visit during the last few days of the incubation period to seek for newly-hatched chicks; and a third one at the end of the reproductive period to detect fledged young in the nest surroundings. Nevertheless, in most cases visits were repeated every two or three weeks during the breeding period. A small sample of accessible nests-sites ($n = 6$) were visited to calculate the clutch size, egg size and egg mass. Egg size was recorded as the largest diameter x the smallest diameter. Nest position was recorded in a Geograph-

FIG. 2.—Reproductive parameters of the peregrine falcon *Falco p. brookei* in the study area (East of Spain), 1982-2002.
[Parámetros reproductores del halcón peregrine Falco p. brookei *en el área de estudio para el período 1982-2002.]*

ic Information System (GIS) for Nearest Neighbour Distance (NND) calculations.

Reproductive parameters

The reproductive parameters were calculated as follows: productivity = fledged chicks/occupied territory (*i.e.* a breeding site where there is evidence of a mated pair), fecundity = fledged chicks/pairs initiating reproduction (i.e. pairs that had laid eggs), breeding success = successful pairs/pairs initiating reproduction, and flight rate = fledged chicks/successful pairs (i.e. pair that raised at least one chick to fledging age; Steenhof, 1987).

Statistical analysis

Differences in fledged chicks between years and between territories were tested by means of a Kruskal-Wallis test (Sokal and Rohlf, 1981). Differences in breeding parameters were tested with chi-square tests. Mean nest orientation was calculated by means of the Rayleigh Uniformity test (Baas, 2000). For calculations, we used the mean orientation of each cliff hosting the nest/s of each pair only one time to avoid pseudoreplication. All computations were performed using STATISTICA version 7.0 for Windows (StatSoft, 2004). Statistical significance was set at $P < 0.05$.

RESULTS

Density

We recorded a total of 120 breeding attempts between 1982 and 2002. We observed a maximum of nine pairs breeding simultaneously, and ten different breeding places were identified in the study area. The number of breeding pairs increased from 5 in 1982 to 9 in 2002 (Fig. 2).The average breeding density in the study

area was 0.41 ± 0.09 pairs / 100km^2 (range = 0.33 - 0.60), increasing progressively with time.

Territory alternation with other species was frequent in the study area. Two territories later occupied by peregrine falcons were initially occupied by common ravens *Corvus corax*; one from 1982 to 1992 (remaining vacant between 1988 - 1989), and the other from 1987 to 1998. One territory was occupied by Eurasian kestrels *Falco tinnunculus* from 1982 to 2001, and another during two periods (from 1989 to 1991, and from 1999 to 2002), with the intermediate period occupied by peregrines. Furthermore, one territory was occupied from 1982 to 1989 by Bonelli's eagles *Aquila fasciata*, remaining vacant until 1998 when it was occupied by peregrines until 2002.

Breeding performance

Average productivity was 2.132 ± 0.402 fledged chicks/occupied territory (CV = 18.83 %, n = 129). More values for reproductive parameters (mean ± standard deviation and coefficient of variation (CV)) are summarized in Table 1. The number of fledged chicks did not vary between years ($H_{20,120}$ = 21.06, P = 0.394) nor between territories ($H_{9,120}$ = 11.72, P = 0.230). Also, we did not find year-to-year variation in breeding parameters neither for productivity (χ^2 = 1.51, df = 20, P > 0.05), fecundity (χ^2 = 1.29, df = 20, P > 0.05), breeding success (χ^2 = 0.20, df = 20, P > 0.05), nor flight rate (χ^2 = 0.87, df = 20, P > 0.05).

Of six nests, the mean clutch size was 3.17 ± 0.41 eggs (CV = 0.13, range = 3 - 4). The mean egg size was 47.82 ± 2.81 mm x 37.94 ± 1.87 mm (n = 19), and the mean egg mass was 36.58 ± 1.79 g (CV = 0.05, range = 33.14 - 39.62, n = 19). The mean NND was 6132 ± 2614 m (CV = 0.43, range = 1300 - 9150, n = 10) and generally, pairs were located far from urban areas with an average distance of 3070 ± 1762 m (CV = 0.57, range = 1000 – 7300, n = 10). The mean nest orientation in the study area was 154.61º ± 61.32º, and nests were not orientated preferably to any direction (R = 0.427, P = 0.163, n = 10). Peregrines usually used caves, cracks and holes for nesting, with three cases of reuse of nests built by common ravens. Also, one pair used a nest built by a large eagle, probably golden eagle *Aquila chrysaetos* or Bonelli's eagle.

Discussion

In this paper we show the results of a long-term monitoring scheme of a peregrine falcon population in an area where a healthy population still remains in the East of Spain. Our results show that the population has almost duplicated in the last twenty years, and this is not due to more intensive search efficiency, given that all cliffs in the study area were thoroughly revised annually for all potential cliff-nesting birds (Verdejo, 1991; López-López *et al*., 2007). Yet, this increase could be included in the general positive trend reported for the Iberian Peninsula (Gainzarain *et al*., 2002).

The average breeding density in the study area was lower than the reported Spanish national mean, whether we use data from Zuberogoitia *et al*. (2002) (with a mean of 0.74 pairs / 100km^2, n = 1450 pairs) or data from Gainzarain *et al*. (2002) (0.51 pairs / 100km^2, n = 2435 - 2743 pairs). The reproductive parameters were higher than those reported in other study areas (for a complete review see Zuberogoitia *et al*. (2002) and Rizzolli *et al*. (2005)). This result could be related to the small number of monitored pairs and the healthy status of the increasing population. The breeding success was exceptionally high, with values only similar to those reported in Sicily (91.1 % of successful pairs) (Schenk *et al*., 1985) or Biscay (Northern Spain) (with 80 - 100 % of successful pairs) (Zuberogoitia *et al*., 2002). The productivity was also one of the highest values obtained consulting literature, with values above the maximum reported in Europe (Rizzolli *et*

TABLE 1

Summary of the annual reproductive parameters of the peregrine falcon *Falco p. brookei* in the southwest of the Castellón province (East of Spain). Abbreviations: SD: Standard Deviation; CV: coefficient of variation.

	1982	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**
Monitored pairs	5	5	5	5	5	5	5	5	5	5	6
Fledged chicks	12	12	12	10	7	10	12	10	11	13	15
Fecundity	2.40	2.40	2.40	2.00	1.75	2.50	3.00	2.50	2.75	2.60	2.50
Breeding success	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Flight rate	2.40	2.40	2.40	2.00	1.75	2.50	3.00	2.50	2.75	2.60	2.50

al., 2005) with 1.91 chicks/territorial pair in Finland (Lindberg *et al*., 1988) and similar to values recorded in other Spanish populations like Ibiza and Formentera Islands (2.3 chicks / pair) (García, 2005), Guara Canyons in the Southern Pyrenees (2.35 chicks / territorial pair) (Gómez-Samitier, 2002) or prelittoral mountain ranges of Catalonia (2.45 chicks / territorial pair) (Gálvez, 2002), but the last three including only one year's data. The fecundity was also high, with values similar to the Midwestern USA (2.0 chicks / laying pair) (Tordoff and Redig, 1997), Greenland (2.30 chicks / laying pair) (Mattox and Seegan, 1988), Fennoescandia (2.9 chicks / laying pair) (Lindberg *et al*., 1988) or Quebec (2.90 chicks / laying pair) (Holroyd and Banasch, 1996). Finally, the flight rate was closer to other long-term monitored populations of Europe, like central and western areas of the Italian Alps (2.40 and 2.60 chicks / successful pair, respectively) (Fasce and Fasce, 1992; Rizzolli *et al*., 2005), Finland (2.48 chicks / successful pair) (Lindberg *et al*., 1988), and England (2.42 chicks / successful pair) (Horne and Fielding, 2002).

It is remarkable to note the lack of variation in breeding performance between years and between territories. This fact could be explained by the low sample size analyzed, making necessary to exist larger differences in the variables compared to be detected by the statistical tests. Yet, territories were homogeneous in terms of quality with a resulting breeding performance higher than those reported in other study areas as mentioned above. Considering that population size has duplicated since the study began, it suggests an optimum state of the population, far from any expected carrying capacity. In this sense, it points towards the lack of a density-dependant effect on breeding performance, given that if population was near the carrying capacity, density-dependent effects on demographic parameters would arise. Similar results have been found for Bonelli's Eagle in an area including our study area (López-López *et al*., 2007).

The egg size we obtained was lower than that reported by Brown and Amadon (1969) with an average of 52.0 x 40.9 mm (n = 300 eggs) and Formon (1969) with an average of 51.9 x 41.5 mm. This result corresponds to the biometry of the *Falco p. brookei* subspecies, typical of the Mediterranean region, with the first-mentioned values supposedly corresponding to the *Falco p. peregrinus* subspecies, present in northern latitudes (Brown and Amadon, 1969).

Peregrine territories are variable in size and shape (Zuberogoitia *et al*., 2002) and yet overlapping of territories has been reported (Enderson and Craig, 1997). Food availability and suit-

TABLE 1

[Resumen de los parámetros reproductores anuales del halcón peregrino Falco p. brookei *en el Suroeste de la provincia de Castellón (Este de España). Abreviaturas: SD: desviación estándar; CV: coeficiente de variación.]*

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total			
										Mean	**SD**	**CV**	***n***
6	6	7	7	6	8	8	8	8	9	6.14	1.35	22.01	129
8	10	11	14	16	18	17	21	20	16	13.10	3.78	28.87	275
1.60	1.67	2.20	2.00	2.67	2.57	2.13	2.63	2.50	1.78	2.292	0.385	16.82	120
0.80	0.83	0.80	0.71	1.00	0.86	0.88	1.00	1.00	0.78	0.925	0.097	10.51	120
2.00	2.00	2.75	2.80	2.67	3.00	2.43	2.63	2.50	2.29	2.477	0.327	13.21	111

able places for nesting are factors regulating nest spacing (Ratcliffe, 1993). In our study area, peregrine territories were rather randomly distributed. The average near neighbour distance was higher than that reported for other regions (for a complete review see Rizzolli *et al*., 2005), but similar to that reported for other European territories. Yet, the highest peregrine density is reported in coastal places when associated with large sea-bird colonies (Thiollay, 1988; Monneret, 2000) or in recent studies from insular lands where suitable cliffs for nesting are limited (García, 2005; Rodríguez and Siverio, 2006; Rodríguez *et al*., 2007). Anyway, comparisons between densities of different study areas should be taken cautiously given that these differences could be caused by the different magnitude of the study area (Zuberogoitia *et al*., 2002).

During the entire study period, territory alternation with other cliff-nesting birds was frequent, with cliffs where peregrines bred being previously occupied by common ravens, Eurasian kestrels and Bonelli's eagles. In some cases, peregrines actively displaced Eurasian kestrels or common ravens from cliffs, but there were cases where the cliff was shared with common ravens, with nests established near to each other. This relative tolerance of common ravens has also been reported in other Spanish populations like Biscay, where 82.35 % of peregrine nests were located less than 500 m away (Zuberogoitia *et al*., 2002). Proximity to common ravens has been suggested as an adaptive choice which may provide early-warning cues against predators (Sergio *et al*., 2004). Alternatively, other authors have reported a fall in breeding performance of peregrines in places where ravens and rock climbing occur (Brambilla *et al*., 2004). In the case of the Bonelli's eagle, nest alternation was separated by a large gap of eight years, with the cliff remaining vacant during this period. Currently, this pair of Bonelli's eagle is still breeding just a few kilometres away from the peregrine's cliff. Competitive interactions between them causing peregrine displacement have been suggested, with Bonelli's eagle being the dominant species (Gil-Sánchez, 1999). Nonetheless both species are still present in our study area, with peregrines increasing over time and Bonelli's eagle maintaining breeding territories since systematic monitoring of both populations started thirty years ago.

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