The unusually large home ranges and poor breeding performance of peregrine falcons *Falco peregrinus* in central Catalonia (NE Iberia) may reveal poor habitat quality

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We studied the movements and home range of two breeding adult Peregrine Falcons *Falco peregrinus* in central Catalonia. Both individuals had large home ranges (3,600 and 345 km^2) and extensive maximum daily movements of 192 and 205 km, respectively. One individual even travelled 102 km from the nest during chick-rearing. These values are among the largest home ranges reported for the species. Additionally, we collected productivity data from the same area for a period of 30 years, which revealed poor breeding performance. Comparing these findings, we suggest that the habitat quality is low in the studied area, which forces these falcons to move large distances. This will potentially have associated costs in terms of adult mortality, which may directly affect population dynamics and have implications for conservation planning.

Key words: Peregrine Falcon, *Falco peregrinus*, movement ecology, GPS-tracking, productivity, mortality.

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Movement ecology is a relatively novel research area whose aim is to understand how and why animals move across the landscape and what implications this may have in evolutionary and conservation terms (Ortega *et al.* 2023). Advances in animal tracking technology allow us to obtain completely new and more accurate sets of data on animal movements and behaviour, which in turn facilitates fresh approaches to analysis and information gathering (Wall *et al.* 2014). Birds of prey are usually considered to be fairly territorial and central-place foragers (Martínez-Hesterkamp 2015), particularly during the breeding period, and range over relatively large areas around their nests in search of food for their chicks. Many raptor species are endangered or protected and information about their ranging behaviour may shed light on the constraints these animals face. An example of this is the Peregrine Falcon *Falco peregrinus*, a very widely distributed raptor species with recognized subspecies in all continents except Antarctica (White *et al.* 2013). In the Iberian Peninsula, the breeding population belongs to the subspecies *brookei*, which is considered to be mostly resident, with juveniles performing significant dispersal movements (sometimes up to several hundred kilometres) after leaving their natal areas (Zuberogoitia *et al.* 2002, Zuberogoitia 2023). In Catalonia (NE Iberian peninsula), the Peregrine Falcon is widely distributed and its breeding population has risen from 75–100 pairs in the 1970s (Muntaner *et al.* 1983) to an estimated population of 225–470 pairs in 2018 (Franch *et al.* 2021). This falcon nests in large rocky cliffs, from coastal areas to the

Pyrenees, although a few pairs now nest in urban areas, generally as a result of successful reintroduction programs such as in Barcelona (García & Durany 2014).

In spite of this well-known and dramatic increase in the Catalan Peregrine Falcon breeding population, little information has been published about its ecology and breeding performance in the area. In this paper, we summarise information on the breeding performance of a Peregrine Falcon population in a natural park in central Catalonia in 1995–2024 and present information obtained from the tracking of two adult birds in the same area in 2022 and 2023. Together, these data may help us understand the constraints faced by this population and will serve to underline the importance of monitoring in conservation decisions.

Materials and methods

Study site

The study was carried out in the area of Montserrat Natural Park (Parc Natural de la Muntanya de Montserrat; central coordinates 41º36'N, 1º49'E). This park boasts an exceptional landscape of unusually complex conglomerate rocks in an area of about 10 x 5 km. Hundreds-of-metres-high vertical cliffs are found throughout the massif, along with many caves and other cavities. The lowest areas of the massif lie at 500 m a.s.l., and the summit is at 1,236 m. The habitat consists of a mix of open rocky areas (mostly the highest peaks and cliffs) and vegetation dominated by dense Mediterranean scrubland with evergreen oaks *Quercus ilex* as the dominant tree. Together with numerous species of scrub in the understory such as common smilax *Smilax aspera*, common box *Buxus sempervirens*, strawberry tree *Arbutus unedo* and Mediterranean heath *Erica multiflora*, to name a few, this oak forms quite dense forests. In the piedmont, young Aleppo pine *Pinus halepensis* are the commonest trees, and to the south there also a number of olive groves *Olea europaea*. The park hosts a typical Mediterranean forest bird community, with Woodpigeons *Columba palumbus*, Eurasian Jays *Garrulus glandarius* and Blackbirds *Turdus merula* as the main medium-sized species, along with a wide variety of smaller passerines.

Nest and breeding monitoring

Eight breeding territories of Peregrine Falcon have been located and monitored during the past 30 years (Gabriel Lampreave & Parc Natural de la Muntanya de Montserrat, pers. obs.). Each year, with the exceptions of 1998 and 2005, the eight Peregrine Falcon territories in

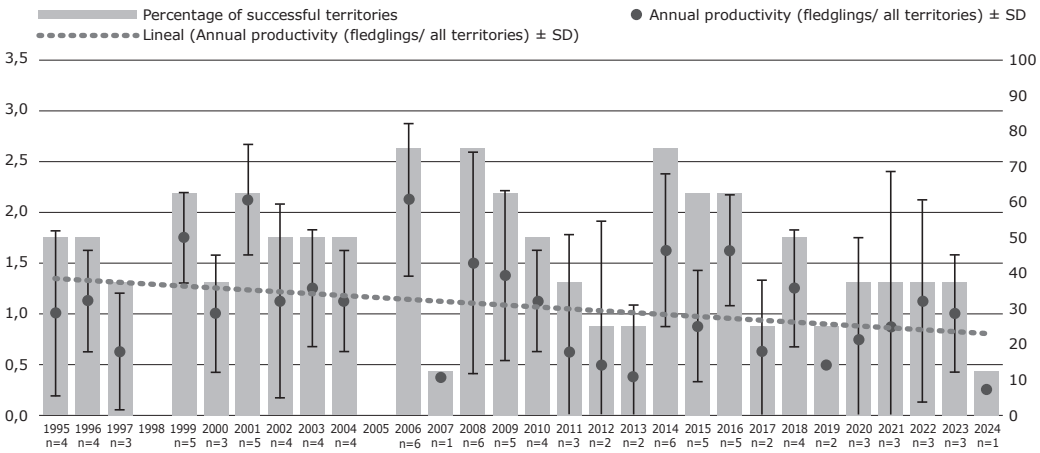

Figure 1. Average (+- s.d.) annual number of fledglings/territory over a period of 30 years (1995–2024, excluding 1998 and 2005). The number of nests monitored each year is indicated below the X-axis The dotted line indicates the linear trend. Columns show the percentage of successful territories each year.
Mitjana (+- d.t.) anual del nombre de volanders/territoris al llarg del període de 30 anys (1995–2024, excloent 1998 i 2005). El nombre de nius seguits cada any es mostra sota l'eix de les X. La línia discontínua indica la tendència lineal. Les columnes mostren el percentatge de territoris amb èxit reproductor cada any.

Table 1. Number of fledglings and number of successful breeding years (at least one fledgling) from each territory during the 28 years of monitoring (1995–2024, excluding 1998 and 2005) in the study area. The average (+-s.d.) number of nestlings/year and the average (+- s.d.) number of nestlings/successful year are also shown for each territory.
Nombre de polls volanders i anys amb èxit reproductor (almenys un pollet volander) per territor durant els 28 anys de seguiment (1995-2024, excloent 1998 i 2005). També es mostra el nombre mitjà (+-d.t.) de pollets / any i el nombre mitjà (+- d.t.) de pollets /any amb èxit per a cada territori.

Territory ID	Total nº of fledglings	Successful years	Overall productivity	Successful-year productivity
1	17 (7.1%)	7 (10.3%)	0.58 ± 1.11	2.42 ± 0.78
2	11 (4.6%)	5 (8.3%)	0.37 ± 0.90	2.20 ± 0.83
3	48 (20.1%)	19 (22.3%)	1.65 ± 1.39	2.52 ± 0.84
4	34 (14.2%)	14 (17.3%)	1.25 ± 1.43	2.42 ± 1.01
5	18 (7.5%)	7 (10.3%)	0.62 ± 1.20	2.57 ± 0.97
6	30 (12.5%)	13 (16.3%)	1.03 ± 1.26	2.30 ± 0.75
7	53 (22.2%)	23 (26.3%)	1.82 ± 1.10	2.30 ± 0.63
8	28 (11.7%)	15 (18.3%)	0.96 ± 1.08	1.86 ± 0.74

Montserrat were surveyed, thereby giving a data series of 28 years. From February onwards, when the pairs start their courtship (Zuberogoitia *et al.* 2002), each territory was visited at least once a week (but occasionally more often) to monitor nest occupancy (empty, one or two birds present), breeding performance and number of nestlings. For this study, we compiled a long-term dataset for the last 30 breeding seasons in Montserrat (1995–2024). Each year, data was collected regarding the occupation of the territory (pair or single individual), breeding success (yes/no), and productivity (number of nestlings).

Trapping and tagging

The nesting areas in Montserrat are difficult to access due to the very abrupt terrain, so of the occupied nesting territories we had to select those that were most accessible for capturing birds. Captures were conducted using dho-gaza nets, following a system adapted from Zuberogoitia *et al.* (2008), and with all the corresponding permits granted by the local administration (Generalitat de Catalunya). A strict protocol was followed: the nests were monitored from distance with a telescope in order to minimise disturbance, and trapping was only conducted when nestlings were older than 20 days, that is, once they were able to thermoregulate (Zuberogoitia *et al.* 2002). In 2021, we made our first unsuccessful trapping attempt. In spring 2022, we trapped one adult female (age euring code 6) Peregrine Falcon in a nesting territory inside the park (territory 8; Fig. 2), which had 2 chicks on the nest. In spring 2023, an adult male (age euring code 8) was trapped in a nesting territory in the proximity of the park (Fig. 2), which had 3 chicks. This latter bird did not belong to any of the eight territories studied as part of the long-term monitoring project (Table 1).

Once trapped, the individuals were ringed with a metal ring and a plastic ring (yellow colour with 3-digit black inscriptions as per the rest of Peregrine Falcon ringing projects in Catalonia). Age, sex, wing length, weight, fat, muscle index, broodpatch state, tarsus length, bill length, hind claw, tail, and moult stage of each bird was recorded, following the protocols of the Institut Català d'Ornitologia (ICO 2023). Each individual was equipped with a OrniTrack GPS-GSM device of 15 grams, always <3% of total body weight, following recommendations by Cochran (1980). Considering the existence of reports of the negative effects of tagging large falcons (Dixon *et al.* 2016), above all on juveniles (Zuberogoitia 2023), we set up a protocol to minimise their potential occurrence as much as possible. The tags were attached using a Garcelon-type harness (García-Matarranz *et al.* 2021) that would eventually break and be lost. The devices were programmed to collect GPS fixes every 10 minutes at first but, since the battery level was generally very good, they were subsequently set to collect data every two

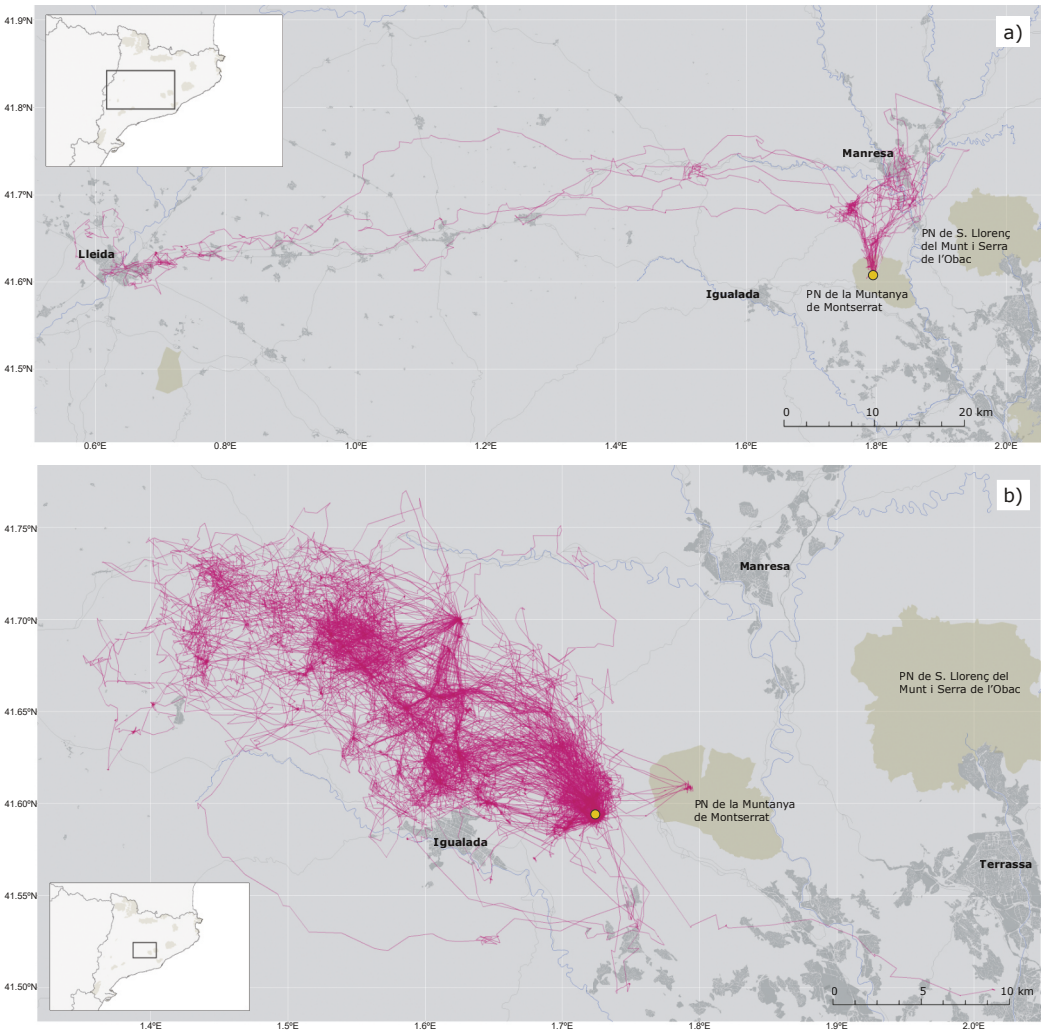

Figure 2. Movements of the female (a) and male (b) Peregrine Falcons. The yellow dots indicate the location of the nests.
Moviments de la femellla (a) i del mascle (b) de falcó pelegrí. Els punts indiquen la ubicació dels nius respectius.

minutes if the battery charge was >75%, every 5 minutes if battery was 50–75%, every 16 minutes when battery was 25–50%, and every 100 minutes when the battery was <25%. The devices were programmed to collect data only during day-time, from half an hour after sunrise until half an hour before sunset, and to transmit the data twice a day (early morning and late evening), so potential issues could be checked for. The individuals were visited at least once a month and observed from a distance to ensure that no abnormalities in their behaviour occurred that could be attributed to the tracking.

GPS Data analysis

GPS data were analysed with RStudio 2021.09.0 Build 351 (R Core Team 2023). The home ranges were defined using the *adehabitat* library (Calenge 2006), more specifically the package *adehabitatHR* (version 0.4.22), and calculated with fixed-kernel methods (Worton 1989). We also used a Wilcoxon rank-sum test to compare daily movements of the male between two periods using the package *car* (Fox & Weisberg 2019).

Results

Breeding performance

During the study period (1995–2024), 3.6 ± 1.41 territories were active annually (range 1–6, n=28), with a total of eight different territories. At least 239 nestlings fledged during the 28 years of monitoring, which gives 8.5 fledglings/year and an average productivity for the eight territories of 1.1 ± 0.5 fledglings per territory/year (2.3 ± 0.5 fledglings per active territory/year). The nesting territories showed great differences in the proportion of successful breeding years, number of fledglings and overall productivity (Table 1). On average, only 45.5 ± 17.7 % of the territories were successful every year. In the long-term, the productivity (fledglings/territory) showed a negative (although non-significant) trend (r_s=-0.32, P = 0.088, n = 28) (Fig. 1).

Ranging behaviour

The female was tracked from 26/5/2022–9/6/2022 (14 days) and delivered 7345 fixes (Fig. 2). She had a total home range of 3600 km^2 (Kernel 95%) with a 528 km^2 (Kernel 50%) core area (Fig. 3). She moved on average 114 ± 47 km (38–192) per day. On one occasion, she unexpectedly left the nesting area and travelled 102 km from the nest, staying away for four full days despite the presence of nestlings in the nest (Fig. 4). Although her nest was inside the boundaries of the natural park, most (89.5%) of the GPS locations were outside the protected area (Fig. 2).

The male was tracked from 17/5/2023–20/10/2023 (156 days) and delivered 44 973 GPS fixes (Fig. 2). He exhibited a total home range of 345 km^2 (Kernel 95%) with a 67 km^2 (Kernel 50%) core area (Fig. 3). He moved on average 79 ± 43 km (8–205) per day. He reached a maximum distance of 34 km from the nest and always returned at least once in every 24-hour period during the breeding season, and at least once every 48 hours after the fledglings had left the nest (Fig. 4). We estimate that the young fledged from the nest on June 7. The total daily distance covered by the male before the young fledged was 115 ± 41 km (range 46–95, n=21) but decreased to 73 ± 41 km (range 8–206, n=135) after fledging (Wilcoxon rank-sum test, W = 632, P<0.001). On June 28 a significant drop of the total daily distance covered was observed, which was probably associated with the independence of the young from the territory (although this was not confirmed by direct observation).

Both individuals visited very different habitats to those found close to the nest. The female

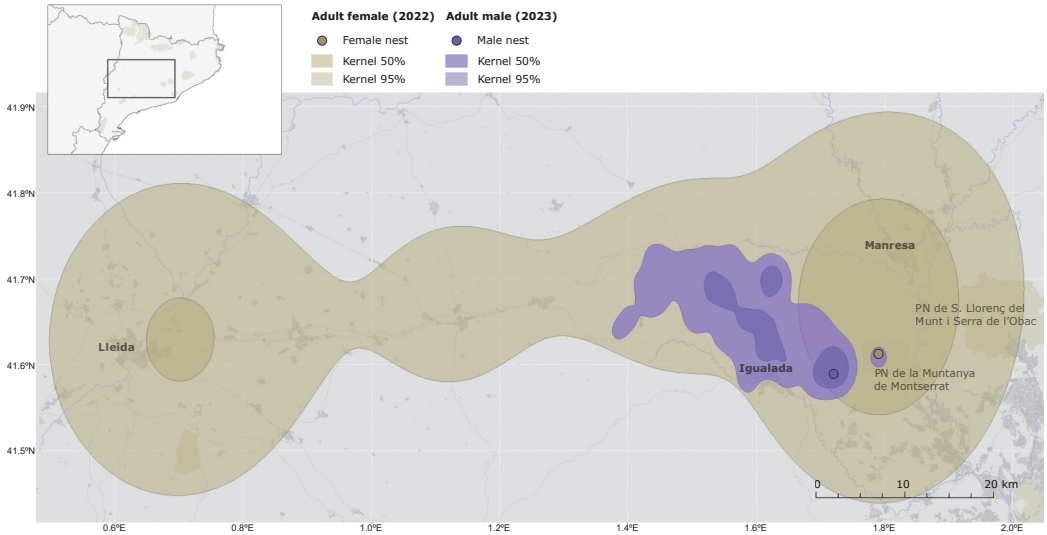

Figure 3. 95% (lighter colour) and 50% (darker colour) Kernel distribution areas for female (beige) and male (purple) peregrine falcons.
Distribucions kernel de la femella (beix) i del mascle (lila), el kernel 95% en color més clar i el kernel 50% en color més fosc.

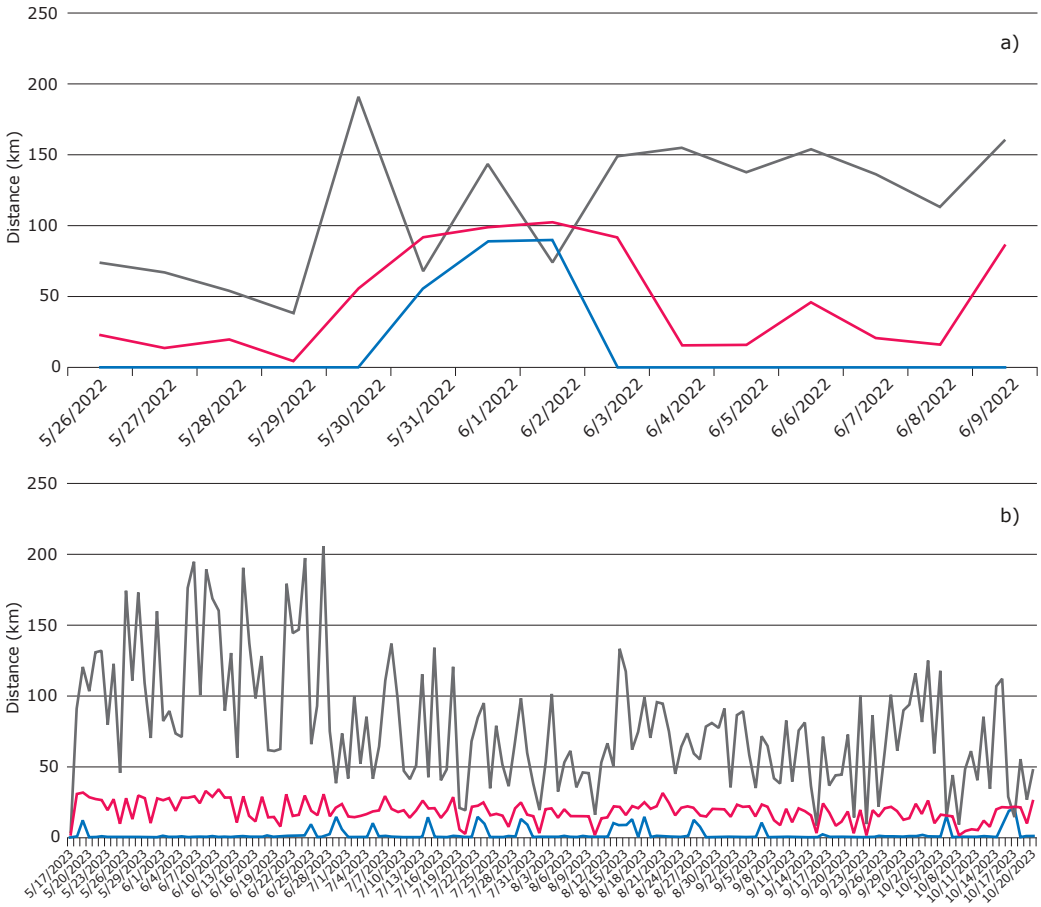

Figure 4. Total distance travelled per day (grey), and minimum (blue) and maximum (red) distances from the nest (0 = at the nest at least once) recorded for the female (a) and male (b) peregrine falcons.
Distància total recorreguda per dia (gris) i distàncies mínima (blau) i màximes (vermell) respecte el niu (0=visita el niu almenys un cop), enregistrades per l'exemplar femella (a) i mascle (b) de falcó pelegrí.

mostly flew north to the lowlands between Montserrat and Manresa city but also headed west and reached the city of Lleida, where she stayed for four days hunting in the surrounding area and eventually flying over the city (Fig. 2). The male mostly hunted over an extensive agricultural area with scattered woodland patches but also in some areas that are much more forested, mostly Aleppo Pine (Fig. 2). He had a favourite perch inside a dense forested area on the northern side of a hill where he slept on several occasions both during the breeding period and afterwards, always in the same tree. He only strayed occasionally from his regular spots and made four visits to the summits in the northwestern part of Montserrat (Agulles area), where according to the data he remained perch for a while.

Mortality records

Both falcons stopped transmitting data when they died. The female was found electrocuted on the railway at Bell-lloc d'Urgell, 86 km away from the nest, 14 days after she had been tagged, in her second long-distance excursion to the west. She had caught a Feral Pigeon *Columba livia* close to an urban area. The male was found dead 156 days after tagging near the town of Rubí, 26 km away from the nest in a densely vegetated dry riverbed, with abundant giant canes *Arundo donax* and a few trees. He

had departed the day before from his usual home range and headed south-west for the first time since the start of the monitoring. He spent the night at the site and was found dead the following morning. Both individuals were taken for examination to official rehabilitation centres (Vallcalent and Torreferrussa), where electrocution and severe traumatism with an unknown object or surface were certified as the cause of death by veterinarians. No evidence of the deleterious effects of the tagging were reported at the necropsy.

Discussion

Although home range calculations of adult Peregrine Falcons reported in the literature may not be directly comparable due to differences in methodologies and between the studied populations (Zuberogoitia 2023), based on previous knowledge of the home range size of the species (Table 2), we were expecting to detect small home ranges for our falcons. Nonetheless, our findings showed comparatively very large home ranges, with both individuals regularly covering daily distances up to 200 km and ranging on some occasions very far from the nest. For comparison, the territorial adults of a large soaring raptor, the Bearded Vulture *Gypaetus barbatus*, were found to move on average only 23.8 ± 20.9 km per day (Margalida *et al.* 2016).

In spite of breeding within or near a protected area, both birds made little use of it. This is particularly remarkable in the case of the female, which had its nest within the Natural Park boundaries but spent most of its time in non-protected areas, including farmland and urban areas. Although the Montserrat mountain has a good availability of suitable cliffs and cavities for nesting, which provide suitable protection against adverse weather conditions (Zuberogoitia 2023) and alternative nest sites to reduce parasite loads (Zuberogoitia *et al.* 2015), the characteristics of its bird community together with the structure of the habitat (as mentioned, rather closed and dense forests) probably forces peregrines to hunt away from the mountain, particularly during the stressful time of chick-rearing (Zuberigoitia 2023). In relation to this, we found evidence that at the end of the rearing period there was a sudden reduction in the males' daily ranging behaviour, supporting the view that the high food demands imposed by

Table 2. Home range estimates from different studies of Peregrine Falcons worldwide. All studies refer to the breeding stage and the home range data applies to the nesting period (before the fledgling period of the nestlings). The two individuals from this study are added as comparison.
Càlculs d'àrea vital en diferents estudis de falcó pelegrí al món. Tots els estudis es refereixen al període de reproducció, i les dades d'àrea vital corresponen al període de nidificació (abans de l'envol dels pollets). Els dos exemplars d'aquest estudi s'inclouen per a la comparació.

Reference	Method	Study site	# individuals	Home range estimate
Jenkins & Benn (1998)	Manual radiotracking	Cape Peninsula, South Africa	4	Average 86.3 km² (kernel 95%)
Ganusevich *et al.* (2004)	Satellite-receivers (PTT)	Kola Peninsula, Russia	4	Average 1175 ± 714 km² (MPC 90%)
Sokolov *et al.* (2014)	Satellite-receivers (PTT)	Yamal Peninsula, Russia	10	Average 106.8 km² (MPC 95%)
Lapointe *et al.* (2013)	Satellite-receivers (PTT)	Quebec, Canada	12	Average 83.9 ± 120.7 km² (kernel 95%)
Morata (2018)	Satellite-receivers (PTT)	California, USA	9	Average 38.6 ± 11.6 km² (kernel 95%)
Taylor *et al.* (2020)	Satellite-receivers (PTT)	Kentucky, USA	1	3.43 km² (kernel 95%)
Zuberogoitia (2023)	GPS-GSM	Bizkaia, N Iberia	1	14.5 km² (kernel 95%) 1.05 km² (kernel 50%)
This study (female)	GPS-GSM	Central Catalonia, NE Iberia	1	3600 km² (kernel 95%) 529 km² (kernel 50%)
This study (male)	GPS-GSM	Central Catalonia, NE Iberia	1	345 km² (kernel 95%) 67 km² (kernel 50%)

chick-rearing may have forced these falcons to forage in areas far from the nests where there was abundant and profitable prey (such as feral pigeons).

Previous research has found that when Peregrine Falcons occupy good-quality territories, defined by suitable breeding locations, regular food availability and a lack of disturbance, their home range is considerably smaller (Zuberogoitia 2023). Therefore, the fact that our population has such extremely large home ranges is a clear indication that the territories are in a low-quality habitat. This is consistent too with the relatively low breeding success reported in our study. The overall productivity and breeding success in the study areas was lower than similar studies found in Europe (see review in Zuberogoitia 2023), which is probably an indication of the poor habitat quality of the area in terms of food supply. Moreover, since the area has a number of nesting pairs, this may increase intraspecific competition and affect parameters such as home range size, since Peregrine Falcons are very territorial (Zuberogoitia 2023). Alternatively – or additionally – nest disturbance in Montserrat could also be a relevant factor explaining the low breeding success, as the park receives a mean 1604 visitors/day (Patronat de la Muntanya de Montserrat 2023), with a peak during the falcon's breeding season. Moreover, Montserrat is a well-known and popular area for climbing. Although regulations for this activity were put in place in 2008, each year there are reports of climbers on cliffs that may directly affect falcons' breeding, and in some years breeding pairs have failed for this reason (own unpublished data). More surveillance is needed to enforce existing regulations.

The two individuals from our study died within the first half year after tagging due to anthropogenic factors (electrocution and collision), two factors that are reported as common causes of mortality elsewhere (Zuberogoitia 2023). This probably indicates that this population is suffering from high human-induced mortality rates, which is reflected in its low reported breeding output (Hunt 1998). Considering all the above mentioned factors (i.e. observed unusually large home ranges, low breeding success and high mortality), we suggest that the Montserrat Peregrine Falcon population could be a sink population (Pulliam 1988), mostly dependant for its subsistence on other source populations, which will have potentially negative effects for the dynamics of the global metapopulation. Therefore, with this in mind, we believe that efforts should continue to be made to ensure a viable local population by improving breeding output (success and/or productivity) and survival rates. Continued marking and fine-scale monitoring of breeding pairs is necessary to provide the essential information for effectively regulating human activities such as hiking and climbing that may lead to disturbance. As well, better data could help improve knowledge of the behaviour and the dynamics of the Montserrat Peregrine Falcon population, which is essential if conservation objectives are to be fulfilled.

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Resum

Àrees vitals molt grans i mala reproducció del falcó pelegrí *Falco peregrinus* a la Catalunya Central pot revelar un hàbitat de mala qualitat

Hem estudiat els moviments i l'àrea vital de dos falcons pelegrins adults i reproductors a la Catalunya Central. Els dos exemplars han mostrat àrees vitals molt grans (3.600 i 345 km^2 respectivament), amb distàncies màximes recorregudes diàriament de 192 i 205 km, respectivament. Un individu fins i tot va allunyar-se del niu 102 km, encara amb pollets al niu. Aquests valors són dels més grans publicats per a aquesta espècie. Addicionalment, hem recollit dades de productivitat a la mateixa zona durant 30 anys, i

aquestes mostren una reproducció baixa. Comparant aquests resultats, suggerim que la qualitat de l'hàbitat és baixa a la zona d'estudi, forçant els falcons a moure's grans distàncies amb els potencials costos associats d'augmentar la mortalitat adulta, que directament impacta en la dinàmica poblacional, i discutim factors clau a considerar a l'hora de prendre accions de conservació.

Resumen

Áreas vitales muy grandes y mala reproducción del halcón peregrino *Falco peregrinus* en la Catalunya Central (NE Iberia) puede indicar un hábitat de mala calidad

Estudiamos los movimientos y el área vital de dos halcones peregrinos adultos y reproductores en la Catalunya Central. Los dos ejemplares han mostrado áreas vitales muy grandes (3.600 y 345 km^2 respectivamente), con distancias máximas recorridas diariamente de 192 y 205 km, respectivamente. Un individuo incluso se alejó del nido 102 km, aún con pollos en el nido. Estos valores son de los más grandes publicados para esta especie. Adicionalmente, recogimos datos de reproducción de la misma zona durante 30 años, y éstos muestran una productividad baja. Comparando los resultados, sugerimos que la calidad del hábitat es baja para la zona de estudio, forzando a los halcones a moverse grandes distancias con los potenciales costes asociados de aumentar la mortalidad adulta, que directamente impacta en la dinámica poblacional, y discutimos factores clave a considerar para la toma de acciones de conservación.

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