

Differential spatial use and spatial fidelity by breeders in Bonelli's Eagle (*Aquila fasciata*)

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Abstract In recent years, long-term studies based on movement monitoring tools have improved our knowledge about spatial ecology and home range behaviour of endangered species. In order to study individual spatial-temporal variations in size, use and fidelity of home ranges and other spatial parameters (kernel at different levels), and determine the influence of sex and different annual periods in these variations, 17 adult breeders (of both sexes) of an endangered territorial raptor, Bonelli's Eagle (*Aquila fasciata*), were equipped with GPS satellite transmitters and tracked over a 7-year period in Aragón (northeast Spain). The home range (kernel 95 %) of these eagles showed high individual variations as well as other spatial parameters (kernels 75, 50 and 5 %). No interannual variations for the same individual were found. Females changed home range size and use during the year, it being different in the breeding season. Home range fidelity was high for all individuals (overlap 76.18 %) over the three annual periods in all years. Nevertheless, fidelity to nesting areas was low (only 30 %) during the same periods. This work highlights

the importance of long-term monitoring studies to elicit information on home range behaviour for developing accurate conservation guidelines. Maintenance of home range size and fidelity across years assures that the adoption of any conservation management plan would have a lasting impact over time. In addition, protection zones should be increased to critical areas (kernel 75 %) and restriction of specific activities causing disturbance during the breeding season should be implemented.

Keywords *Aquila fasciata* · GPS satellite telemetry · Home range · Overlapping spatial parameters

Zusammenfassung

Raumnutzungsmuster und Reviertreue bei Brutvögeln des Habichtadlers (*Aquila fasciata*)

In den letzten Jahren haben Langzeitstudien unter Anwendung von Bewegungsmonitoring-Methoden unsere Kenntnisse zu Raumnutzungsmustern bedrohter Tierarten stark verbessert. In Aragón, Nordostspanien, wurden 17 adulte Brutvögel (beider Geschlechter) des planungsrelevanten, territorialen Habichtsadlers (*Aquila fasciata*) mit GPS Satellitensendern markiert und über einen Zeitraum von sieben Jahren verfolgt. Die Studie sollte individuelle Raumnutzungsmuster zeigen, bezüglich Aktionsraumgröße, Habitatnutzung, Reviertreue, sowie anderer Funktionsraumparameter (verschiedene Kernelniveaus). Der Einfluss des Geschlechts und verschiedener jahreszeitlicher Perioden wurden ebenfalls untersucht. Die Habichtsadlerreviere (Kernel 95 %) und andere räumliche Parameter hatten sehr unterschiedliche individuelle Größen, zeigten aber für dasselbe Individuum keine Unterschiede in verschiedenen Jahren. Nur die Weibchen

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veränderten ihr Raumnutzungsmuster im Jahresverlauf, wo sich die Brutzeit von den anderen Perioden unterschied. Alle Habichtsadler waren sehr reviertreu (Überschneidung 76 %) in den drei Jahresperioden und in allen Untersuchungsjahren. Allerdings war die Gebietstreue zum unmittelbaren Horststandort während der unterschiedlichen Jahresperioden gering (nur 30 %). Diese Arbeit belegt die Wichtigkeit von Langzeituntersuchungen zur Raumnutzung und ihre korrekte Anwendung bei Artenschutzrichtlinien. Die Reviertreue sowohl bezüglich der Reviergröße als auch bezüglich der Flächennutzung sichert, dass Schutzmaßnahmen langfristig greifen. Darüber hinaus sollten Schutzgebiete bis zu Tabuzonen (Kernel 75 %) ausgedehnt werden und keine störenden Aktivitäten während des Brutgeschäfts zugelassen werden.

Introduction

Home ranges are the spatial expressions of the behaviours that animals perform to survive and reproduce (Burt 1943). They are determined by a large number of single movement steps (Moorcroft and Lewis 2006), each of which results from the interactions among individual characteristics, individual states and the external environment, with fundamental consequences for ecological processes (Börger et al. 2008). Over the past few years, a new line of research has been opened in order to test the variations of home range behaviour (see review in Börger et al. 2008). However, long-term monitoring studies about the spatial-temporal variations of the size and shape of home ranges are still limited (e.g. Adams 2001; Börger et al. 2006). Long-term studies (Møller and Fiedler 2010) provide information about population dynamics, and may help identify conservation problems and suggest possible solutions. In addition, they are a useful tool to improve knowledge about home range behaviour and will play an important role in the conservation of long-lived territorial endangered species (Thomas 1996).

Recently, an increasing number of long-term studies about home range behaviour using telemetry devices have been published (Schradin et al. 2010; García-Ripollés et al. 2011; Hart et al. 2013). For example, studies of large raptors such as the Spanish Imperial Eagle (*Aquila adalberti*) (Fernández et al. 2009), Golden Eagle (*Aquila chrysaetos*) (Collopy and Edwards 1989; Marzluff et al. 1997) and Lesser Spotted Eagle (*Aquila pomarina*) (Meyburg et al. 2006) are having important applications in conservation.

Our research focuses on Bonelli's Eagle (*Aquila fasciata*), an endangered territorial raptor that has experienced a sharp population decline in Spain (Arroyo et al. 1995; Ontiveros 2010) and other European countries such as

Portugal, France (Hernández-Matías et al. 2013), and Italy (López-López et al. 2012). One of the most important causes of mortality is electrocution (Real et al. 2001), which is strongly related to the spatial ecology and land use of individuals. Therefore, home range behaviour studies are necessary when addressing conservation issues for this species.

Most studies about spatial ecology in Bonelli's Eagle have focused on juvenile habitat use (Mañosa et al. 1998; Balbontín 2005; Cadahía et al. 2005; Balbontín and Ferrer 2009) but have rarely dealt with breeding adults (Sanz et al. 2005; Bosch et al. 2009; Cabeza Arroyo and De la Cruz 2011; Pérez-García et al. 2012).

Satellite radio-tracking systems to analyse spatial-temporal variation of adult Bonelli's Eagle territories have only been used on a few breeding individuals (Cabeza Arroyo and De la Cruz 2011; Pérez-García et al. 2012), or the study is based on terrestrial radio-tracking data (Bosch et al. 2009). The latter provides useful information, but the accuracy of data is low compared to that obtained by modern systems of GPS satellite-tracking devices (Withey et al. 2001).

To our knowledge, this is the first investigation focusing on different spatial-temporal use and home range fidelity that includes large numbers of Bonelli's Eagle breeders of both sexes over a long time series of consecutive years using GPS satellite telemetry. We divided the year into three periods due to the biological cycle of the animals. The territorial behaviour of breeders can be influenced by several factors like the breeding stage, the quality/quantity of food and the dependence stage of recently fledged juveniles (Real et al. 1998). The latter has not yet been studied.

We specifically evaluated the spatial and temporal variation in home ranges, examining the differences among individuals, sexes, years and the three annual periods, because this information may provide powerful applications in conservation highly necessary for this endangered species, not only in the Aragón Region (catalogued in critical danger, D 326/2011) but also in Spain as a whole (catalogued vulnerable, RD 139/2011) and Europe (least concern, IUCN Red List, Annex I of EU Bird Directive and/or SPEC three classification according to Tucker and Heath 1994).

Methods

Study area

The study was conducted in the Aragón Region (Fig. 1), northeast Spain, over a 47,719-km² area which holds fewer than 30 Bonelli's Eagle breeding pairs representing 4 % of the entire Spanish population.

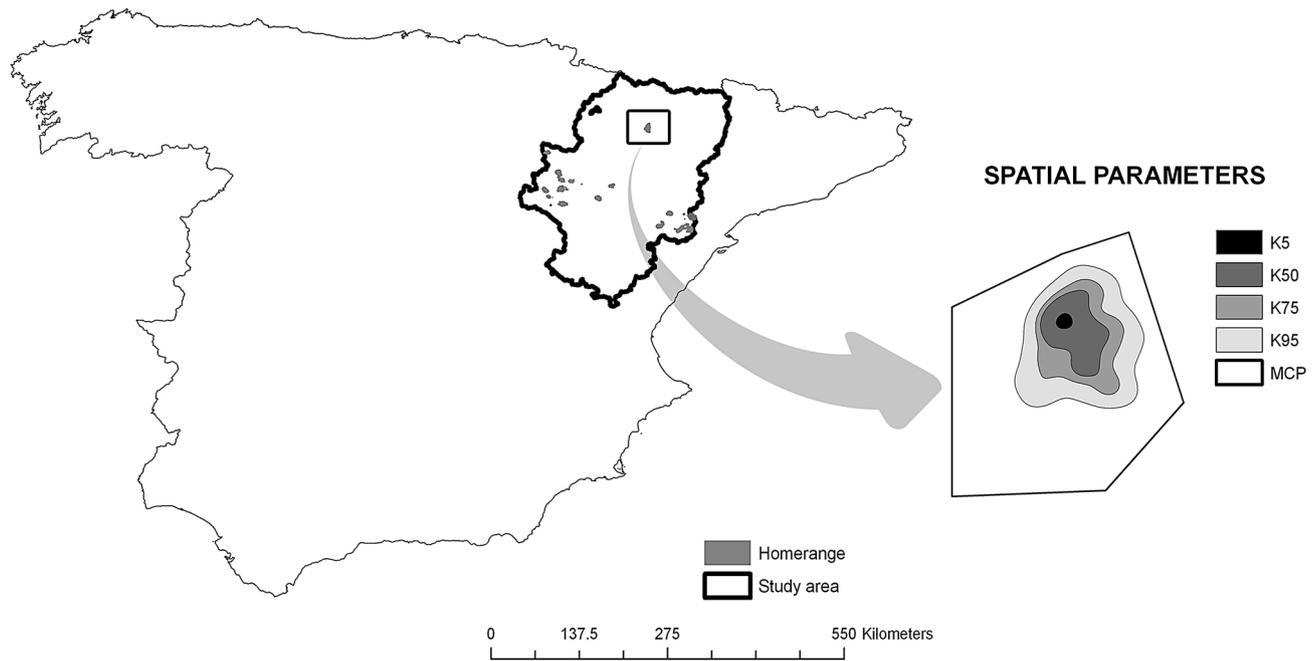


Fig. 1 Study area and spatial parameters for Bonelli's Eagle (*Aquila fasciata*): 5 % kernel (*K5*) nesting area, 50 % kernel (*K50*) core area, 75 % kernel (*K75*) critical area, 95 % kernel (*K95*) and minimum convex polygon (*MCP*)

Land cover consists mainly of coniferous forests, large areas of Mediterranean scrub, steppe areas or crops, and crags and cliffs as nesting substrates in mid-mountain areas (Sampietro et al. 1998).

Trapping and monitoring

During the years 2004–2011, 17 breeding Bonelli's Eagles (10 males, 7 females) were trapped in Aragón. The eagles were trapped by a radio-controlled bow-net trap; all individuals were ringed with a metal ring and were equipped with a 45-g Argos/GPS PTTs (Microwave Telemetry, MD, USA). Transmitters were powered with solar panels and fixed to the birds as backpacks by a Teflon harness with a central ventral rupture point (Garcelon 1985). The weight of the transmitters only represented 2.25 % of total body weight (Kenward 2001). PTTs were programmed to work between 0600 and 2100 hours. A total number of 48,000 locations from the 17 individuals were obtained (see supplementary material).

Spatial parameters and home range analysis

The spatial parameters and home ranges were estimated using Hawth's tools (Beyer 2004) in ArcGIS 9.3 (ESRI, Redlands, CA, USA). Fixed kernel methods (Worton 1989) with a default smoothing factor (1) were used (Bosch et al. 2009; Fernández et al. 2009). Isopleths 5 % (*K5*) and isopleths 50 % (*K50*) were designated as the nesting and

core areas, respectively (Samuel et al. 1985). Isopleths 75 % (*K75*) were calculated as the actively selected areas for hunting or roosting (critical areas) (Bosch et al. 2009), and isopleths 95 % (*K95*) were defined as an estimate of the total home range (Seaman and Powell 1996; Kenward 2001; Laver and Kelly 2008). Minimum convex polygon (*MCP* 100 %) was defined as the maximum area used by individuals, which was calculated with all valid locations including outermost locations. Home range sizes were constructed using only diurnal locations. To avoid bias towards roosting areas, consecutively repeated locations in the early morning and late evening of inactive eagles were excluded because they were considered to be non-independent (Swihard and Slade 1985; Seaman and Powell 1996; Kenward 2001).

For the temporal variation analysis, we divided the year into three periods related to the biological cycle of the species (Arroyo et al. 1995). Period 1 was defined as the non-breeding season (NBr), from September 1 to February 14, when breeding individuals are less tied to their nesting area and accomplish long-distance movements (Newton 1979). In period 2, or the breeding season (Br) (from February 15 to June 14), both parents invest in clutches but females spend most of the time in the nest, and in general parents' movements are restricted (Ontiveros 2010). During period 3, or the post-fledging dependence period (Pfdp), between June 15 to August 31, parents continue to feed fledglings near their nesting areas until the juveniles leave the territories where they were born and disperse (Real et al. 1998).

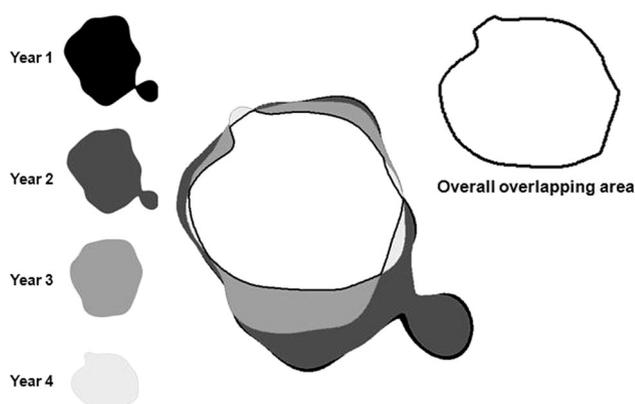


Fig. 2 Example of overlapping areas for one individual over a 4-year period

Home range fidelity analysis

We used the Kernel overlap function in the Adehabitat HR package for R (Calenge 2006) to assess the degree of overlap over consecutive years and home range fidelity (range of 2–4 years depending on the individual tracked) in eight individuals (four males and four females) that had been tracked for more than 2 years. The index selected to estimate the home range overlap was the result of the intersection statistic index (VI) (Fieberg and Kochanny 2005). The VI index provides a measure of overlap that is a function of the full home range in different seasons. VI index ranged between zero (no overlap) and one (complete overlap).

Due to methodological limitations, the overlapping area for other spatial parameters (K5 and K50) was calculated as the percentage of any of the spatial parameters on an annual basis related to the maximum area that was used over all tracking years for each individual. To calculate the maximum area the Data Management module in ArcGIS 9.3 (ESRI) was used; merged polygons were obtained for each spatial parameter and the dissolve function was used in such a way that duplicate values were deleted in overlapping areas to avoid overestimation of the area. To identify the degree of overlap, we calculated the percentage of area fidelity on a yearly basis (Fig. 2). The spatial parameter K75 was not included in the analysis because these areas are randomly used by breeders and may change (Bosch et al. 2009).

Overlapping seasonal variation was determined in all of the three periods defined above.

Statistical analysis

General linear mixed models (GLMM) in SAS statistical software (SAS Institute, Cary, NC, USA) were conducted

to analyse variations in home range according to individuals, sexes, years and annual periods. K5, K50, K75, K95 and MCP were used as response variables in all models and they were checked for normality (Kolmogorov–Smirnov, all $p > 0.05$).

Individual variations in home range behaviour were checked. The identity of individuals was considered as a fixed factor and year was included as a random factor. We studied differences between sex in home range using year and identity of the individual as random factors and sex as a fixed factor. To test annual variations in home range, we used year as a fixed factor and the identity of the individual as a random factor. In addition, we studied variation among annual periods using year and identity of the individual as random factors and period and sex as fixed factors.

Home range fidelity by individuals was tested by Chi square analysis for all spatial parameters. In order to check differences between sexes, we used general linear models (GLM) in all periods for all spatial parameters. Sex was used as a fixed factor and year as a random factor.

The statistical significance of differences between categories of the same variable was computed using the LSMEANS statement of SAS. Degrees of freedom were calculated following the Satterthwaite method.

Results

Individual and sex size variations of home range

We found significant differences in all spatial parameters for all individuals (all $p < 0.001$).

There were significant differences when we compared males and females in all spatial parameters (Table 1).

The graphical representation shows that kernel areas are of irregular shape and the nesting area is often placed at one side of the total home range (Fig. 1). MCP is more than double the size of K95 (Table 1).

Temporal and interannual size variations of home range

Significant differences were found between the three annual periods in home range behaviour (K5: $F_{2,93} = 10.14$, $p = 0.0001$; K50: $F_{2,93} = 8.82$, $p = 0.0003$; K75: $F_{2,93} = 7.88$, $p = 0.0007$; K95: $F_{2,93} = 3.67$, $p = 0.029$) but not for MCP ($p > 0.05$), with all areas being smaller during the breeding season (LSMEANS, NBr and Pfdp > Br). When sex was included in the analysis, only females showed significant differences among periods for all spatial parameters (K5: $F_{2,39} = 11.03$, $p = 0.002$; K50: $F_{2,39} = 11.60$, $p = 0.0001$; K75: $F_{2,39} = 11.42$, $p = 0.0001$; K95: $F_{2,39} = 9.79$, $p = 0.0004$; MCP: $F_{2,39} = 3.28$,

Table 1 Mean values (km²) and ranges (min–max) of sizes of all spatial parameters for Bonelli’s Eagle (*Aquila fasciata*)

	K5	K50	K75	K95	MCP
♂ (<i>n</i> = 10)	0.47 (0.23–0.89)	8.45 (3.57–21.27)	20.09 (7.99–60.16)	55.05 (23.48–152.24)	149.26 (26.97–563.45)
♀ (<i>n</i> = 7)	0.53 (0.20–0.98)	10.11 (3.37–20.49)	23.76 (8.32–43.78)	59.44 (24.95–101.55)	109.09 (27.18–414.98)
Total (<i>n</i> = 17)	0.5 (0.20–0.98)	9.28 (3.37–21.27)	21.93 (7.99–60.16)	57.25 (23.48–152.24)	131.22 (26.97–563.45)
♂ (<i>n</i> = 10)	7.07	6.66	6.62	6.29	4.16
<i>F</i> _{9,48}					
♀ (<i>n</i> = 7)	5.80	6.01	7.20	5.80	5.19
<i>F</i> _{6,41}					
Total (<i>n</i> = 17)	6.04	6.24	6.86	6.45	4.82
<i>F</i> _{16,95}					

F values of statistical differences (all *p* < 0.001) between the total of individuals and sexes for the designated spatial parameters

n Sample size, *F* degrees of freedom and number of cases are listed in the first column

p = 0.0481), with areas being smaller during the breeding season (LSMEANS, NBr and Pfdp > Br) (Fig. 3).

We did not find differences in home range sizes or other spatial parameters between years for all individuals (all *p* > 0.05).

Home range fidelity

In general, home range fidelity showed stable patterns for periods and sexes. The degree of overlap for home range was 76.18 % in all periods during the study and similar between males and females (Table 2).

Core area fidelity was different between periods. More than 70 % of the core area was regularly used during the non-breeding season (Table 2). However, these values were smaller during the breeding season (mean: 58.60 %, range: 36.15–87.29 %) and during fledgling dependence

(mean: 59.29 %, range: 41.01–80.27 %). We found a difference between males and females during breeding season (*F*_{1,18} = 8.0152, *p* = 0.011457). The degree of overlap in this period was higher in males than females.

Only 32.13 % of the nesting area was regularly used during all monitored seasons. Fidelity to the nesting area differed between individuals and periods, and was even non-existent in some periods for some individuals (Table 2). We found sex differences during the non-breeding season (*F*_{1,18} = 11.64350, *p* = 0.002777), fidelity being higher in males than females.

Discussion

Our findings show the importance of long-term studies on movement ecology of endangered raptors like the Bonelli’s Eagle. This allowed us to reveal that, although every individual has a different-sized home range, they show great home range fidelity, maintaining that size over time. Individuals make differential land use depending on the season. Females reduce the size of home ranges and other spatial parameters in the breeding season due to the presence of eggs and chicks in the nest. This is In contrast to the fidelity to nesting areas, which changes depending on the time of the year.

Spatial patterns such as MCP or fixed kernel estimation are commonly used to calculate and characterise home range behaviour (Börger et al. 2006). Many studies have used MCP for estimating the size of home ranges, but this method overestimates the areas that are used by the individuals and often makes inadequate biological assumptions such as a convex form of the home range determined only by the positions of the outermost locations (Worton 1995) (see Fig. 1). Therefore, the use of MCP, which includes long and peripheral movements, should be improved by the use of kernel fixed models (Worton 1989). Kernel

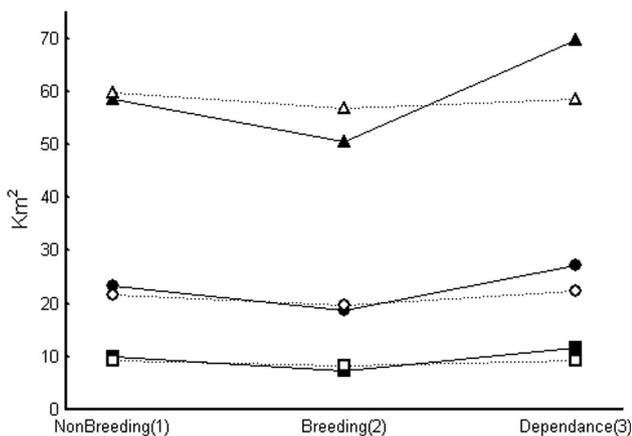


Fig. 3 Mean values for spatial parameters in males (*n* = 10) (open symbols) and females (*n* = 7) (solid symbols) in three periods over all years of study. Squares correspond to the size of core areas (K50), circles to the size of actively selected areas (K75) and triangles are total home range size (K95)

Table 2 Overlapping percentage for the three designated periods over the study period

Sex	Years	K95			K50			K5		
		NBr	Br	Pfdp	NBr	Br	Pfdp	NBr	Br	Pfdp
♂	4	78.15	73.24	74.18	73.82	71	74.8	0	57.71	30.15
♂	3	80.26	82.58	77.77	85.65	75.87	80.27	47.17	54.92	24.84
♂	2	79.17	71.79	75.58	82.47	53.24	59.22	50.77	3.24	0
♂	3	79.28	66.99	77.54	61.08	44.41	41.01	64.06	54.81	0
♀	4	77.96	68.31	82.24	79.51	40.22	61.27	4.16	0	0
♀	4	77.62	77.99	72.23	63.86	60.65	48.6	18.51	17.83	36.73
♀	2	78.28	64.66	80.94	66.47	36.15	47.13	76.52	40.90	58.89
♀	3	80.33	81.83	69.43	77.38	87.29	62.03	39.13	74.99	15.74
Mean males		79.22	73.65	76.27	75.75	61.13	63.82	40.50	42.67	13.75
Mean females		78.55	73.20	76.21	71.81	56.08	54.76	34.58	33.43	27.84
Mean total		78.88	73.42	76.24	73.78	58.60	59.29	37.54	38.05	20.79
Mean all periods			76.18			63.89			32.13	

Mean values for each period and all periods are listed at the bottom of the table

Percentages in bold show statistical differences (Chi square test, $p < 0.05$) in overlapping for that particular individual over the years of study

estimators provide a better estimation and a more realistic view of the size and shape of the home range (Börger et al. 2006). In addition, the large and precise number of locations (48,000) obtained by GPS satellite telemetry and long-term monitoring over years shows the real area used. Our results highlight the differences between the two methods of analysis. The mean MCP would have been more than double the size of K95.

We obtained an average home range size of Bonelli's Eagles in Aragón (based on kernel estimation, $K95 = 57.25 \text{ km}^2$), with higher values than those obtained in other studies with terrestrial radio tracking in other regions of the Iberian Peninsula such as Catalonia (36.1 km^2 , range: $33.4\text{--}110.7 \text{ km}^2$; Bosch et al. 2009) or Valencia (30.5 km^2 , range: $15.82\text{--}44.48 \text{ km}^2$; Sanz et al. 2005). These differences could be due to the fact that GPS satellite telemetry provides more accurate information than that obtained in radio tracking studies. Pérez-García et al. (2012) found home range sizes of around 44.4 km^2 (range: $31.8\text{--}91.9 \text{ km}^2$) in GPS-tracked Bonelli's Eagle in the Valencia-Tarragona area. This is in line with those described for large raptors such as Spanish Imperial Eagle (range: $2.06\text{--}139.19 \text{ km}^2$; Fernández et al. 2009) and Golden Eagle (32.76 km^2 , range: $11.61\text{--}48.98 \text{ km}^2$, Collopy and Edwards 1989; 30.48 km^2 , Marzluff et al. 1997) using conventional tracking methods, and Lesser Spotted Eagle (41.92 km^2 ; Meyburg et al. 2006) using GPS satellite telemetry. Despite differing methodologies, these values agree with those obtained in our study.

Individuals showed different home range size and shape as well as other spatial parameters. This difference may be influenced by several ecological and environmental factors. Suitable habitats with favourable areas for nesting or

hunting are very important in territorial species (Newton 1979). The presence of food resources and variation of prey abundances between areas will shape this variation. Besides this, the presence or absence of other species (like Golden Eagle or Griffon Vulture in the case of Aragón) that could compete for nesting sites and hunting areas may determine the selection of each individual territory (Martínez et al. 1994; Ontiveros and Pleguezuelos 2000; Gil-Sánchez et al. 2004). Individual performance (i.e. ability to find food or territorial defence; Ontiveros et al. 2005) also plays a major role in such a selection process. Man-built infrastructure like roads, and major infrastructure such as wind farms and high-speed railroad lines, can also determine the size and shape of territories. In addition, all of the above can show variation related to the period of the year (Bosch et al. 2009).

We found differences in home range size as well as other spatial parameters in relation to the period of the year. Börger et al. (2008) noted that one of the factors influencing the establishment of territories is the physical and physiological state of the individual. In our study, females showed smaller sizes in their spatial parameters during the reproduction period. They decreased their activity due to the presence of eggs or chicks in the nest (Arroyo et al. 1995), restricting their movements and focusing on reproduction, remaining closer to the nest and making shorter flights in the search for food (Bosch et al. 2009), which is a common behaviour in other raptors (Marzluff et al. 1997; Haworth et al. 2006). However, no differences were found in males. This could indicate that, despite the fact that they also decrease their activity during the breeding season, they are still more active than females. The male's role is usually restricted to the custody of the

nest and food supply (Newton 1979). In relation to food supply, Ontiveros and Pleguezuelos (2000) described how successful breeding of the species is not related to the abundance of their main prey, rabbits and pigeons (Martínez et al. 1994; Gil-Sánchez et al. 2004), but more so to the presence or detectability of alternative prey (Ontiveros et al. 2005). In our case, it is likely that males require the use of the entire home range to find food to feed the females and chicks. Thus, home range does not shrink in the breeding season and does not vary from the rest of the annual cycle.

There were no interannual variations for the same individual. Individuals also showed great fidelity to their home range over consecutive years. Home range fidelity is not a frequently evaluated topic in birds of prey. In contrast to the results described by Pérez-García et al. (2012) for Bonelli's Eagle in Valencia and Tarragona, which showed only a 30 % overlap, our results show a greater overlap, of about 76.18 % (Table 2), similar to that described in other species of raptor such as the Spanish Imperial Eagle (75 %; Fernández et al. 2009) and fidelity in the Golden Eagle (60 %; Marzluff et al. 1997). As for home range size, the degree of overlap could be determined by the availability of food resources and suitable nesting areas. The high degree of overlap in core areas could indicate that the availability of food is not a limiting factor for home ranges in Aragón. The high trophic plasticity described by Ontiveros and Pleguezuelos (2000) for Bonelli's Eagle enables them to establish a specific territory size and to maintain it over time in order to obtain all necessary resources. On the other hand, in Aragón, it does not seem to influence partner replacement after the death of one individual, or reproductive success in maintaining the territory (authors' unpublished data). Although females have a lower degree of overlap in the core area in the breeding season, this is related to decreased activity by the female in the period associated with breeding.

However, fidelity to nesting areas is low (Table 2). Several raptors have different nests within their territories that they may occupy in different years (Newton 1979). In Aragón, nest competition with Griffon Vultures is quite strong. Starting their breeding season early, the vultures occupy Bonelli's Eagle platforms before they begin reproduction. In addition, breeding failure or the death of one of the breeders could lead to a change in the nest in subsequent years (Ontiveros and Pleguezuelos 2000). Alternative nests also help mitigate the presence of ectoparasites (Ontiveros et al. 2008).

Our results provide compelling information with very important implications for conservation management. An essential measure is the conservation and protection of the home range, but some conservation programs only protect known nesting areas (Ontiveros 2010). In addition, many

conservation programs have recommended buffer protection. This is usually designated as a 5-km circle around nest areas because there is insufficient information about spatial-temporal variations of individuals. In Aragón, the breeding Bonelli's Eagles showed strong individual variations in home range size and shape as well as in core and nesting areas. Therefore, establishing identical protection areas for all individuals is an inadequate measure that does not guarantee full protection because it may leave important areas unprotected or may waste resources on protecting areas that are not used by individuals.

Moreover, our results show that Bonelli's Eagle not only maintains home range sizes and core areas between years but they also have a high degree of home range fidelity. We believe it is indispensable to extend certain protection measures to the total home range size, including correction of power lines, which are responsible for the highest number of deaths. We consider that the minimum area of protection must include not only the nesting areas but also all other areas chiefly used for hunting and roosting. We propose these areas to be limited by the K75 areas. Furthermore, some conservation measures such as restricting climbing, hunting and other outdoor activities should be carried out throughout the year, becoming more restrictive during the breeding season when individuals, especially females, are more vulnerable to human disturbance.

The fidelity to home range implies that conservation actions like correcting power lines or restricting infrastructure would have a lasting impact over time. Other factors such as habitat preference and food availability may determine fidelity to home ranges for this species and should also be addressed in the future. In addition, sound habitat management may assure the long-term persistence of this species in Aragón, Spain, and, therefore, in Europe.

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