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Satellite telemetry reveals individual variation in juvenile Bonelli's eagle dispersal areas

Luis Cadahía · Pascual López-López · Vicente Urios · Juan José Negro

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Abstract Natal dispersal is the time elapsed between departing from the natal site and settling to attempt breeding for the first time. In long-lived species with deferred sexual maturity this period may last several years, making this process crucial for their survival and conservation. Here we present a large-scale outline of juvenile Bonelli's eagle's dispersal areas in the Iberian Peninsula. We describe the ranging and movement patterns of 14 juvenile Bonelli's eagles during their dispersal period, studied by satellite telemetry. Three distinct phases during the juveniles' first year of life were detected, namely, the dependence period, the departure from the parental territory, and the settlement in dispersal areas. In general, between-sex differences in relation to ranging behavior

were not significant. Interestingly, there seems not to be a few, clearly delimited, overlapping Bonelli's eagle's juvenile dispersal areas within the Iberian Peninsula. A total of 17 dispersal areas were detected, with some animals using more than one. These areas were located in eight autonomous communities (Spanish administrative units), being the most important Castilla-La Mancha and Andalucía. Juveniles were more frequently located in cultivated man-managed areas, with non-irrigated herbaceous crops. This is probably due to higher prey availability and higher efficiency in prey capture in these open areas, as well as to the absence of breeding pairs. This has important management implications, suggesting that conservation efforts should focus on the whole landscape matrix of man-managed ecosystems rather than in a few clearly delimited geographic areas.

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L. Cadahía
Centre for Ecological and Evolutionary Synthesis (CEES),
Department of Biology, University of Oslo,
P.O. Box 1066 Blindern,
0316 Oslo, Norway

P. López-López (✉)
Cavanilles Institute of Biodiversity and Evolutionary Biology,
Terrestrial Vertebrates Group, University of Valencia,
Polígono de la Coma s/n,
46980 Paterna, Valencia, Spain
e-mail: Pascual.Lopez@uv.es

V. Urios
Grupo de Zoología de Vertebrados, University of Alicante,
Apdo. correos 99,
03080 Alicante, Spain

J. J. Negro
Evolutionary Ecology Department,
Estación Biológica de Doñana, CSIC,
C/Americo Vespucio s/n. Isla de la Cartuja,
41092 Sevilla, Spain

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Introduction

Dispersal is an ecological process with important implications in spatial population structure, survival, and gene flow among populations (Clobert et al. 2001; Bullock et al. 2002), hence affecting persistence, evolution, and conservation of species (Clobert et al. 2001; Bullock et al. 2002). The ecological and evolutionary aspects of dispersal are directly linked with the processes of 'natal dispersal' (movement between the birthplace and the first breeding site) and 'breeding dispersal' (movement between successive breeding sites; Greenwood and Harvey 1982), which are the ones that involve flow of individuals and genes

among different areas and populations. The time elapsed between departure from the natal site and settling to attempt breeding for the first time may last several years in long-lived species with deferred sexual maturity. This makes the fate of dispersing individuals during this time crucial, since whether or not animals complete successfully the natal dispersal period and transmit their genes to the next generation will importantly affect the maintenance of the species in the long-term.

Bonelli's eagle *Aquila fasciata* (Accipitridae, Falconiformes) reaches sexual maturity at 3–4 years (Cramp and Simmons 1980). This bird of prey is catalogued as “Least Concern” in Europe (BirdLife International 2009) and as “Endangered” in Spain (Real 2004), where the main fraction of the population from the Western Palearctic dwells. Studying dispersal in this species has been traditionally difficult, basically owing to the long movements that juveniles perform. Studies have relied on the use of rings and wing-tags (Cheylan et al. 1996; Real and Mañosa 2001; Hernández-Matías et al. 2010) or conventional radio-tracking (Balbontín and Ferrer 2009). However, there is no clear picture of where juveniles from different areas of the distribution range stay during their juvenile dispersal period until they are recruited into the breeding population.

Bonelli's eagle nestlings fledge at an approximate age of 60 days (Real et al. 1998; Mínguez et al. 2001) and spend several weeks in the nest surroundings until they leave the parental territory (Real et al. 1998; Mínguez et al. 2001; Balbontín 2003; Cadahía et al. 2005, 2007). Previous studies based on direct observations and radio-tracking data have shown that juvenile Bonelli's eagles perform long-distance movements and settle in the so-called dispersal areas. These areas are characterized by high prey abundance, mainly rabbits and pigeons, where juveniles settle during long-time periods before recruitment into the breeding population, sometimes shared with juveniles of other raptor species such as Golden eagle *Aquila chrysaetos* and Spanish Imperial eagle *Aquila adalberti* (Cheylan et al. 1996; Real and Mañosa 2001; Balbontín 2003; Cadahía et al. 2005, 2007; Balbontín and Ferrer 2009; Moleón et al. 2009a). However, dispersal areas hold several threats that directly affect birds' survival, mainly direct persecution, bird electrocution in dangerous poles of power lines, and poisoning in extensive game reserves (Real et al. 2001; Real 2004; Cadahía et al. 2005). This has become especially important after the rabbit viral hemorrhagic disease and myxomatosis outbreaks, which have led to the confinement of Bonelli's eagle to areas with a relatively high level of human influence, hence increasing juvenile's mortality risk (Moleón et al. 2009a). For this reason, the accurate delineation of these areas is of paramount importance in order to establish adequate management

actions aimed at ensuring the long-term persistence of the species in Spain.

Herein we describe the movement and ranging patterns of 14 Bonelli's eagles during juvenile dispersal in Spain, using continuous, long-term satellite tracking data. The main goals of this work are to explore the distancing pattern from the natal areas, and to outline and describe the dispersal areas, discussing the implications for the conservation of this endangered species.

Methods

Between 2002 and 2004, we tagged 14 Bonelli's eagle juveniles, 12 nestlings and two recent fledglings, with satellite transmitters (hereafter PTTs—platform transmitter terminals) in eastern Spain (autonomous communities of Catalonia, Valencian Community, and Murcia, encompassing a latitudinal range between 41°18'05" N to 37°36'26" N; Fig. 1). All nests were located in rocky cliffs, except for one on a pine tree, surrounded by Mediterranean scrubland. All birds were weighed, measured, and fitted with PTTs using a Teflon harness (Kenward 2001). Birds' gender was established by molecular techniques using a blood sample (Fridolfsson and Ellegren 1999).

Three types of PTTs were used: five 30-g battery powered Argos/PTT-100s, seven 35-g solar powered Argos/PTT-100s, and two 45-g Argos/GPS PTT-100s, manufactured by Microwave Telemetry, Inc. (www.microwavetelemetry.com). Combined Argos/GPS transmitters permit birds to be tracked by the Argos and the GPS systems simultaneously, whereas for the other transmitters information was provided by the Argos system. Transmitters were set to an 8-h on/120-h off duty cycle, except for the two Argos/GPS PTTs, which were set to 16-h on/72-h off. Transmitter weight never exceeded 3% of the birds' body mass ($2.1 \pm 0.5\%$ SD; $n=14$; range, 1.3–3.0%), as recommended by Kenward (2001). To determine best time for tagging (ca. 50 days old), nestlings' age was estimated based on feather and plumage pattern using a spotting telescope (Gil-Sánchez 2000). When actually handling the birds, we estimated age more precisely as $\text{age} = 0.200 \times \text{tail length (mm)} + 16.262$ (Mañosa et al. 1995).

Locations' initial management was made by Argos, a satellite-based location reception and data collection system. A satellites network collects PTTs' data and relays them to ground processing stations (Argos 2008). Argos/PTTs positions are computed based on measuring the Doppler shift (for a detailed description see Kenward 2001 and Argos 2008). This system provides seven location classes (LCs) that reflect the nominal accuracy of each data. These LCs are necessary because several factors, either intrinsic or external to the PTT, may affect locations

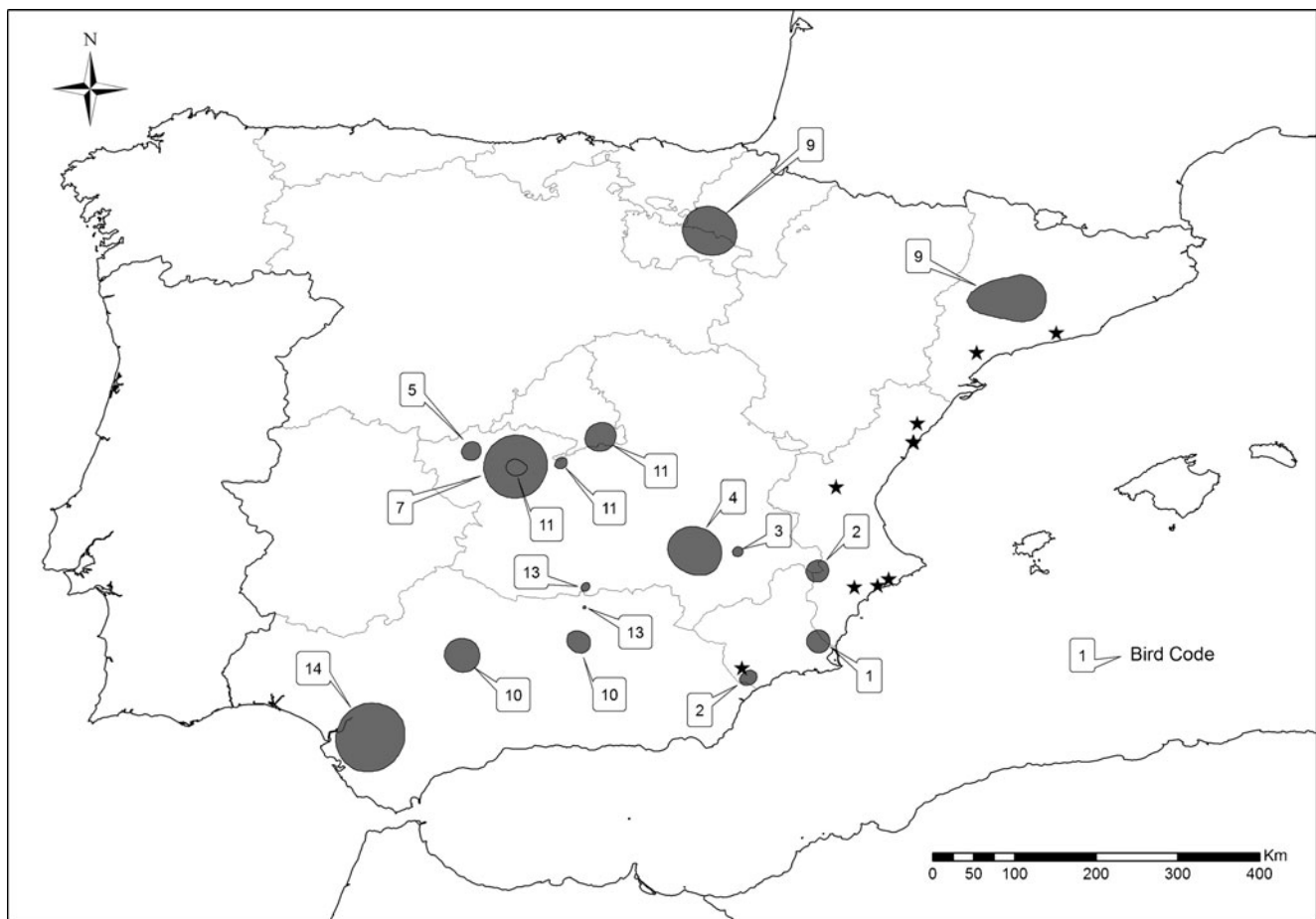


Fig. 1 Location of Bonelli's eagle juveniles' dispersal areas in Spain. Natal nests are represented by a *star*. Note that some birds used up to three distinct dispersal areas during natal dispersal

accuracy (thoroughly discussed in Kenward 2001; Soutullo et al. 2007; Argos 2008). In this study, we used LCs 3, 2, and 1, with nominal accuracy <250, 250–500, and 500–1,500 m, respectively (Argos 2008). We also included locations of lower quality (LC 0, A, and B), but filtered them using available information on eagles' movements, based on comparisons with high-quality GPS data and on Argos accuracy tests (Cadahía et al. 2007; Soutullo et al. 2007). To avoid bias connected with spatial and temporal autocorrelation, we computed the harmonic means of all the locations collected on each given day (Dixon and Chapman 1980; Kenward 2001) and used them for subsequent calculations.

The onset of dispersal was considered to occur when birds flew beyond the average inter-nest distance (11.4 km) and did not return within that distance in the following two locations, as described in Cadahía et al. (2008). To study the distancing pattern at the onset of dispersal, the first year of life was divided into 30-day long months and monthly distance to natal nest was computed as the mean of all distances within a given month (Soutullo et al. 2006). For each bird, we

recorded date and age at the onset of dispersal and estimated home ranges using kernel contours (Worton 1989; Kenward 2001) optimized by a least square cross validation procedure (Kenward 2001; Kenward et al. 2001). We considered as total area the surface enclosed within a 95% kernel of the whole-transmitting-period collected locations. Dispersal areas' size was estimated with the 'Animal Movement SA v 2.04' extension for ArcView 3.2 (Hooge and Eichenlaub 1997). For dispersal areas estimation, we used a 25% kernel computed after departure from natal areas. We used this figure in particular because hourly and daily distances covered within and outside the so estimated areas were observed to be significantly different (Cadahía et al. 2007), enabling distinction between exploratory movements and settlements in dispersal areas (Ferrer 2001). In those individuals with more than one dispersal area, we considered the pooled size of all of them for calculations. We computed the gravity center of dispersal areas as the harmonic mean of all the locations contained within each area (Dixon and Chapman 1980; Kenward et al. 2001) and measured the distance between this point and the natal nest in each case. In

birds with more than one dispersal area, we estimated this distance using the area where they stayed longer. The number of autonomous communities (Spanish administrative units) with part of their territory within a dispersal area was also registered.

We used a Kruskal–Wallis test to search for differences among monthly distances to natal nests during the first year of life and a Games–Howell test (Zar 1999) to perform monthly pairwise comparisons. The Mann–Whitney test was used to test between-sex differences in date and age at dispersal, differences in maximum distance reached during the whole transmitting period, size of total ranges and number, and size and distance to natal nests of dispersal areas.

To explore whether juveniles spent more time in certain types of habitat than expected by chance, the Global Land-cover Map 2000 (Pekel et al. 2003) was used to roughly characterize dispersal area in terms of soil coverage. This GIS coverage includes 18 different habitat types, varying from forests, scrublands, cultivated areas, wetlands, grasslands, water bodies, and urban areas (for a detailed description see Pekel et al. 2003). We used the ‘Animal Movement SA v 2.04’ extension to select 50 points randomly distributed within the dispersal areas and then the ‘Get grid value’ extension to assign a land-use class both to these random points and to the telemetry locations. We only used the highest quality location classes (LC 3, 2, and 1) for this analysis. To search for between-individuals differences in the habitat of their dispersal areas, we compared the frequency of random points in each type of coverage using contingency tables (Soutullo et al. 2008b). To find out whether birds preferably selected particular habitat types (within-individuals differences), we compared the frequency of each type of coverage in each group of points, i.e., locations and random points, using a χ^2 test for each individual. All statistical analyses were performed with SPSS ver. 13.0. Significance level was established at $p < 0.05$.

Results

Birds were tracked during the period 2002–2006 (Table 1). The end of transmission occurred during the dispersal stage in all birds but one, which was recruited into the breeding population when it was 4 years old (Cadahía et al. 2009). In relation to sex, females tended to disperse younger (age at dispersal: Mann–Whitney, $U=4.000$, $Z=-2.160$, $p=0.034$) but not earlier than males (dispersal date: Mann–Whitney, $U=12.000$, $Z=-0.926$, $p=0.414$; Fig. 2, Table 2). Monthly distance varied throughout the first year of life (Kruskal–Wallis, $H=58.308$, $df=9$, $p < 0.001$). Three distinct phases were observed (Games–Howell, $p > 0.069$ in groups of similar months): an initial stage of restricted movements around the nest during the third and fourth months of life

(the “dependence period”), followed by a rapid increase in distance to the nest (including the “onset of dispersal”), and a settling from the seventh month onwards. The onset of dispersal, that happened suddenly and in short time, occurred between the fifth and sixth month in females and in the sixth month in males (Fig. 2).

Considering the whole transmitting period, maximum distance to natal nests ranged between 90 and 663 km (after excluding birds no. 6, 8, and 12 for which only a few locations after the onset of dispersal were recorded) and did not differ between sexes (Mann–Whitney, $U=17.500$, $Z=-0.077$, $p=0.940$), similar to the total range size covered by juveniles (Mann–Whitney, $U=8.000$, $Z=-1.543$, $p=0.148$; Table 2). Dispersal areas’ size and their distance to natal nests did not differ between sexes either (size: Mann–Whitney, $U=7.000$, $Z=-1.697$, $p=0.106$; distance: Mann–Whitney, $U=17.000$, $Z=-0.154$, $p=0.940$; Table 2). Dispersal areas encompassed land from eight autonomous communities, mainly Castilla-La Mancha and Andalucía (Fig. 1, Table 1). Interestingly, only birds 7 and 11 overlapped their dispersal areas, at least partially, while the others remained geographically separated (Fig. 1).

Overall, ten land-use classes were present in the dispersal areas, and significant differences were found among juveniles regarding the habitat composition of these areas ($\chi_{90}^2=65.336$, $p=0.002$). In most of them, the habitat class “cultivated and managed areas with non-irrigated herbaceous crops” was most abundant, whereas others showed a more heterogeneous mixture of habitats. By individual, in all birds but two (bird 4: $\chi_4^2=11.649$, $p=0.02$; bird 9: $\chi_8^2=180.506$, $p < 0.001$), there were no differences between the frequency of satellite locations in the assortment of land-use classes and the proportion of these habitats observed within the dispersal areas (remaining individuals $p > 0.115$). Thus, juveniles were found more frequently in the most abundant type of habitat, i.e., “cultivated and managed areas, with non-irrigated herbaceous crops”, and, secondarily, in “cultivated and managed areas with irrigated herbaceous crops” and in “closed scrubland”. The two birds with significant differences were also found more frequently in these two types of land-use classes, although their dispersal areas showed a more heterogeneous habitat. In fact, no differences among individuals were found regarding the frequency of locations in the different land-use classes within their dispersal areas ($\chi_{90}^2=39.949$, $p=0.158$).

Discussion

The juvenile dispersal period has remained one of the most unknown stages of the Bonelli’s eagle’s life cycle so far, mainly because of the long-distance movements these birds

Table 1 Summary data of 14 juvenile Bonelli's eagles studied by satellite telemetry in Spain

Bird	Type of PTT	Origin	No. locations	No. filtered locations	Tagging date	Signal end	Transmitting time (days)	No. dispersal areas	Autonomous communities including dispersal areas
1	Solar	Murcia	115	63	22/04/2002	01/12/2002	223	1	Murcia, Comunidad Valenciana
2	Solar	Valencia	701	394	26/04/2002	12/06/2006	1,508	2	Comunidad Valenciana, Castilla-La Mancha, Murcia, Andalucía
3	Solar	Alicante	300	148	08/05/2002	14/01/2005	982	1	Castilla-La Mancha
4	Battery	Alicante	144	64	08/05/2002	13/07/2003	431	1	Castilla-La Mancha
5	Solar	Castellón	665	459	09/05/2002	04/03/2006	1,395	1	Castilla-La Mancha
6	Battery	Castellón	17	10	09/05/2002	31/12/2002	236	–	–
7	Battery	Barcelona	139	85	20/05/2002	23/11/2003	552	1	Castilla-La Mancha
8	Solar	Alicante	25	15	30/04/2003	26/08/2003	118	–	–
9	GPS	Castellón	885	876	14/05/2004	21/02/2005	283	2	La Rioja, Navarra, Cataluña
10	GPS	Castellón	576	576	17/05/2004	13/11/2004	180	2	Andalucía
11	Solar	Tarragona	248	160	11/06/2004	09/04/2006	667	3	Madrid, Castilla-La Mancha
12	Solar	Tarragona	45	29	11/06/2004	20/09/2004	101	–	–
13	Battery	Alicante	125	85	11/08/2004	18/02/2005	191	2	Castilla-La Mancha, Andalucía
14	Battery	Alicante	120	67	11/08/2004	17/04/2005	249	1	Andalucía

No. number

perform during this period. At present, the only available data came from traditional ringing, wing-tags, and radio-tracking methods (e.g., Cheylan et al. 1996; Real and Mañosa 2001; Balbontín and Ferrer 2009; Hernández-Matías et al. 2010). However, although necessary when no other information is available, these methods usually provide few data (with some exceptions, e.g., Hernández-Matías et al. 2010), are highly time consuming and may not be effective at gathering good-quality information about eagles' movements, given the potential bias due to birds' movements outside surveyed areas and the limited accuracy of data that can be obtained. As an alternative, satellite telemetry allows continuous tracking of the individuals, regardless of their ranging patterns and the geographic extension of their movements (Cadahía et al. 2005; Soutullo et al. 2006). Although this technique is expensive in economic terms, hence limiting the number of birds that can be tracked, its main advantage is that it is especially useful to obtain accurate locations systematically and permits long-term tracking of birds' movements, in some cases as long as birds are recruited in the breeding population (Urios et al. 2007; Cadahía et al. 2009). This information is therefore especially useful in identifying the main threat factors in risk-assessment studies aimed at establishing optimal management actions.

This paper presents a large-scale outline of juvenile Bonelli's eagle dispersal areas in the Iberian Peninsula. Interestingly, there seems not to be a few, clearly delimited, overlapping, dispersal areas within the Iberian Peninsula.

By contrast, although birds tracked in this study come from a wide geographic range, there is no clear overlap between juvenile dispersal areas, and each bird seems to use a different one during their first years of life. In fact, 17 dispersal areas were detected for 11 birds, with some animals using more than one. This individual variation has important management implications and therefore suggests that conservation efforts should focus on the whole landscape matrix of man-managed ecosystems rather than in a few clearly delimited geographic areas.

Our results show that the first months of dispersal are made up by several phases that probably reflect successive stages of the species' ontogeny (Fig. 2; Soutullo et al. 2006). Initial movements take place within the parental territory and represent the so-called dependence period, in which juveniles still depend upon their parents in terms of food supply (Real et al. 1998; Ferrer 2001). Fledging occurs in Spain when nestlings are 44 to 69 days old (Real et al. 1998; Mínguez et al. 2001), and the onset of dispersal we registered here took place between 114–177 days old (Table 2). Hence, the post-fledging dependence period in Bonelli's eagle lasts 70–108 days, which is in agreement with data previously reported when studying the species by other methods (Real et al. 1998; Mínguez et al. 2001; Balbontín 2003). Average age at the onset of dispersal is coincident with former studies with the species, with reported data of 142 days old (Cadahía et al. 2005), 147 days old (Balbontín 2003), 149 days old (Mínguez et al. 2001), and slightly lower than the 163 days reported by

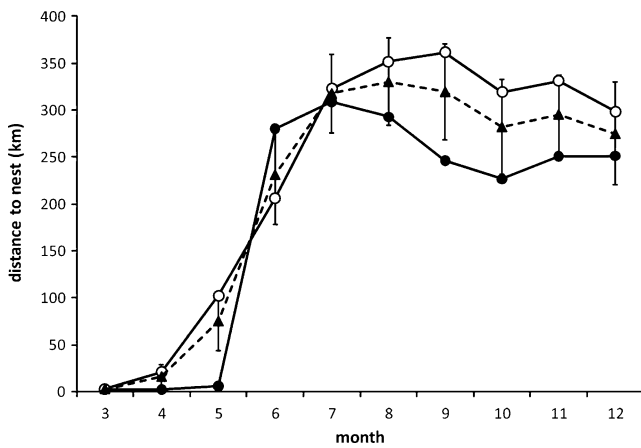


Fig. 2 Evolution of monthly distance to natal nest in 11 Bonelli's eagle juveniles during their first year of life. *Black dots* males; *white dots* females; *dotted line* all individuals' mean (standard error–SE lines are depicted in this case)

Real et al. (1998). In other raptor species, like Spanish Imperial eagle or Golden eagle (Ferrer 2001; Soutullo et al. 2006), a transitional phase between juveniles' independence from their parents and the definite departure from the parental territory has been described, named 'local dispersal' by Ferrer (2001). Unlike these species, Bonelli's eagle shows clear disperser behavior (*sensu* Walls and Kenward

1995), and once juveniles leave the parental territory, they cover long distances, without remaining in the surroundings of their natal area. This becomes evident in the abrupt increase in the average distance to natal nest during the fifth and sixth month after birth in all birds (Fig. 2; for a further discussion on the estimation of the onset of dispersal in this species, see Cadahía et al. 2008).

Around the end of the first year, we observed a slightly (non-significant) decrease in the distance to natal nests (Fig. 2), which is caused by four juveniles' behavior. Interestingly, two males and two females performed short movements out of their usual dispersal areas and moved towards their parental territories. In these movements, approaches to the natal nests as short as 33 km were recorded. Similar results were found by Balbontín and Ferrer (2009) who also reported natal returns during the second year of 16 radio-tracked juvenile Bonelli's eagles coming from the Cádiz population (southern Spain). Returns to natal areas have been observed in other species, such as the Spanish Imperial eagle (Ferrer 2001), the Golden eagle (Urios et al. 2007), or the Common Buzzard *Buteo buteo* (Walls and Kenward 1995), and were already suggested to occur in Bonelli's eagle (Real and Mañosa 2001). This behavior could be explained by food searching strategies based on their previous knowledge of the location

Table 2 Range-related variables and between-sex differences of 14 juvenile Bonelli's eagles tracked by satellite telemetry in Spain

Bird	Sex	Dispersal date	Age at dispersal (days)	Total range size (km ²)	Max. distance nest (km)	Dispersal area size (km ²)	Distance dispersal area–natal nest (km)
1	F	01/08/2002	150	5,292	90	903	81
2	M	04/09/2002	177	15,205	367	2,132	245
3	F	09/08/2002	150	980	185	264	148
4	M	16/08/2002	158	39,130	589	6,929	421
5	F	05/07/2002	114	6,692	541	844	442
6	F	31/07/2002	135	— ^a	367	—	—
7	F	09/09/2002	163	24,938	663	6,409	534
8	F	— ^b	—	—	19	—	—
9	M	20/08/2004	150	49,488	346	10,125	321
10	F	22/08/2004	147	17,488	592	3,815	519
11	M	02/10/2004	154	13,126	471	3,180	433
12	F	15/09/2004	141	— ^a	377	—	—
13	F	21/08/2004	135	4,956	278	1,296	256
14	F	03/09/2004	148	63,775	548	7,906	513
Males (n=4)		2 September±21	160±12	29,237±17,930	443±111	5,592±3,657	355±89
Females (n=7)		14 August±22	144±15	17,732±21,956	414±225	3,062±3,049	356±191
Max.–min.		2 October–5 July	177–114	63,775–980	663–90	10,125–264	534–81
Total		21 August±23	148±15	21,915±20,479	425±185	3,982±3,349	356±156

Values represent mean±standard deviation. Note that for range-related calculations only n=7 females were used in the analysis

^a Only one or two locations were received after dispersing from the parental territory, so no range size could be computed for these birds

^b This bird did not start dispersal from the natal territory

of prey patches and by checking the breeding population in the search for a vacancy in an active territory or a potential mate.

In relation to sex, significant interactions between sex and area of birth have been reported, with females dispersing farther than males and differing between populations (Hernández-Matías et al. 2010). Different results were found by Balbontín and Ferrer (2009), who did not find between-sex differences in ranging behavior and movement patterns of juvenile Bonelli's eagles. The main difference between our study and others were the distances between the natal population and the dispersal areas, shorter in the case of Balbontín and Ferrer (2009), with two juvenile females recruited as far as 4.4 and 120.8 km from their natal nest, and larger in Hernández-Matías et al (2010) that reported a mean natal dispersal distance for recruited birds of 107.1 ± 103.5 km, ranging from 19.4 to 430 km. In our study, only a female was recruited in the breeding population 441 km away from its natal nest (Cadahía et al. 2009). These results rule out the existence of compulsory philopatry in the species, and could be a consequence of the different origin of the birds tracked, from the Cádiz population (Balbontín and Ferrer 2009), Catalonia, and France (Hernández-Matías et al 2010) and from the eastern Iberian populations of the birds tracked in this study. Differences in ranging behavior and recruitment distances among birds of different geographic origin should be explored in detail in the future as more birds are tracked. It would be likely that dispersal areas in southern Spain could be acting as population sinks for juveniles coming from other Iberian populations (Moleón et al. 2009a). Geographic variation in prey availability could be an underlying mechanism explaining the tendency of birds of eastern populations to disperse further than those of southern populations (Moleón et al. 2009b).

The development of lightweight satellite tracking has enabled researchers to gain new insights into juvenile bird movements and areas covered during this important life stage of this endangered species. We have shown that juvenile Bonelli's eagles use during dispersal a number of areas distant from their parental territories. Our study corroborates the autonomous communities of Castilla-La Mancha and Andalucía (total surface = 166.731 km^2 , 32.9% of the Spanish territory) to be those with the most important young Bonelli's assemblages (specially the provinces of Toledo, Albacete, and Cádiz), but also highlights the relevance of other areas in northern and eastern Spain (between Navarra and La Rioja, inner Catalonia, and southern Alicante; Fig. 1). Habitat characterization points out that juveniles concentrate in open habitats, particularly human-managed areas with extensive non-irrigated crops and herbaceous plants. Higher prey availability, such as rabbits or partridges in these open areas, along with the

absence of breeding pairs, would account for this preference and for the spatial distribution of dispersal areas in the Iberian Peninsula (Mañosa et al. 1998; Real 2004; Moleón et al. 2009a). However, these areas pose important threats, like dangerous power lines, or direct persecution, since, in some instances, dispersal areas are placed within the limits of private hunting reserves in which poison to control predators is illegally used (Real et al. 2001; Real 2004).

The possible source-sink dynamics and the existence of several non-overlapping dispersal areas have major implications for the conservation of the species. Since dispersal areas are located over territories managed by different autonomous communities with particular jurisdictions, this brings into focus the need for organization among regional governments to undertake inter-regional conservation measures targeting the non-breeding fraction of Bonelli's eagle population. An adequate action plan for the species will need a combination of international and inter-regional coordinated actions aimed at improving juvenile survival. This, as demographic studies of population viability have demonstrated (Soutullo et al. 2008a), will ultimately be reflected in an enhancement of the population trend of this endangered species.

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References

- Argos (2008) User's manual. CLS/Service Argos, Toulouse
- Balbontín J (2003) El águila perdicera en Andalucía: ecología y dispersión juvenil. PhD thesis, University of Sevilla
- Balbontín J, Ferrer M (2009) Movements of juvenile Bonelli's Eagles *Aquila fasciata* during dispersal. *Bird Study* 56:86–95
- BirdLife International (2009) Species factsheet: *Hieraaetus fasciatus*. Downloaded from <http://www.birdlife.org> on 14/9/2009
- Bullock JM, Kenward RE, Hails RS (eds) (2002) *Dispersal ecology*. Blackwell, Oxford, UK
- Cadahía L, Urios V, Negro JJ (2005) Survival and movements of satellite-tracked Bonelli's Eagles *Hieraaetus fasciatus* during their first winter. *Ibis* 147:415–419

- Cadahía L, Urios V, Negro JJ (2007) Bonelli's Eagle *Hieraetus fasciatus* juvenile dispersal: hourly and daily movements tracked by GPS. *Bird Study* 54:271–274
- Cadahía L, López-López P, Urios V, Negro JJ (2008) Estimating the onset of dispersal in endangered Bonelli's eagle *Hieraetus fasciatus* tracked by satellite telemetry: a comparison among methods. *Ibis* 150:416–420
- Cadahía L, López-López P, Urios V, Negro JJ (2009) Natal dispersal and recruitment of two Bonelli's eagles *Aquila fasciata*: a four-year satellite tracking study. *Acta Ornithologica* 44:193–198. doi:10.3161/000164509X482777
- Cheylan G, Ravayrol A, Cugnasse JM, Billet JM, Joulot C (1996) Dispersion des Aigles de Bonelli *Hieraetus fasciatus* juveniles bagués en France. *Alauda* 64:413–419
- Clobert J, Danchin E, Dhont AA, Nichols J (eds) (2001) Dispersal—causes, consequences and mechanisms of dispersal at the individual, population and community level. Oxford University Press, Oxford
- Cramp S, Simmons KEL (1980) Handbook of the birds of Europe, the Middle East and North Africa—vol. 2. Oxford University Press, Oxford
- Dixon KR, Chapman JA (1980) Harmonic mean measure of animal activity areas. *Ecology* 61:1040–1044
- Ferrer M ((2001)) The Spanish imperial Eagle. Lynx Editions, Barcelona
- Fridolfsson AK, Ellegren H (1999) A simple and universal method for molecular sexing of non-ratite birds. *J Avian Biol* 30:116–121
- Gil-Sánchez JM (2000) Efecto de la altitud y de la disponibilidad de presas en la fecha de puesta del águila-azor perdicera (*Hieraetus fasciatus*) en la provincia de Granada (SE de España). *Ardeola* 47:1–8
- Greenwood PJ, Harvey PH (1982) The natal and breeding dispersal of birds. *Ann Rev Ecol Syst* 13:1–21
- Hernández-Matías A, Real J, Pradel R, Ravayrol A, Vincent-Martin N, Bosca F, Cheylan G (2010) Determinants of territorial recruitment in Bonelli's Eagle (*Aquila fasciata*) populations. *The Auk* 127:173–184
- Hooge PN, Eichenlaub B (1997) Animal movement extension to ArcView. Ver. 1.1. Alaska Science Center—Biological Science Office, U.S. Geological Survey, Anchorage
- Kenward R (2001) A manual for wildlife radio tagging. Academic, London
- Kenward RE, Clarke RT, Hodder KH, Walls SS (2001) Density and linkage estimators of home range: nearest-neighbour clustering defines multinuclear cores. *Ecology* 82:1905–1920
- Mañosa S, Real J, Codina J (1995) Age estimation and growth patterns in nestling Bonelli's eagles. *J Raptor Res* 29:273–275
- Mañosa S, Real J, Codina J (1998) Selection of settlement areas by juvenile Bonelli's eagle in Catalonia. *J Raptor Res* 32:208–214
- Mínguez E, Angulo E, Siebering V (2001) Factors influencing length of the post-fledging period and timing of dispersal in Bonelli's eagle (*Hieraetus fasciatus*) in Southwestern Spain. *J Raptor Res* 35:228–234
- Moleón M, Bautista J, Sánchez-Zapata JA, Gil-Sánchez JM (2009a) Diet of non-breeding Bonelli's eagles *Hieraetus fasciatus* at settlement areas of southern Spain. *Bird Study* 56:142–146
- Moleón M, Sánchez-Zapata JA, Real J, García-Charton JA, Gil-Sánchez JM, Palma L, Bautista J, Bayle P (2009b) Large-scale spatio-temporal shifts in the diet of a predator mediated by an emerging infectious disease of its main prey. *J Biogeogr* 36:1502–1515
- Pekel JF, Vancutsem N, Deofurney P, Champeaux JL, Gouveia C, Lobo A, Griguolo S, Perdigo A, Bartholomé E (2003) The land cover map for Europe in the year 2000. GLC2000 database, European Commission Joint Research Centre. <http://www-gvm.jrc.it/glc2000>
- Real J (2004) Águila-azor perdicera, *Hieraetus fasciatus*. In: Madroño A, González C, Atienza JC (eds) Red Book of the Birds of Spain. Libro Rojo de las Aves de España. General Direction for Biodiversity—SEO/Birdlife, Madrid, pp 154–157
- Real J, Mañosa S (2001) Dispersal of juvenile and immature Bonelli's eagles in Northeastern Spain. *J Raptor Res* 35:9–14
- Real J, Mañosa S, Codina J (1998) Post-nestling dependence period in the Bonelli's eagle *Hieraetus fasciatus*. *Ornis Fenn* 75:129–137
- Real J, Grande JM, Mañosa S, Sánchez-Zapata JA (2001) Geographic variation of the causes of death of Bonelli's eagle *Hieraetus fasciatus* in Spain. *Bird Study* 48:221–228
- Soutullo A, Urios V, Ferrer M, Peñarrubia S (2006) Post-fledging behaviour in Golden eagles *Aquila chrysaetos*: onset of juvenile dispersal and progressive distancing from the nest. *Ibis* 148:307–312
- Soutullo A, Cadahía L, Urios V, Ferrer M, Negro JJ (2007) Accuracy of lightweight satellite telemetry: a case study in the Iberian Peninsula. *J Wildl Manage* 71:1010–1015
- Soutullo A, López-López P, Urios V (2008a) Incorporating spatial structure and stochasticity in endangered Bonelli's eagle's population models: implications for conservation and management. *Biol Conserv* 141:1013–1020
- Soutullo A, Urios V, Ferrer M, López-López P (2008b) Habitat use by juvenile Golden Eagles *Aquila chrysaetos* in Spain. *Bird Study* 55:236–240
- Urios V, Soutullo A, López-López P, Cadahía L, Limiñana R, Ferrer M (2007) The first case of successful breeding of a Golden Eagle *Aquila chrysaetos* tracked from birth by satellite telemetry. *Acta Ornithol* 42:205–209
- Walls S, Kenward R (1995) Movements of radio-tagged buzzards *Buteo buteo* in their first year. *Ibis* 137:177–182
- Worton BJ (1989) Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* 70:164–168
- Zar JH (1999) Biostatistical analysis, 4th edn. Prentice Hall, New Jersey