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SHORT REPORT

Bonelli's Eagle *Hieraaetus fasciatus* juvenile dispersal: hourly and daily movements tracked by GPS

LUIS CADAHÍA[1]*, VICENTE URIOS[1] and JUAN J. NEGRO[2]
[1]*Estación Biológica Terra Natura (Fundación Terra Natura – CIBIO), Universidad de Alicante, Apdo. correos 99, E-03080, Alicante, Spain and* [2]*Departamento de Conservación de la Biodiversidad, Estación Biológica de Doñana, CSIC, Avda. de María Luisa, s/n, Pabellón del Perú, 41013, Sevilla, Spain*

Capsule Birds cover daily distances not normally exceeding 20 km during the initial phase of dispersal, with the daily peak of movement/activity in the afternoon.

The main strongholds of Bonelli's Eagle *Hieraaetus fasciatus* in the Western Palaearctic occur in the Iberian Peninsula and Morocco (Arroyo *et al.* 1995, Palma *et al.* 1996, Real & Mañosa 1997). This western population has undergone a marked decline during recent decades (Real & Mañosa 1997, Real *et al.* 2001), and the species has been reclassified from 'vulnerable' to 'endangered' in Spain (Madroño *et al.* 2003). Most studies of Bonelli's Eagle have been concerned with breeding biology and population status (Real & Mañosa 1997, Real *et al.* 1998, Ontiveros 1999, Gil-Sánchez *et al.* 2004), as well as dispersal behaviour (Cheylan *et al.* 1996, Real & Mañosa 2001, Cadahía *et al.* 2005). Nevertheless, some features of the dispersal process, such as the distance the species covers during a given time, remain unknown. Such information is important for understanding behaviours such as foraging or habitat selection (Clobert *et al.* 2001). Furthermore, as pre-adult mortality is high in this species (Real & Mañosa 1997, Carrete *et al.* 2002), knowledge of the distances covered by juveniles during the early stages of dispersal, a particularly vulnerable time (Newton 1979), might help to advise conservation measures.

Here we use GPS satellite telemetry to investigate the distances juvenile Bonelli's Eagles cover in an hour and in a day, during the initial phase of dispersal. This information may also be a useful guide for researchers using less accurate tracking systems, such as the conventional Argos telemetry system, when removing unreliable locations from the data sets (Douglas 2000, Hays *et al.* 2001, Vincent *et al.* 2002). As the movements of Bonelli's Eagles during the post-fledging dependence period are limited to a restricted area (Real *et al.* 1998, Mínguez *et al.* 2001), we only analysed movements undertaken after the onset of dispersal (first movement beyond 20 km from the nest; Cadahía *et al.* 2005) and collected data until November, when the transmitter on one of the birds ceased functioning. Consequently, we present distances covered by Bonelli's Eagles during the first three months of juvenile dispersal.

Two nestling Bonelli's Eagles (a male and a female), whose natal nests were 23.8 km apart, were tagged with Argos/GPS solar-powered transmitters (Microwave Telemetry Inc.; 45 g, 83.5 × 28.8 × 21.0 mm, antenna 18 cm) in eastern Spain (province of Castellón) on 14 and 17 May 2004, respectively. Both nests were located on cliffs surrounded by Mediterranean shrubland. Blood samples were taken to sex the individuals by molecular techniques (Griffiths *et al.* 1998, Fridolfsson & Ellegren 1999). The GPS transmitters were attached to the birds' backs using a breakaway Teflon harness (Kenward 2001) when they were approximately 50 days old. This is the first time Bonelli's Eagles have been fitted with this type of transmitter.

Argos/GPS transmitters contain a GPS receiver which records locations at pre-set intervals (one hour in this study) from the GPS satellite network. These data are then relayed to ground-based Argos processing centres. The GPS system holds two advantages over

*Correspondence author
Email: luis.cadahia@gmail.com

conventional Argos telemetry: (1) its resolution accuracy is higher than 100 m, better than all Argos locations (Service Argos 1996, Microwave Telemetry 2006); and (2) it can record positions at regular time intervals, making it possible to study particular behaviour patterns, such as hourly movements.

Hourly distances were computed as the straight distance between two successive locations recorded one hour apart. Locations were recorded between 08:00 and 23:00 hours, local time (GMT+2). The Kruskal–Wallis test was used to evaluate between-hour differences on the distances covered by each bird throughout the day. Subsequently, the data from both birds were pooled together and the Games–Howell multiple comparison test (Zar 1999) was performed to define the daily peak of movement/activity. Daily distances were estimated as the length of the straight line joining the two locations recorded furthest away within a given day (Soutullo *et al.* 2006). Argos/GPS transmitters, although potentially providing hourly fixes, do not always perform to optimal standards, so gaps in the transmitting period were present. We therefore considered only days in which at least three locations were recorded, with at least one of them within the individuals' peak of movement/activity (Soutullo *et al.* 2006), avoiding excessive underestimation of the actual daily distances. The Wilcoxon test was used to explore seasonal changes by comparing the daily distances in summer and autumn (before and after 1 October; Walls *et al.* 2005). Altogether, 283 hourly movements from 49 days in the female and 359 hourly movements from 58 days in the male were analysed. Statistical analyses were carried out in SPSS version 11.5 (SPSS Inc. 1990).

In both birds, hourly distances changed significantly throughout the day (female $H = 131.29$, df = 14, $P < 0.01$; male $H = 110.97$, df = 14, $P < 0.01$) (Table 1). The maximum distance recorded in one hour was close to 50 km, although it was below 5 km (83.6%) in most instances. In 89% of the hourly movements the distance covered was less than 10 km and in 95% it was less than 20 km (Fig. 1). The majority of long-distance movements took place between 13:00 and 18:00 hours, the peak of movement/activity, with maximum distances being covered between 13:00 and 14:00 hours. Both birds moved hardly at all after 21:00 hours (Table 1).

The median daily distance was 6.3 km (mean = 23.7). On only 3.7% of the days did the birds cover more than 100 km. These long movements occurred almost exclusively within the first three days after the onset of dispersal, except for one large movement performed by the male in mid-October. In the remaining time, periods with daily distances not exceeding 20 km (68.2%) alternated with less frequent episodes of higher movement/activity, although no seasonal pattern was observed ($P > 0.110$). The maximum distance covered in a particular day was 236.6 km, and the most distant locations were 592 km away from the nest for the female and 346 km for the male.

The initial phase of juvenile dispersal is a crucial moment in the life history of raptors, since it is the time when juveniles definitively leave the nest area but are still vulnerable and naive (Newton 1979). The

Table 1. Hourly distances (in km) covered by two juvenile Bonelli's Eagles tracked by GPS satellite telemetry in Spain during the initial phase of dispersal.

	Female (n = 283)		Male (n = 359)		Both birds		
Local time (hours)	Median	Min.–Max.	Median	Min.–Max.	Median	Mean	sd
08:00–09:00	0.3	0.0–1.6	0.3	0.0–2.2	0.3	0.5	0.5
09:00–10:00	0.5	0.0 –1.5	0.1	0.0–1.8	0.2	0.4	0.5
10:00–11:00	0.4	0.0–15.1	0.3	0.0–5.6	0.3	1.4	2.7
11:00–12:00	0.2	0.0–17.5	0.6	0.0–12.2	0.4	2.6	4.2
12:00–13:00	2.8	0.0–25.2	0.6	0.0–37.9	0.7	6.8	11.0
13:00–14:00	16.9	0.0–49.9	3.3	0.0–45.8	3.8	11.8	14.3
14:00–15:00	8.3	0.0–25.2	1.0	0.0–29.8	5.7	8.6	9.4
15:00–16:00	6.0	0.3–32.9	0.9	0.0–17.6	1.6	6.2	8.4
16:00–17:00	1.5	0.0–28.5	1.2	0.0–18.7	1.3	4.9	7.4
17:00–18:00	1.8	0.0–40.2	1.1	0.0–18.3	1.4	4.8	8.0
18:00–19:00	0.4	0.0–28.9	0.3	0.0–6.5	0.4	2.4	5.3
19:00–20:00	0.2	0.0–3.6	0.1	0.0–4.7	0.2	0.5	0.9
20:00–21:00	0.0	0.0–1.0	0.0	0.0–2.6	0.0	0.2	0.5
21:00–22:00	0.0	0.0–0.1	0.0	0.0–0.1	0.0	0.0	0.0
22:00–23:00	0.0	0.0–0.1	0.0	0.0–0.4	0.0	0.0	0.1

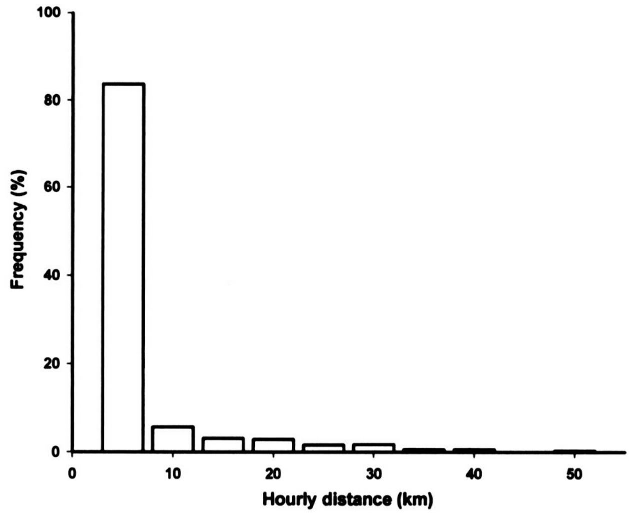

Figure 1. Distribution of the hourly distances travelled by two juvenile Bonelli's Eagles tracked by GPS satellite telemetry in Spain.

distances they cover, the places they visit and the daily activity patterns they exhibit will probably affect their chances of surviving.

The greatest movements of Bonelli's Eagles are registered predominantly during the afternoon. This may be explained by the juveniles taking advantage of thermals, which are more likely to occur around midday and during the afternoon (Ballam 1984). Soaring on thermals to gain height, alternating with periods of gliding, has been proved to favour long-distance movements (Pennycuick 1998), and is the most likely explanation for the pattern we observe here. The use of thermals has been reported to account for higher flying activity at midday in a number of raptor species (Haller 1996, Ferrer 2001, Sarasola & Negro 2005).

Although Bonelli's Eagles can be regarded as long-distance dispersers (Cheylan *et al.* 1996, Real & Mañosa 2001, Cadahía *et al.* 2005), the majority of their daily movements occur in a limited area, with an average distance of less than 20 km. The largest movements the species performed were restricted to isolated and infrequent episodes, which usually occurred immediately after the onset of dispersal. This suggests that juveniles moved long distances after leaving the natal territory but settled and performed movements of lesser extent soon after that. Thus, the initial phase of dispersal must have occurred over a short period of time, as suggested for other raptors, such as Common Buzzards *Buteo buteo* (Walls *et al.* 2005).

Besides providing the first detailed description of the daily movements of Bonelli's Eagles, our results may also be useful for researchers using conventional Argos satellite telemetry, which often provides data of low accuracy (Keating *et al.* 1991, Hays *et al.* 2001). The distances recorded using the GPS system, which is more accurate than Argos, may be of help when filtering Argos data. Fixes corresponding to movements in which birds seem to cover unrealistically long distances can be removed according to the actual (hourly or daily) distances registered with the GPS. The degree of reliability of a particular location can be deduced from the likelihood of birds covering a certain distance in a given time period. This can be estimated from the frequency of different movement distances of the kind that we provide here (Fig. 1). Therefore, our results can be used by other researchers to assess the reliability of locations obtained using the Argos system.

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