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

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Short title: Bonelli's Eagle hourly and daily moves.

Keywords**:** Bonelli's Eagle; *Hieraaetus fasciatus*; dispersal; GPS; satellite tracking; satellite telemetry; Argos.

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Summary

Bonelli's eagles *Hieraaetus fasciatus* cover daily distances that do not normally exceed 20 km during the initial phase of dispersal, with the daily peak of movement-activity occurring in the afternoon.

The Bonelli's Eagle *Hieraaetus fasciatus* is an endangered raptor whose main strongholds 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 the last decades (Real & Mañosa 1997, Real *et al.* 2001), that has led the species to be re-catalogued from "vulnerable" to "endangered" in Spain (Madroño *et al.* 2003). The species has largely been studied with regard to breeding biology and population status (e.g. Real & Mañosa 1997, Real *et al.* 1998, Ontiveros 1999, Gil-Sánchez *et al.* 2004), as well as to dispersal behaviour (Cheylan *et al.* 1996, Real & Mañosa 2001, Cadahía *et al.* 2005). Nevertheless, various features of the dispersal process, like the distance the species actually covers in a given time-span, remain unknown. Such information is important to understand aspects as diverse as foraging behaviour, habitat selection or territoriality (Clobert *et al.* 2001, Soutullo *et al.* 2006). Furthermore, since pre-adult mortality is high in the species (Real & Mañosa 1997, Carrete *et al.* 2002), knowledge of the distances covered by juveniles during the beginning of dispersal, a particularly vulnerable period (Newton 1979), might help to undertake adequate conservation measures. This information might, as well, constitute a useful guide for researchers using other less accurate tracking systems, like Argos system, when removing unreliable locations from the data sets (see Douglas 2000, Hays *et al.* 2001, Vincent *et al.* 2002).

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. Since Bonelli's Eagle movements before the onset of dispersal are limited to a restricted area around the nest (Real *et al.* 1998, Mínguez *et al.* 2001), we only analysed movements undertook after that event (August, see Cadahía *et al.* 2005) and collected data until

November. Consequently, here we present the 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. USA, weight 45g, 83.5 x 28.8 x 21.0 mm, antenna 18 cm) in eastern Spain (province of Castellón) on the 14th and 17th of May 2004, respectively. In both cases, the nest was located on a cliff, and 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' back by means of a breakaway Teflon harness (Kenward 2001) when they were *ca.* 50 days old. This is the first time Bonelli's Eagle was fitted with this type of transmitters. Birds were monitored from the onset of dispersal, in August (Cadahía *et al.* 2005), to November 2004.

Argos/GPS transmitters contain a GPS receiver, which collects fixes at pre-set intervals (one hour in this study) from the GPS satellites network. These data are then relayed to ground-based Argos processing centres. The GPS system holds two advantages over conventional Argos telemetry. Its accuracy is higher than 100 m, better than all Argos locations (Service Argos 1996, Microwave Telemetry), and, also, it can provide positions at a regular time period, 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. Birds were located between 08:00 hours and 23:00 hours, local time (GMT + 2, summer daylight saving time). The Kruskal-Wallis test was used to evaluate among-hour differences on the distances covered by each bird throughout the day. Subsequently, the data from both birds were pooled together and the

73 Games-Howell multiple comparison test (Zar 1999) was performed to define the daily
74 peak of movement-activity. Daily distances were estimated as the length of the straight
75 line joining the two locations recorded furthest away within a given day (Soutullo *et al.*
76 2006). This measure may provide an underestimation of actual distances. To avoid this,
77 we only considered days in which at least three locations were recorded, with at least
78 one of them within the period of the individual's greatest movement-activity (Soutullo
79 *et al.* 2006). Altogether, 283 hourly movements for the female and 358 for the male
80 were recorded. Data from 49 days in the female and 58 days in the male were analysed.
81 All statistical analyses were carried out in SPSS version 11.5 (SPSS Inc. 1990).
82 In both birds hourly distances changed significantly throughout the day (female H
83 = 131.29, d.f. = 14, $p < 0.01$; male H = 110.97, d.f. = 14, $p < 0.01$) (Table 1). The
84 maximum distance recorded in one hour was close to 50 km, although it was below 5
85 km (83.6%) in most instances. In 89% of the hourly movements the distance covered
86 was less than 10 km and in 95% it was less than 20 km (Fig. 1). The majority of long-
87 distance movements took place between 13:00 hours and 18:00 hours, the peak of
88 movement-activity, and the birds barely moved after 21:00 hours (Table 1).
89 The average daily distance was 23.7 km (SD = 40.6; median = 6.3). Most of the
90 time, daily distances did not exceed 20 km (68.2%), and only 3.7% of the days the birds
91 covered more than 100 km. The maximum distance covered in a particular day was
92 236.6 km. Concerning the most distant locations reached, they were placed 592 km
93 away from the nest in the female and 346 km in the male (mean = 469, SD = 174).
94 The initial phase of the juvenile dispersal is a crucial moment in the life history of
95 raptors, since it is the time in which juveniles definitively leave the nest area but are still
96 vulnerable and naïve (Newton 1979). The distances they cover, the places they visit and
97 the daily activity patterns they exhibit will probably affect their chances of surviving.

98 Bonelli's Eagle's largest movements are registered predominantly during the
99 afternoon. Thermals and updraughts, necessary for soaring and gliding flights, are more
100 frequent at midday (Ferrer 2001, Sarasola & Negro in press), explaining the greater
101 distances travelled by eagles at that time, as it happens in other raptor species, like
102 Golden Eagles *Aquila chrysaetos* (Watson 1997, Soutullo *et al.* 2006). Very likely,
103 foraging behaviour is also involved in this pattern, as most raptors' movements may be
104 explained in terms of food searching (Newton 1979).

105 Even though the Bonelli's Eagle can be regarded as a long-distance disperser
106 (Cheylan *et al.* 1996, Real & Mañosa 2001, Cadahía *et al.* 2005), the majority of its
107 daily movements occur in a limited area, with an average span not greater than 20 km.
108 This denotes that the largest movements the species performs are in reality restricted to
109 particular episodes which take place at a relatively low frequency, being, therefore,
110 relatively rare events in Bonelli's juveniles' life (only around 4% of the days the birds
111 covered more than 100 km).

112 The distances covered by Bonelli's Eagles are greater than those registered for
113 other eagle species in Spain. Daily movements of Golden Eagles reached a maximum of
114 53 km (Soutullo *et al.* 2006) whereas 237 km were registered in Bonelli's Eagle.
115 Golden Eagle juveniles' maximum distance from the nest was 184 km (Soutullo *et al.* in
116 press), and 138 km in the case of Spanish Imperial Eagle *Aquila adalberti* (Ferrer
117 2001). In Bonelli's Eagle, birds in the present study reached locations placed an average
118 distance of 469 km away from their nests and a maximum of 663 km has been reported
119 elsewhere (Cadahía *et al.* 2005).

120 Besides providing the first detailed description of Bonelli's Eagle daily
121 movements, our results may also be useful for other researchers studying the species
122 using conventional Argos satellite transmitters. Satellite telemetry using the Argos

system often faces the problem of the low accuracy of some of the data collected (Keating *et al.* 1991, Hays *et al.* 2001). The distances recorded using the GPS system, far more accurate than Argos locations, may be of help when filtering Argos data. Thus, fixes corresponding to movements in which birds seem to cover unrealistic long distances can be reasonably 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 eagles covering certain distance in a given time-span. This can be estimated based on the frequency of different movement distances we provide here (Fig. 1). Therefore, our results can be used by other researchers working with Bonelli's Eagle to assess the reliability of locations obtained using the Argos system.

Acknowledgements

We are grateful to the Consellería de Territori i Habitatge of the Generalitat Valenciana (P. Mateache, M. Romanillos, C. Dolz, A. Izquierdo and A. García i Sanz) and the Spanish Ministerio de Medio Ambiente (V. García Matarranz, P. García Domínguez) for their permission to get access to the nests and invaluable field assistance. Argos staff patiently solved our hesitations. Comments from A. Soutullo, R. Limiñana, O. Monroy-Vilchis and A. Gamauf significantly improved early drafts of the manuscript. This project was funded by Terra Natura Foundation. L. Cadahía is supported by a grant of the Spanish Ministerio de Educación y Ciencia (reference AP2001-1444). This paper is part of L. Cadahía's Ph.D. at the University of Alicante.

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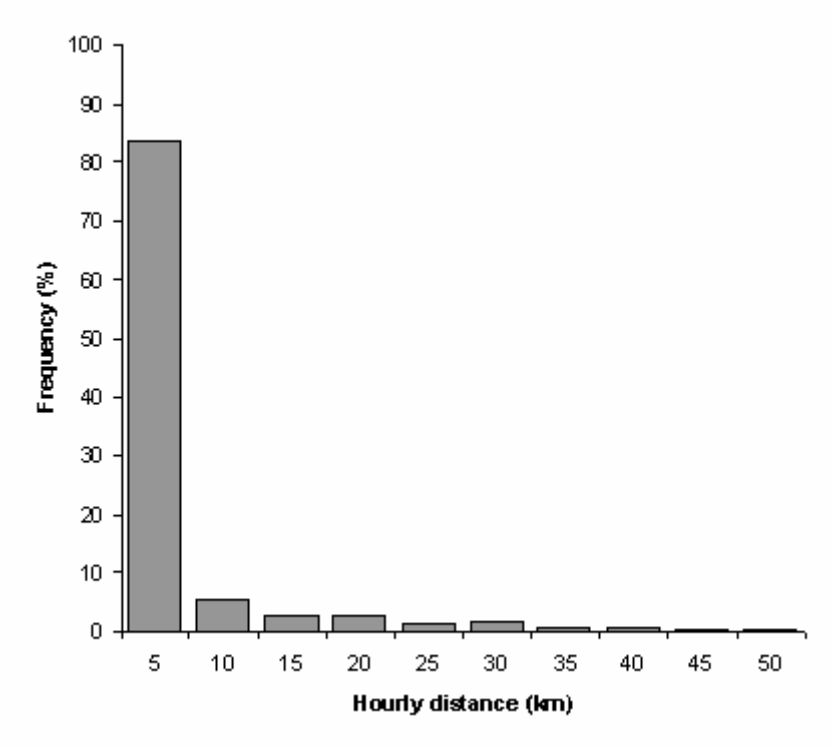
Table 1: Bonelli's Eagle hourly movements.

	Female (n = 283)		Male (n = 359)		Both birds		
Local hour	Median	Min-Max	Median	Min-Max	Median	Mean	SD
8 – 9	0.3	0.0 – 1.6	0.3	0.0 – 2.2	0.3	0.5	0.5
9 – 10	0.5	0.0 –1.5	0.1	0.0 – 1.8	0.2	0.4	0.5
10 – 11	0.4	0.0 – 15.1	0.3	0.0 – 5.6	0.3	1.4	2.7
11 – 12	0.2	0.0 – 17.5	0.6	0.0 – 12.2	0.4	2.6	4.2
12 – 13	2.8	0.0 – 25.2	0.6	0.0 – 37.9	0.7	6.8	11.0
13 – 14	16.9	0.0 – 49.9	3.3	0.0 – 45.8	3.8	11.8	14.3
14 – 15	8.3	0.0 – 25.2	1.0	0.0 – 29.8	5.7	8.6	9.4
15 – 16	6.0	0.3 – 32.9	0.9	0.0 – 17.6	1.6	6.2	8.4
16 – 17	1.5	0.0 – 28.5	1.2	0.0 – 18.7	1.3	4.9	7.4
17 – 18	1.8	0.0 – 40.2	1.1	0.0 – 18.3	1.4	4.8	8.0
18 – 19	0.4	0.0 – 28.9	0.3	0.0 – 6.5	0.4	2.4	5.3
19 – 20	0.2	0.0 – 3.6	0.1	0.0 – 4.7	0.2	0.5	0.9
20 – 21	0.0	0.0 – 1.0	0.0	0.0 – 2.6	0.0	0.2	0.5
21 – 22	0.0	0.0 – 0.1	0.0	0.0 – 0.1	0.0	0.0	0.0
22 – 23	0.0	0.0 – 0.1	0.0	0.0 – 0.4	0.0	0.0	0.1

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

Caption to figure.

Fig. 1: Distribution of the distances travelled in one hour by two juvenile Bonelli's Eagles tracked by GPS satellite telemetry in Spain.



Cadahía, L., Urios, V. & Negro, J.J.

Figure 1.