

SHORT REPORT

Satellite tracking of a Booted Eagle *Aquila pennata* during migration

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The Booted Eagle *Aquila pennata* is mainly a trans-Saharan migratory species, but some individuals overwinter in southern Europe and North Africa (Zalles & Bildstein 2000, Thévenot *et al* 2003). It is considered a 'rare species' in Europe (Baghino *et al* 2007), with two distinct populations of several thousand breeding pairs: one in western Europe (France, Portugal and Spain) and one in eastern Europe (mostly in Russia, Turkey and Ukraine). During their migration across the Mediterranean Basin, most western Booted Eagles concentrate at the Strait of Gibraltar, whilst those from the eastern populations concentrate at the Bosphorus (Zalles & Bildstein 2000, Thévenot *et al* 2003).

Very few biological aspects of the Booted Eagle are known, and this species is considered one of the least known of all European raptor species (Suarez *et al* 2000, Bosch *et al* 2005). The few scientific studies already published considered their feeding habitats (Suarez *et al* 2000, Diaz 2005, Martínez *et al* 2007) and their distribution (Araujo 1973). However, no publications have yet described the migration between Europe and Africa, except for observations in Europe during migration (Baghino *et al* 2007). In recent years, satellite telemetry has proved to be a very efficient method of investigating raptor migration (eg Grubb *et al* 1994, Meyburg *et al* 1998, 2003, Martell *et al* 2001). Here we present the first results of a satellite-tracking programme started in 2007 to follow the Booted Eagle during its migrations. The tracks reported here are those of an adult female tagged in France with an Argos GPS solar transmitter. We discuss the results obtained from this eagle, which was followed during three years for an uninterrupted series of five migratory tracks.

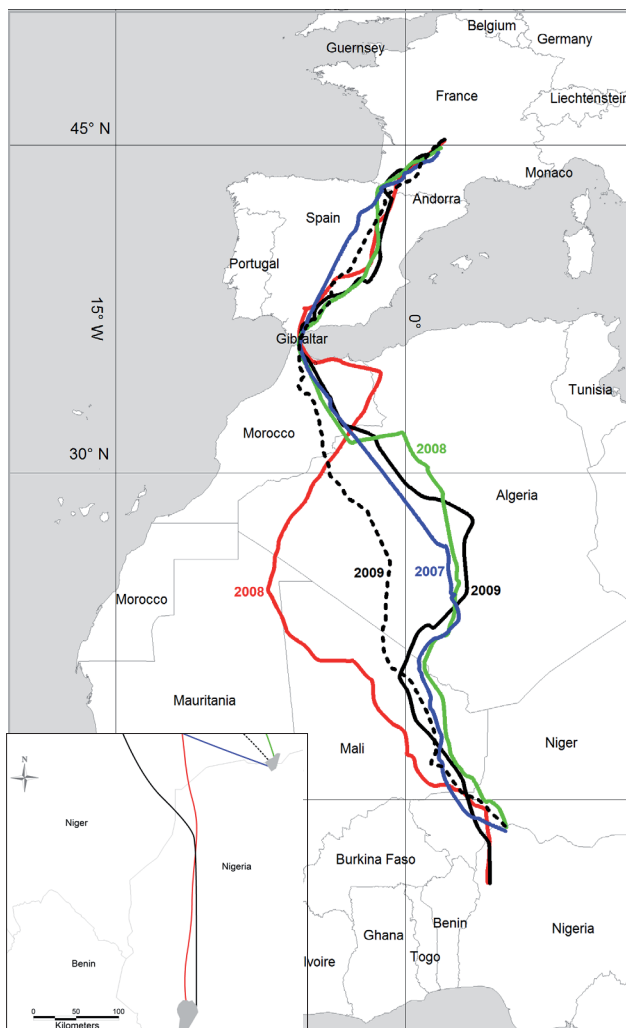
The Booted Eagle (named 'Thérèse') was the female of a breeding pair, trapped on 12 July 2007 in Saint Martin la Méanne (45°17'N 1°98'W; Fig 1). The pair raised one chick in 2007, did not lay eggs in 2008 and raised two chicks in 2009. The bird was equipped with a 22 g Solar-GPS PTT satellite platform (Microwave Telemetry, Columbia, USA). PTTs were encased in a backpack and attached as high as possible on the back of the eagle with a Teflon ribbon harness in order to prevent feathers covering the solar panels. The Solar-GPS was programmed to collect data every hour during daylight (from 0500 hrs to 2100 hrs) and to download the data every 72 hours via Telnet. All location data were checked individually and then stored in a database. For analysing movements over five one-way migration journeys (three in autumn and two in spring), we used only GPS locations because of their greater precision (± 10 m) and we did not use the Argos location (± 150 m LC3; 150–350 m LC 2; 350–1,000 m LC 1; >1,000 m LC 0). Since the daily movements of the eagle during wintering and breeding periods seldom exceeded 30 km, we used the threshold of 30 km/day to distinguish between migration and non-migratory periods. We used the software SIGOGNETRACK (version 2005, Géo-Hyd Société, Olivet, France) in MAPINFO 8.0 for tracing and calculating daily courses during the migration.

We followed the eagle by satellite from 2007 to 2009 for a total migration distance of 23,700 km, providing a total of 2,250 locations (see Table 1). The duration of each of the five migrations fluctuated between 21 and 27 days, for an average of 24 ± 3 days. Whereas the departure dates from the breeding grounds varied by a maximum of eight days, the arrival date on wintering areas varied by up to 20 days. This is in contrast with the departure dates

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Table 1. Details of post- and prenuptial migration of the tracked Booted Eagle *Aquila pennata*, including stopovers, for five periods over three years.

Season	Year	No. of records	Start date	End date	Start point	End point	Distance (km)	Time (days)	Stopover period	Stopover location
Autumn	2007	500	13/09/07	09/10/07	45.20N/2.02E	13.72N/5.17E	4,660	27	21.09–22.09	Spain, 37.39N/4.87W
Autumn	2008	360	08/09/08	29/09/08	45.20N/2.02E	13.72N/5.17E	4,480	21	-	-
Autumn	2009	360	05/09/09	26/09/09	45.20N/2.02E	13.72N/5.17E	4,200	22	11.09–12.09	Spain, 36.07N/5.45W
Spring	2008	620	23/03/08	17/04/08	11.19N/4.28E	45.20N/2.02E	5,220	26	10.04–11.04	Morocco, 34.99N/4.68W
Spring	2009	400	24/03/09	16/04/09	11.19N/4.28E	45.20N/2.02E	5,100	24	10.04–11.04	Spain, 42.73N/0.95W

**Figure 1.** Routes for autumn (green, blue and black dotted line) and spring (black and red) migrations of the satellite-tracked Booted Eagle *Aquila pennata* for five tracking periods (for details, see Table 1 and text). The wintering areas are indicated in grey (see inset of the figure on the bottom left).

from the wintering areas and the arrival in breeding areas, which differed only by one day (though we had only two samples; cf Table 1).

Migration route

To a large extent, migration routes were almost identical in the migratory corridor over France, Spain and Africa (see Fig 1) during autumn migration in 2007, 2008 and 2009 and spring migration in 2008 and 2009. However, during the 2008 prenuptial and 2009 postnuptial migrations, there was a clear divergence in the paths, especially over Africa.

Indeed, during the 2008 prenuptial period, the Booted Eagle began its migration from the wintering area (western Nigeria, see Fig 1), then flew to the north of Nigeria before moving to northwestern Niger then crossing Mali longitudinally in a northwesterly direction.

Once it had crossed the northeast of Mauritania, the eagle flew northwards (Tindouf, Algeria), then moved northeast (Jebel Tenouchfi Mountains, Algeria) before finally flying in a northwesterly direction along the Moroccan coastline towards Gibraltar (see Fig 1).

During the 2009 prenuptial period the eagle followed a different path from the northeast of the Malian border. Contrary to earlier migrations, it crossed western Algeria then joined a similar route to previous migrations once it arrived at the Moroccan border (see Fig 1). In Spain, the eagle followed the same path used during the 2009 prenuptial and 2008–09 postnuptial migrations.

Stopover

Among the five migration routes taken by the eagle, four were each observed to include one stopover (used during the day) mainly in Spain or Morocco (cf Table 1). A site was considered as a stopover when the speed (defined as the ratio of distance between two locations and the time elapsed between these two positions) of the bird was ≤ 30 km/day (Hourlay 2003, Shimazaki *et al* 2004). As stopovers ecologically correspond mainly to foraging bouts, night

stops were excluded from the analysis. The stopover sites used by the eagle did not correspond to forced stops while facing orographic difficulties (eg a mountain pass with unfavourable meteorological conditions).

Wintering

As shown in Fig 1, during all periods of investigation (ie each period of investigation including outward and return migration) the eagle persistently occupied the two same wintering areas, 300 km apart, in northern and western Nigeria, which highlights a fidelity to winter quarters (cf Table 1). Furthermore, the bird systematically switched from a first wintering area (where it arrived after the autumn migration) to a second wintering area further south in Nigeria, used until the spring migration departure.

Migratory behaviour and the choice of wintering areas may vary from year to year, or even within one season, and are probably adapted to weather conditions and food availability. In this context, the choice of migratory behaviour and wintering areas can be considered an important component in the migratory strategy of this species (Meyburg & Meyburg 2004). Equipped with an Argos GPS solar transmitter, the Booted Eagle studied has not only performed five long-distance migrations between Europe and Africa, but also managed to breed successfully during this period. Perhaps the most surprising results from the track of this first Booted Eagle were its fidelity to breeding and wintering sites, and the similarity in departure dates from African grounds and arrival dates on breeding grounds during the spring migrations. Whether this was a particular characteristic of this bird or a general character of adult Booted Eagles will be determined by the future results of the tracking programme.

ACKNOWLEDGEMENTS

We would like to express our gratitude to everyone who helped in the capture of the eagles: V. Jorland, D. Planque, E. Preiss, O. Schiltz, A. Virondeau, M. Boutaud, R. Riols, D. Ristow, O. Villa, D. Legland, S. Bonillot, C. Malle, J. Ventrux, J. Chamard, T. Darnis, J.-M. Hertay, S. Travichon, E. Cavallin and J. Cavallin. The work was financially supported by the Région Limousin, the Direction Régionale de l'Environnement du Limousin, the Union Européenne (Natura 2000), the Institut de Recherche pour le Développement (IRD) and the Centre de Recherches sur la Biologie des Populations d'Oiseaux.

REFERENCES

- Araujo, J.** (1973) Falconiformes del Guadarrama. *Ardeola* **19**, 264–269.
- Baghino, L., Premuda, G., Gustin, M., Corso, M., Mellone, U. & Cardelli, C.** (2007) Exceptional wintering and spring migration of the Booted Eagle *Hieraetus pennatus* in Italy in 2004 and 2005. *Avocetta* **31**, 57–62.
- Bosch, J., Borrás, A. & Freixas, J.** (2005) Nesting habitat selection of Booted Eagle *Hieraetus pennatus* in central Catalonia. *Ardeola* **52**, 225–233.
- Diaz, J.** (2005) La vida privada del aguila calzada *Hieraetus pennatus*. *Quercus* **227**, 14–21.
- Grubb, T.G., Bowerman, W.W. & Howey, P.H.** (1994) Tracking local and seasonal movements of wintering Bald Eagles *Haliaeetus leucocephalus* from Arizona and Michigan with satellite telemetry. In *Raptor Conservation Today* (eds Meyburg, B.-U. & Chancellor, R.D.) pp 347–358. Pica Press, London.
- Hourlay, F.** (2003) Wintering of Western-European Black Storks in West Africa: results of satellite monitoring campaigns and carried out between 1995 and 2000 by the "Cigognes sans frontières" program and University of Liège. *Aves* **40**, 172–174.
- Martell, M.S., Henny, C.J., Nye, P.E. & Solensky, M.J.** (2001) Fall migration routes, timing and wintering sites of North American Ospreys as determined by satellite telemetry. *Condor* **103**, 715–724.
- Martínez, J.E., Pagán, I., Palazón, J.A. & Calvo, J.F.** (2007) Habitat use of Booted Eagles (*Hieraetus pennatus*) in a Special Protection Area: implications for conservation. *Biodiversity and Conservation* **16**, 3481–3488.
- Meyburg, B.-U. & Meyburg, C.** (2004) Migration, wintering and breeding of a Lesser Spotted Eagle (*Aquila pomarina*) from Slovakia tracked by satellite. *Journal of Ornithology* **145**, 1–7.
- Meyburg, B.-U., Meyburg, C. & Barbraud, J.-C.** (1998) Migration strategies of an adult Short-toed Eagle *Circaetus gallicus* tracked by satellite. *Alauda* **66**, 39–48.
- Meyburg, B.-U., Paillat, P. & Meyburg, C.** (2003) Migration routes of Steppe Eagles between Asia and Africa: a study by means of satellite telemetry. *Condor* **105**, 219–227.
- Shimazaki, H., Masayuki, T. & Higuchi, H.** (2004) Migration routes and important stopover sites of endangered oriental white storks (*Ciconia boyciana*) as revealed by satellite tracking. *Memoirs of National Institute of Polar Research Special Issue* **58**, 162–178.
- Suarez, S., Balbontin, J. & Ferrer, M.** (2000) Nesting habitat selection by Booted Eagles *Hieraetus pennatus* and implications for management. *Journal of Applied Ecology* **37**, 215–223.
- Thévenot, M., Vernon, R. & Bergier, P.** (2003) *The Birds of Morocco: an annotated checklist*. British Ornithologists' Union, Tring.
- Zalles, J.I. & Bildstein, K.L.** (2000) *Raptor watch: a global directory of raptor migration sites*. BirdLife Conservation Series **9**. BirdLife International, Cambridge.

(MS received 23 January 2010; accepted 21 February 2010)