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SHORT REPORT

First description of migration and wintering of adult Egyptian Vultures *Neophron percnopterus* tracked by GPS satellite telemetry

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Capsule Over two years birds showed high territorial and high winter site fidelity in the Sahel.

Egyptian Vultures *Neophron percnopterus* have declined over most of their European range and are classified as 'endangered' at global and regional levels (BirdLife International 2008). Fewer than 2000 pairs breed in Europe, with the majority (<1500) in Spain (SEO/BirdLife unpubl. data). Most research has focused on breeding ecology and little is known about these birds outside of their breeding areas. Ringing has shown that Egyptian Vultures migrate to the southern Sahara, but precise data about adult migration ecology and ranging behaviour in the wintering areas are rarely available (Mundy *et al.* 1992, Donázar 1993). The only available data on Egyptian Vulture migration are from the satellite tracking of three juveniles, two from southern France and one from Bulgaria, tracked in the late 1990s by means of Argos satellite telemetry (Meyburg *et al.* 2004). Here we describe the migratory routes, timing of migration, migratory parameters and ranging behaviour in wintering areas of two adult Egyptian Vultures tracked by global positioning system (GPS) satellite telemetry.

The first adult was captured on 9 August 2007 at a vulture restaurant located in the Villahermosa del Río district (Castellón province, eastern Spain, 40° 13′ N, 0° 28′ W). We named the bird *Azahar* (Tag #75657): a female, 1850 g when trapped. The second adult was captured on 14 August 2008 at a vulture restaurant located in Molina de Aragón (Guadalajara province, central Spain, 40° 48′ N, 1° 49′ E). It was named *Molina* (Tag #80419): a male, 1900 g when trapped. Birds were sexed by molecular methods (Fridolfsson & Ellegren 1999). A 45 g solar-powered GPS tag from Microwave Telemetry was fixed to their backs using a Teflon® harness sewn with a cotton ribbon, designed to ensure that the harness would fall from the bird at the end of the tag's life. The mass of the equipment, including the harness, metal ring and tag, was less than 3% of the bird's body mass, which is within recommended limits (Kenward 2001). The GPS tags were programmed to obtain GPS fixes every 2 hours on a 24 hours ON duty cycle during the migratory period, and on a 16 hours ON/8 hours OFF duty cycle for the wintering and breeding months. Data were retrieved and managed using the Satellite Tracking and Analysis Tool (Coyne & Godley 2005). Cartography was elaborated in ARCMAP 9.2 (ESRI Inc.; www.esri.com) and kernel analyses were performed with the 'Animal Movement' extension for ARCVIEW 3.2 (Hooge & Eichenlaub 1997). Fixed kernel home ranges were calculated by means of the least squares cross validation method (Silverman 1986). Since only two birds were tracked in this study, no comparisons were made between individuals, years and migration periods because it was considered that these would lack statistical and biological meaning.

For *Azahar*, 4036 GPS locations were received up to August 2009, 566 during migration, 3122 during wintering and the rest in the breeding area. For *Molina* a total of 1882 locations were received, 316 during migration and 1332 during wintering. The complete migratory routes and migratory parameters of both birds are shown in Fig. 1 and Table 1. In summary, these vultures travelled an

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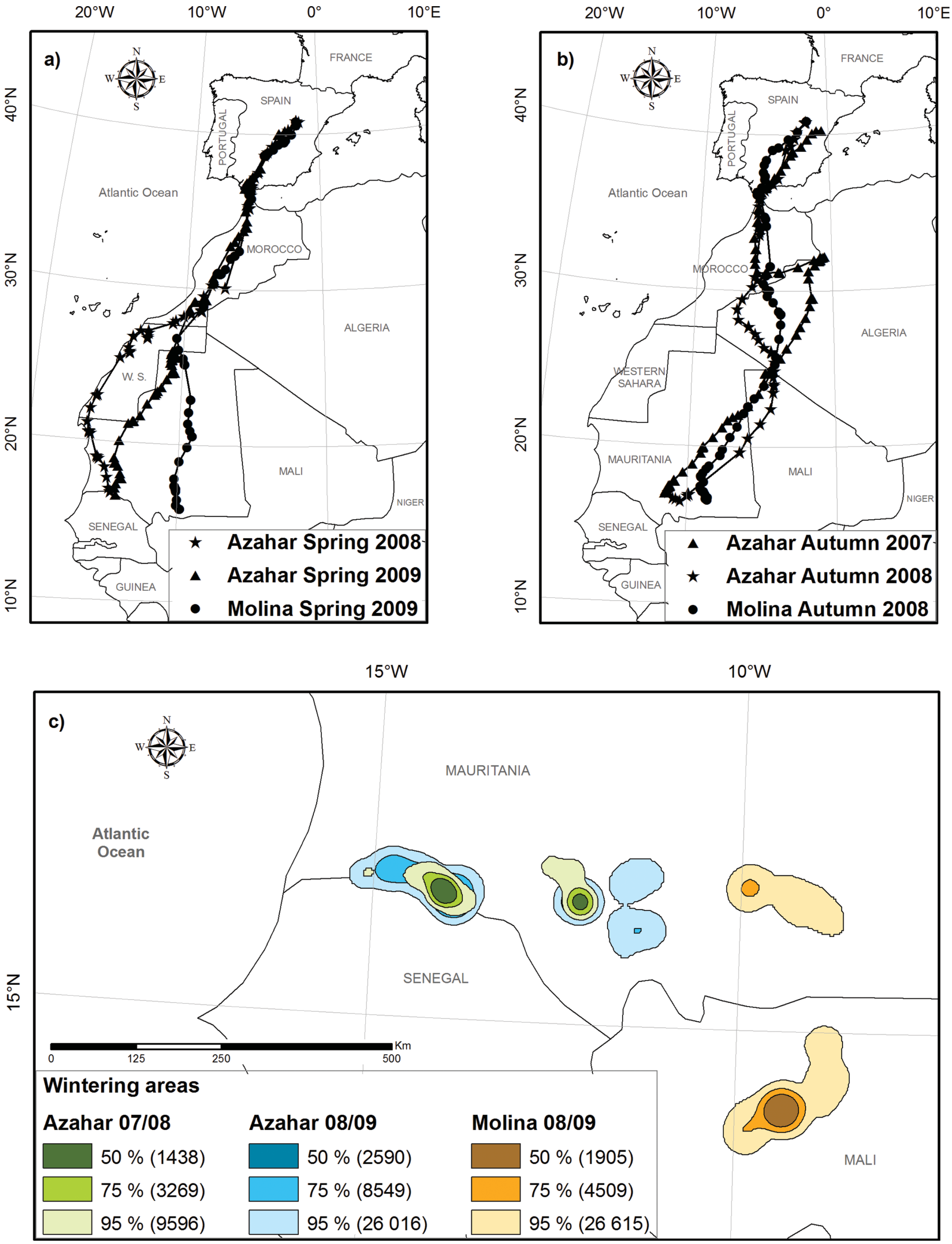

Figure 1. Migratory routes of two adult Egyptian Vultures tracked with global positioning system satellite telemetry from Spain to Africa during (a) spring and (b) autumn migration; (c) wintering ranging behaviour according to the Kernel Home Range analysis of wintering locations (see text for details). Range sizes are indicated in brackets and measured in km^2.

Table 1. Migratory parameters of two adult Egyptian Vultures tracked by global positioning system satellite telemetry during 2007–09.

	Autumn migration			Spring migration		
	Azahar		Molina	Azahar		Molina
Parameter	2007	2008	2008	2008	2009	2009
Departure	8 September (08:00–10:00)	2 September (10:00–12:00)	19 September (10:00–12:00)	1 March (10:00–12:00)	23 February (10:00–12:00)	18 February (10:00–12:00)
Crossing Strait of Gibraltar	10 September (09:00–11:00)	5 September (10:00–12:00)	23 September (14:00–16:00)	11 March (12:00–14:00)	13 March (14:00–16:00)	2 March (12:00–14:00)
Arrival at destination	24 September (16:00–18:00)	12 September (16:00–18:00)	2 October (10:00–12:00)	14 March (18:00–20:00)	17 March (14:00–16:00)	9 March (14:00–16:00)
Linear distance	2799	2798	2777	2939	2944	2704
Cumulative route distance	3568	3054	2942	3149	3120	2870
Time spent on migration	16	10	13	13	22	19
Average distance between consecutive roosting places	255	339	245	262	149	191
Minimum and maximum daily distances	18–448	150–529	100–398	154–592	0–343	0–690

Local times are given in brackets; distances are in km.

average Euclidean linear distance of 2791 ± 12 km with an average cumulative distance of 3188 ± 334 km during autumn migration. Similar distances were recorded on spring migration, with an average distance of 2862 ± 137 km and an average cumulative distance of 3046 ± 153 km. The maximum distance covered in one day was 690 km, during the 2009 spring migration of *Molina*. The autumn migration was completed in a shorter time than the spring migration (average migration days in autumn = 13 ± 3 days; spring = 18 ± 5 days) (Table 1). Birds travelled longer distances during autumn migration than during spring migration, with an average distance between consecutive roosting places of 280 ± 52 km in autumn versus 201 ± 57 km recorded in spring migration.

The birds migrated almost entirely during daytime, between 06:00 and 22:00 hours. Only eight short movements during nighttime were recorded during the three years of the study, and these were possibly because of disturbance at roosting sites. Hence, there is no evidence of nocturnal migration. Also, no stopover sites were detected. Ranging behaviour differed between migration seasons. Long-distance migration segments were more frequent during autumn migration than during spring migration.

There are only three recoveries of Spanish ringed Egyptian Vultures in Africa (Spanish National Database of Migratory Species): one ringed as a chick in Aragón (Spain) on 29 July 1989 and recovered on 25 January 1994 in northern Morocco; the second ringed in Western Sahara (former Spanish Sahara) on 22 June 1971 and recovered on 30 March 1974 in Mauritania; and the third ringed as a chick in Aragón on 28 June 1987 and recovered hurt on 27 April 1989 also in Mauritania.

Our results show that the migratory routes varied between birds and between years. Unlike other GPS-tracked raptors which are able to fly over extensive open water, both Egyptian Vultures migrated to Africa by crossing the narrowest part of the Strait of Gibraltar. This is in agreement with observational data reported during migration counts at this migratory bottleneck, where up to several hundred Egyptian Vultures cross to Africa daily during outward and homeward migratory movements. Once in northern Africa, the birds migrated following a more eastward route during autumn than during spring (Fig. 1). This could be the result of strong wind conditions when crossing the Sahara Desert (Liechti 2006) that force birds to curve autumn routes between 31 and 17° N (from Algeria to Mauritania and Mali). In fact, migratory routes during autumn migration seemed to curve in parallel between these latitudes (Fig. 1b).

Egyptian Vultures are soaring raptors that use thermal lift when travelling (Donázar 1993). Birds concentrated their daily movements between 06:00 and 22:00 hours, crossing the Strait of Gibraltar between 09:00 and 16:00 hours, both during autumn and spring migration (Table 1). Interestingly, both birds spent more days and showed slower daily speed during spring migration than autumn migration, and they did not go directly to their breeding locations after spring migration, but visited previously known vulture restaurants which perhaps represent a predictable food source (García-Ripollés *et al.* 2004). This is specially remarkable for the bird *Azahar*, which after arriving in Spain went first to the vulture restaurant located in Molina de Aragón (Guadalajara, Spain) and moved towards its breeding location two days later 125 km southeast, repeating the same sequence in 2008 and 2009. It is likely that prevailing northeast to southwest dominant tail-winds during autumn migration could help to explain the shorter autumn migration compared with spring migration (Rodríguez *et al.* 2009). Furthermore, birds crossed over the Sahara Desert during autumn migration, whereas they travelled close to the coastline during spring. Since the Sahara Desert is an ecological barrier for migratory birds, this would suggest that Egyptian Vultures adjust their migratory behaviour in response to landscape characteristics, accelerating migration speed over unsuitable landscapes (López-López *et al.* 2009, López-López *et al.* unpub. data).

Our results show high breeding location and wintering site fidelity in the two years of tracking. Birds winter in the African Sahelian region, which is defined by the area encompassed between the isolines of 200 mm and 600 mm mean annual rainfall (approx. latitudinal range between 13 and 17° N). This transitional ecoregion is composed of semi-arid grasslands, savannas, steppes, and thorn scrublands where traditional semi-nomad shepherds raise livestock in a system of transhumance, which are taken advantage of by Egyptian Vultures (review in Thiollay 2006). *Azahar* wintered in three areas in 2007 and 2008, located in southern Mauritania and along the Senegal border (Fig. 1c). The two western areas were the same over the two years (Fig. 1c). All *Azahar* wintering sites were characterized by landscape covered by closed-open herbaceous cover, sparse herbaceous and sparse shrub cover (Olson *et al.* 2001). The 95% kernel surface was smaller in 2007 (encompassing 9596 km^2) than in 2008 (26 016 km^2). *Molina* used two separated wintering sites in 2008. The first area was located in southern Mauritania, and was also characterized by sparse herbaceous and sparse shrub cover (Fig. 1c). The second area was located in Mali 285–320 km southwards. In contrast, this area was covered by closed-open deciduous shrub, cultivated and managed areas, mosaic of cropland, shrub and/or grass cover and bare areas (Fig. 1c). The 95% kernel encompassed 26 615 km^2. In both cases, wintering home-ranges were clearly smaller than those of two juvenile Egyptian Vultures reported in Meyburg *et al.* (2004), which encompassed 33 420 and 56 500 km^2, respectively. This may be the result of better knowledge of the landscape in the adult birds. Fidelity to wintering areas by adults can probably be related to the productivity in the region plus the unpredictability of Egyptian Vulture food resources. Our preliminary data coupled with further similar studies should allow the accurate determination of wintering areas and the accurate knowledge of migratory routes. This will facilitate the conservation of Egyptian Vultures outside of their breeding range.

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