J Ornithol (2006) 147: 69–72
DOI 10.1007/s10336-005-0020-x

ORIGINAL ARTICLE

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How far away in an hour? Daily movements of juvenile golden eagles (*Aquila chrysaetos*) tracked with satellite telemetry

Received: 24 January 2005 / Revised: 25 April 2005 / Accepted: 26 June 2005 / Published online: 20 October 2005

Abstract We tracked the daily movements of three juvenile golden eagles (*Aquila chrysaetos*) using satellite telemetry. Straight distances covered in an hour and throughout a day were calculated. Daily movements of golden eagles are mostly characterized by short-distance excursions, with 64% of the distances covered in an hour shorter than 1 km and 95% shorter than 9 km. Both the longest movements and the largest proportion of long-distance movements, were concentrated between 1100 and 1800 hours, the peak of daily activities. Average hourly distances during that peak oscillated between 2 and 6 km, with records of more than 20 km. Distances covered in a day ranged between 0.1 and 53.2 km with an average of 14.0 km (SD = 13.4). Differences in the distances covered at different times of the day probably reflect a balance between the temporal pattern of preferred prey's activity and the eagles' progressive satiation along the day on one hand, and the higher likelihood of thermal and updraughts (which facilitate long-distance movements) occurring at noon and the early afternoon, on the other.

Keywords *Aquila chrysaetos* · Distance · Dispersal · Movements · Satellite telemetry

Communicated by F. Bairlein

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Knowledge of the distances covered by individuals in their daily movements is key for understanding aspects of behaviour as diverse as foraging, habitat selection, mating system, migration routes, and territoriality (e.g., Bullock et al 2001; Clobert et al 2001; Sutherland 1996). In our studies of golden eagles' (*Aquila chrysaetos*) dispersal and ranging behaviour, we often find ourselves asking how far away from a point it is expected to find individuals after a certain amount of time, or how likely it is that a point will be visited by an individual in its daily movements. Most often we do not have a clear answer to those questions, as precise information regarding the distances covered by golden eagles in a day or a few hours is rarely available (but see Haller 1996). Here, we give a partial answer to such questions, using information of three golden eagles captured in Spain and followed using satellite telemetry. Individuals where tagged with GPS transmitters in June 2004, while still in the nest, and monitored until December 2004. As pre-dispersal movements are restricted to a small area around the natal nest (e.g., Haller 1996; Walker 1987; Watson 1997), only locations recorded after the onset of the juvenile dispersal (September) were analysed. Hence, distances provided here correspond to the first 3 months of the individuals' juvenile dispersal. Soutullo et al. (2005a, b) provide further details of the study area, the individuals monitored, the monitoring techniques, and the criteria used to determine the onset of the juvenile dispersal.

Average straight distances covered in an hour and during a day were calculated. Both constitute the basic units of measure in many dispersal and ranging behaviour studies (Kenward 2001; Sanderson 1966). For each individual, distance covered in an hour was calculated as the length of the straight line joining two locations recorded with an hour of difference. That distance, though, is not necessarily the maximum distance covered by a bird in an hour, as in that period the bird could have flown further away from the first

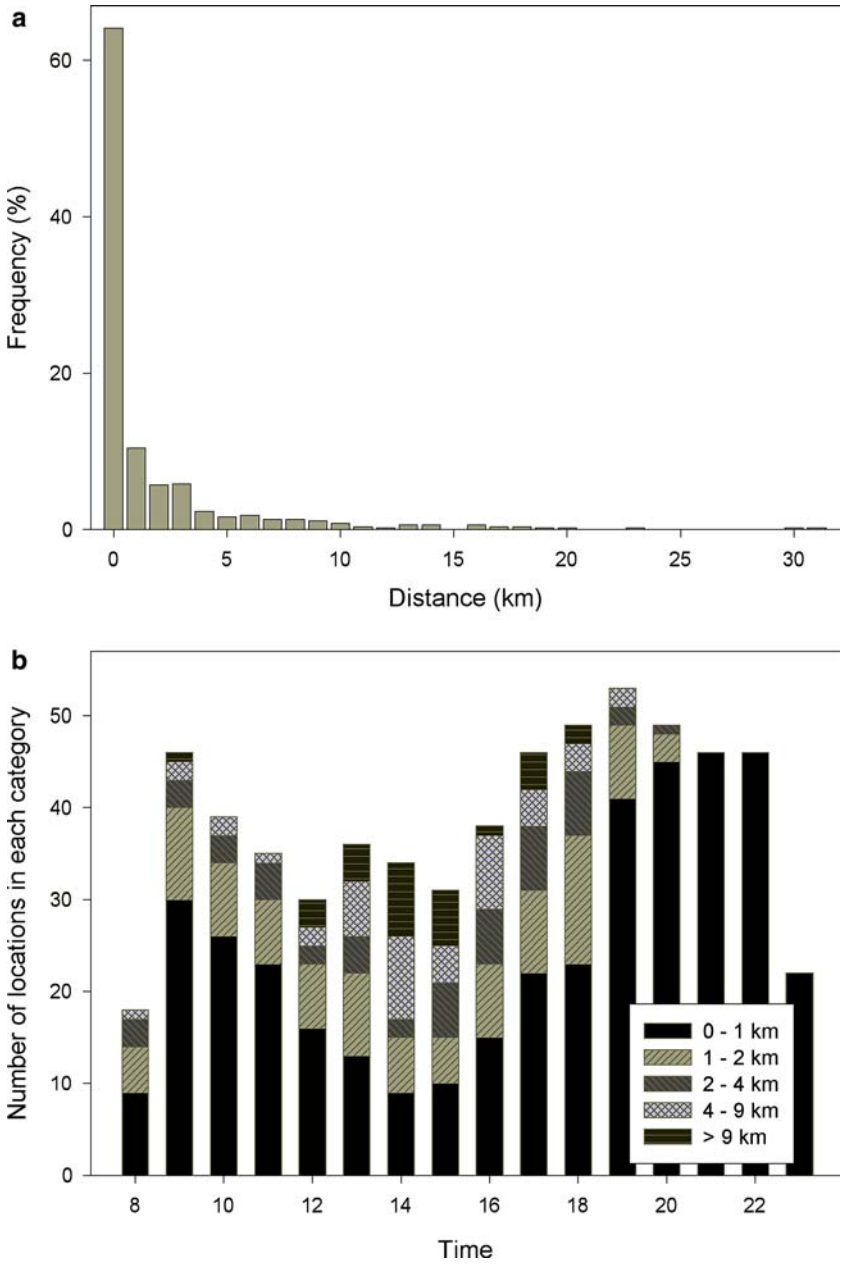

Fig. 1 Daily movements of three golden eagles (*Aquila chrysaetos*): **a** distances covered in an hour and frequency ($n = 618$) of movements of different length (distance categories are 1 km wide); **b** differences in the frequency of movements of different length throughout the day. "*Time*" indicates the time of the last location (e.g., "9" indicates movements recorded between 0800 and 0900 hours). Note time is the Spanish official time, which is GMT + 2 during the summer and until the last weekend of October, and GMT + 1 the rest of the year

location than where it was finally located. The same applies for the distance covered in a day, estimated here as the length of the straight line joining the two locations furthest away from each other. To avoid excessive underestimation, only days for which at least three locations were recorded, with at least one of them within the peak of birds' activity (see below), were considered. We used the Kruskal-Wallis test to explore hourly differences in distances covered. To explore the possibility of daylong distances changing with birds' age, temporal trends were tested using Spearman's correlations. For the analyses of the distances covered in a day, the length of movements at different times of the day, and the frequency of movements of different lengths, the data of all individuals were pooled together.

The three eagles showed significant differences in the distances moved at different times of the day ($P < 0.05$ in the three cases). Although there were records of eagles travelling more than 20 km in an hour, 95% of the movements did not exceed 9 km and 64% were shorter than 1 km (Fig. 1). This suggests that although golden eagles do eventually perform long-distance journeys, their daily movements are largely characterized by short-distance excursions. Both the longest movements and the largest proportion of long-distance movements were undertaken between 1100 and 1800 hours, the peak of daily activities, with a sharp decline in the distances travelled after 1800 hours and no movements after 2100 hours (Fig. 1; Table 1). This is in line with Haller's (Haller 1996) observations in the Alps. Distances covered in an hour during the peak of activity vary widely,

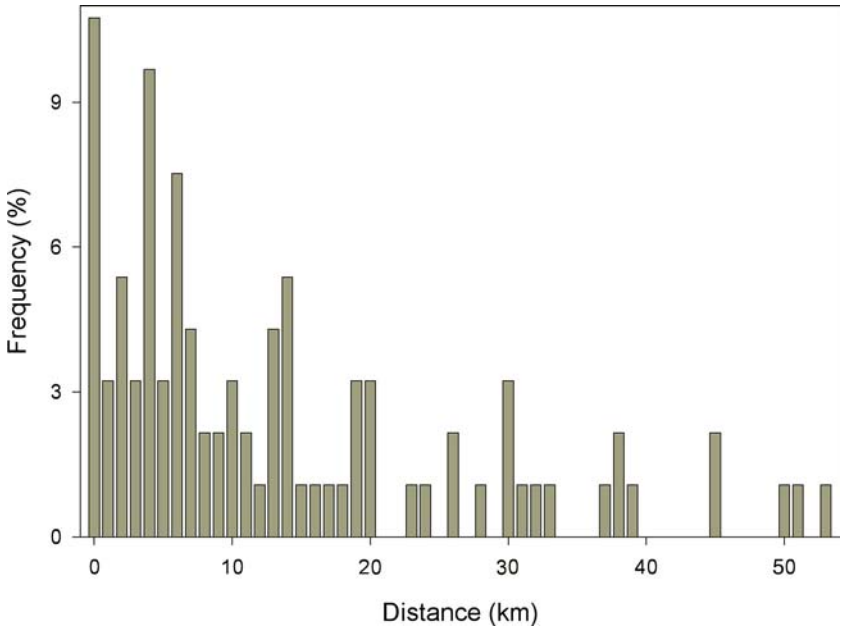

Fig. 2 Distances covered in a day by three golden eagles. Frequency of movements of different length (distance categories are 1 km wide) is shown ($n = 93$)

with averages around 2–6 km. Distances covered in a day ranged between 0.1 and 53.2 km, with an average of 14.0 km (SD = 13.4; median = 9.1) and 75% of the movements covering less than 20 km (Fig. 2). No temporal trends in those distances were observed ($P > 0.19$ for the three individuals). Compared to the distribution of the hourly movements, the frequency of daylong movements of different lengths is much more evenly distributed along the range of observed distances.

Given the elusive behaviour of golden eagles and the remoteness and difficulty of access to many of the areas they dwell about, very little is actually known about the species' ranging behaviour and daily movements (Watson 1997). Until the recent development of lightweight satellite transmitters (Platform Terminal Transmitters), detailed monitoring of golden eagles' movements was largely impracticable. Therefore, the results we present here constitute the first detailed account of the species' daily movements. Due to the small number of individuals monitored no between-sex comparisons were conducted. However, such differences are likely to exist (see, e.g., Soutullo et al. 2005a, b).

Table 1 Distances (km) covered by three golden eagles (*Aquila chrysaetos*) in an hour, calculated as the distance between two locations recorded with an hour of difference

	Male		Male		Female	
	$n = 34$		$n = 484$		$n = 100$	
Time	Mean ± SD	Min–max	Mean ± SD	Min–max	Mean ± SD	Min–max
8			1.4 ± 1.5	0.0–4.8	10.0	
9	0.3 ± 0.4	0.0–0.6	1.8 ± 3.3	0.0–19.0	0.7 ± 0.8	0.0–2.3
10	0.0		1.2 ± 1.7	0.0–8.6	0.4 ± 0.5	0.1–1.1
11	2.2 ± 2.4	0.5–3.8	1.1 ± 1.4	0.0–6.6	0.1 ± 0.1	0.0–0.2
12	7.3 ± 2.3	5.7–8.9	2.2 ± 3.7	0.0–14.3	5.9 ± 10.0	0.1–23.6
13	3.4 ± 2.8	1.0–6.4	3.6 ± 4.5	0.0–18.1	4.7 ± 5.6	0.0–13.1
14	9.8 ± 6.3	4.7–16.8	5.7 ± 5.3	0.0–17.8	5.7 ± 7.5	0.0–16.9
15	13.2		5.6 ± 8.9	0.0–31.5	5.4 ± 4.4	0.0–10.5
16	17.7		3.0 ± 3.1	0.0–9.6	2.0 ± 2.8	0.0–8.0
17	1.9 ± 2.2	0.4–3.5	2.7 ± 3.9	0.0–16.0	3.6 ± 4.7	0.0–14.3
18	5.4 ± 9.3	0.0–19.4	1.4 ± 1.5	0.0–6.5	4.3 ± 5.8	0.2–20.2
19	0.6 ± 1.0	0.0–2.0	0.9 ± 1.8	0.0–8.6	0.8 ± 1.2	0.0–3.7
20	0.2 ± 0.2	0.0–0.5	0.5 ± 0.8	0.0–3.5	0.3 ± 0.2	0.0–0.5
21	0.0 ± 0.0	0.0–0.0	0.1 ± 0.1	0.0–0.6	0.1 ± 0.3	0.0–0.9
22	0.0		0.0 ± 0.0	0.0–0.0	0.0 ± 0.0	0.0–0.0
23	0.0		0.0 ± 0.0	0.0–0.0	0.0 ± 0.0	0.0–0.0

"Time" indicates the time of the last location (e.g., the row "9" indicates the distances covered between 0800 and 0900 hours). Individuals' gender and the number of locations analysed are indicated. Note time is the Spanish official time, which is GMT + 2 during the summer and until the last weekend of October, and GMT + 1 the rest of the year

On the other hand, here we analyse the distances moved by golden eagles during the first stages of their juvenile dispersal, when, although individuals are still improving their flying techniques, they tend to dwell about areas considerable larger than those used by adults (Haller 1982, 1994, 1996). Actually, the existence of two distinct phases during the juvenile dispersal has been suggested, with the earliest "dispersive" phase probably characterised by more frequent long-range exploratory movements (Watson 1997). Thus, the distances we provide here are probably close to the upper limit of the range of distances covered by golden eagles in their daily movements throughout their lives.

Finally, differences in the distances moved at different times of the day are probably linked to foraging behaviour to some degree (Newton 1979; Watson 1997), though not uniquely. Thus, while they probably reflect the temporal pattern of preferred preys' activity and eagles' increasing chances of satiation during the day on one hand, they probably also reflect the higher likelihood of thermal and updraughts occurring at noon and during the early afternoon. This agrees with Haller's (1996) observations that flight activity is strongly influenced by thermal upwinds and occurs mainly on sun-exposed slopes and around noon. Actually, when soaring, golden eagles use thermals or updraughts to gain height and spend long periods in the air gliding (Watson 1997), which facilitates long-distance movements.

Zusammenfassung

Wie weit in einer Stunde? Tägliche Bewegungen von juvenilen Steinadlern (*Aquila chrysaetos*) anhand Satelliten-Telemetrie

Wir verfolgten die täglichen Bewegungen dreier juveniler Steinadler (*Aquila chrysaetos*) mit Hilfe der Satelliten-Telemetrie. Wir berechneten die je Stunde und Tag zurückgelegten Strecken. Die täglichen Bewegungen von Steinadlern sind meistens charakterisiert durch kurze Exkursionen, wobei 64% der in einer Stunde zurückgelegten Strecken kürzer als 1 km waren und 95% kürzer als 9 km. Sowohl die weitesten zurückgelegten Strecken als auch die Anzahl von langen Strecken waren zwischen 11.00 und 18.00 Uhr, zum Höhepunkt der täglichen Aktivität, am häufigsten. Die durchschnittlichen stündlichen Strecken während dieser Zeit schwankten zwischen 2 und 6 km, mit Spitzen von über 20 km. Die an einem Tag zurückgelegten Strecken reichten von 0.1 bis 53.2 km mit einem Durchschnitt von 14.0 ± 13.4 (SD) km. Die Unterschiede zwischen den zu verschiedenen Tageszeiten zurückgelegten Strecken reflektieren wahrscheinlich ein Gleichgewicht zwischen den zeitlichen Aktivitätsmustern der bevorzugten Beute und der fortschreitenden Sättigung der Adler über den Tag auf der einen Seite und die höhere Wahrscheinlichkeit dafür, dass Thermik und Aufwinde, die Langstreckenflüge unterstützen, am Mittag und frühen Nachmittag auftreten, auf der anderen Seite.

Acknowledgements Thanks are due to the Conselleria de Territori i Habitatge of the Generalitat Valenciana (P. Mateache, M. Romanillos and A. Izquierdo), and to Luis Cadahía for his collaboration in the fieldwork and the retrieval of the data. This paper is part of A.S.'s Ph.D. thesis at the Universidad de Alicante.

References

Bullock JM, Kenward RE, Hails RS (eds) (2001) Dispersal ecology. Blackwell, Oxford

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

Haller H (1982) Raumorganisation und Dynamik einer Population des Steinadlers *Aquila chrysaetos* in den Zentralalpen. Ornithol Beob 79:163–211

Haller H (1994) Der Steinadler *Aquila chrysaetos* als Brutvogel im schweizerischen Alpenvorland: Ausbreitungstendenzen und ihre populations - ökologischen Grundlagen. Ornithol Beob 91:237–254

Haller H (1996) Der Steinadler in Graubünden. Langfristige Untersuchungen zur Populationsökologie von *Aquila chrysaetos* im Zentrum der Alpen. Ornithol Beob Beiheft 9:1–167

Kenward RE (2001) A manual for wildlife radio tagging. Academic Press, London

Newton I (1979) Population ecology of raptors. Poyser, Berkhamsted

Sanderson GC (1966) The study of mammal movements—a review. J Wildl Manag 30:215–235

Soutullo A, Urios V, Ferrer M, Peñarrubia SG (2005a) Post-fledging behaviour in golden eagles: onset of the juvenile dispersal and progressive distancing from the nest. Ibis (in press)

Soutullo A, Urios V, Ferrer M, Peñarrubia SG (2005b) Dispersal of golden eagles *Aquila chrysaetos* during their first year of life. Bird Study (in press)

Sutherland WJ (1996) From individual behaviour to population ecology. Oxford University Press, Oxford

Walker DG (1987) Observations on the post-fledging period of the golden eagle *Aquila chrysaetos* in England. Ibis 129:92–96

Watson J (1997) The golden eagle. Poyser, London