

Geolocators map the wintering grounds of threatened Lesser Kestrels in Africa

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ABSTRACT

Aim To identify the wintering grounds of the threatened western European Lesser Kestrels to focus conservation efforts in those areas.

Location Huelva Province, southern Spain, as breeding range, and western Africa (Senegal and Mauritania), as wintering range.

Methods We used archival light level geolocators (1.5 g) to map the wintering areas and determine some characteristics of the migratory journeys of 20 adult Lesser Kestrels from the Iberian Peninsula tagged in 2007.

Results Thirteen geolocators were recovered the following breeding season (2008) after attachment in 2007. Four recovered geolocators provided useful data. According to kernel density analyses, kestrels wintered near the Senegal River (border between Mauritania and Senegal). Pre-nuptial migration took longer than the post-nuptial migration, which may be the consequence of a loop migration.

Main conclusions Geolocators have solved a crucial conservation question (i.e. the winter destination of western European Lesser kestrels), and these devices have thus proved useful to determine the location of the winter quarters of small sized migratory species. Our data indicate that European Lesser Kestrels winter in West Africa, in accordance with previous suggestions based on scattered observations during the winter months. This valuable information should serve to focus conservation efforts both in northern Senegal and southern Mauritania. Large roosts gathering thousands of lesser kestrels had been recorded in these areas over the years, but there was no previous confirmation of individuals staying all winter long. Specific and sustained protection of the roost sites, where the birds may be most vulnerable, should be sought in conjunction with local authorities.

Keywords

Conservation, geocator, Lesser Kestrels, migration, sub-Saharan region, wintering quarters.

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INTRODUCTION

The Lesser Kestrel *Falco naumanni* is a small migratory falcon which breeds in the Palearctic from the Iberian Peninsula through the Mediterranean basin, Asia Minor, Western Asia, to Mongolia and China. Its populations have decreased dramatically (c. 95%) in the western Palearctic since the 1950s, and a reduction of more than 30% of the world population has been estimated, leading to its current Vulnerable status. Habitat degradation and loss, as a result of agriculture intensification, afforestation and urban sprawl in its Western Palearctic breeding grounds, as well as in some winter areas, have been suggested as the main causes of the decline suffered by the

species (BirdLife International, 2008). However, there is no contrasted information about threat factors in its winter quarters, as the actual location of the wintering grounds in Africa of birds of known origin has never been mapped.

Flocks of foraging Lesser kestrels and roost aggregations have been sighted from November to February in the Sub-Saharan region, East and South of Africa and South of Arabian Peninsula (Ferguson-Lees & Christie, 2001). Moreau (1972) reported that populations from different parts of the breeding range tended to remain separated in the winter; however, evidence for this pattern is sparse and inconclusive. Genetic analyses based on sequencing of mitochondrial DNA indicated that individuals wintering in South Africa originated from the

Eastern populations of the breeding range, although the origin of some haplotypes was unknown and several individuals from Western Mediterranean colonies clustered within Eastern populations (Wink et al., 2004). The recovery of banded birds in the presumptive African winter quarters seems to support this pattern, but the number of band recoveries to support this hypothesis is low (Appendix S1A). Furthermore, migration routes are unknown. Heim de Balsac & Mayaud (1962) hypothesized that Lesser Kestrels from Western European populations carried out a loop migration. Thus, during the post-nuptial migration, the individuals would cross the Sahara desert in a wide front, while the return would be mainly carried out through the Western Sahara and/or coastal Africa.

The aim of our study was to locate the wintering areas, as well as the migration routes, of Western European Lesser Kestrels by using light level geolocation (a type of Global Location Sensing – GLS). At present, mapping bird wintering areas of long-distance migratory species are mainly based on banding recoveries or band controls (e.g. Ottosson et al., 2005), satellite telemetry if the species is large enough for the individuals to carry Platform Transmitter Terminal's (PTT's) (e.g. Strandberg et al., 2008), stable isotope analysis of feathers or other tissues (e.g. Sarasola et al., 2008) and through the use of genetic markers (Wink, 2006; Lopes et al., 2008). Light level geolocation is a relatively new technology mainly restricted so far to marine animals such as tuna, seals, penguins, albatrosses and shearwaters, which are capable of carrying heavy loggers, are easy to re-capture and range over large pelagic areas ensuring distance from man-made light sources. Although there is no reason why other animal groups presenting similar characteristics will not be successfully tracked, this technique has not yet been widely used in terrestrial animals (but see Eichhorn et al., 2006 and Stutchbury et al., 2009). The currently available (and affordable) miniaturized data loggers make it possible to track and determine migration, stop-over and wintering areas of a wide range of smaller animals with far greater accuracy than is currently possible with other methodologies (see above). Especially for those endangered species which have experienced alarming declines, this information is crucial to their conservation (Newton, 2004). Tracking endangered birds to their wintering grounds will help identify threats in these previously unknown areas.

METHODS

Light level geolocation is based on logging diurnal changes in light levels (Hill, 1994). Archival data loggers equipped with an accurate internal clock record light intensities enabling the estimation of sun elevation. These measurements are used to estimate geographical position (a daily sunrise and sunset recording can give two fixes per day with an average accuracy of 186 ± 114 km – Phillips et al., 2004). Day and/or night length determines the latitude and time of local midday and/or midnight the longitude. The loggers measured light every minute, and recorded the maximum light level at the end of every 10-minute period (see details in Afanasyev, 2004). The

advantages over PTT are reduced costs (with no satellite requirements), small size, extended battery life, and if attached securely, indefinite device retention. However, archival light threshold-level geolocation shows several inherent disadvantages: recapture is necessary to download data, and only two locations are available per day. In addition, it is impossible to estimate latitude around each equinox, when day time is approximately equal to night time at all latitudes. Furthermore, location accuracy varies according to geographical area, thus latitude determinations are poor between tropics becoming worse closer to the equator, and position cannot be calculated without both a day and night period (Hill, 1994).

We used twenty 1.5 g data loggers designed and developed by the British Antarctic Survey (models Mk14S and Mk14 – British Antarctic Survey, 2008), which were fitted to 10 Lesser Kestrel pairs during the 2007 breeding season in an urban colony at La Palma del Condado ($37^{\circ}23'N$, $6^{\circ}33'W$), Huelva province, southern Spain. Data loggers were attached in two ways: on Teflon harnesses as back mounts (five pairs), and on darvic rings as leg mounts (five remaining pairs). During the 2008 breeding season, we looked for marked birds at the colony to retrieve geolocators and download the data they had accumulated. All retrieved geolocators were pre- and post-calibrated during 7–10 days following manufacturer instructions. Downloading, processing and data analysis were carried out with BasTrak, TransEdit and BirdTracker programs respectively (British Antarctic Survey, 2008). Positions were calculated by inspecting the integrity of the daily light curve and marking sunrise and sunset times. Using calibrated data, the sun elevation value for threshold analysis was set to $>4.7^{\circ}$ corresponding to the arbitrary threshold level of 32. To filter unrealistic positions during the wintering period, the following data points were removed: (a) those obtained from light curves showing interferences at dawn or dusk, and (b) those with a speed index (V_i) above 25 km h^{-1} , as calculated by the square root speed average of the segments formed with the two preceding and the two following positions:

$$V_i = \sqrt{\frac{1}{4} \sum_{j=i-2}^{j=i+2} \delta v_{ij}^2}$$

where $V_{i, j+i}$ is the velocity between successive positions i and $j + i$. Data were smoothed twice, and the iterative speed filter then applied to remove the unlikely locations remaining. The great-circle distance between consecutive fixes was used in all velocity calculations (Phillips et al., 2004). Kernel density distributions maps were derived from filtered and validated locations using the kernel function implemented in the Animal Movement extension of ArcView 3.2 (ESRI, Redlands, CA, USA) and a UTM 28N projection. The smoothing parameter (h) was set to 45,000 m and grid size to 500 m. Although locations are not serially independent, this is not a requirement for kernel analysis (De Solla et al., 1999).

Since Lesser Kestrel migration coincides approximately with the spring and autumn equinoxes, it was not possible to determine migration routes precisely. Therefore, we only took

into account the longitude data during the migration time, which are not biased during equinoxes (Hill, 1994). In this case, only longitude data from unrealistic positions obtained from light curves showing interferences at dawn or dusk were deleted. Timing and rate of migration were calculated assuming that birds finished migration when longitude stabilized (Guilford et al., 2009; Stutchbury et al., 2009). This assumption is certainly not valid, but lets us compare the patterns of post- and pre-nuptial migrations.

RESULTS

At least 15 different individuals carrying geolocators were sighted during the 2008 breeding season at the colony. We were able to retrieve 13 geolocators, of which six failed to download or only contained data of a few days after attachment, largely due to physical damage. Out of seven birds recaptured with geolocators which contained some data, one did not migrate and remained in the Iberian Peninsula (see Appendix S2). Geolocators fitted as leg mounts on darvic rings ($n = 7$) showed damage caused by bites, scratches and ingrained dirt, and none contained usable data. However, recorded data in three of these damaged leg mounted geolocators suggested that the birds did migrate, and that they probably wintered in the same general area as the other birds with back-mounted geolocators.

The detailed migration results discussed here came from three harness mounted birds. All individuals ($n = 3$) wintered in the same area in the North of Senegal and South of Mauritania (Fig. 1). They were present in the area from the end of September until early March. Home range individually varied in area, but there was a partial overlap in the winter areas of the three individuals (Appendix S3). These figures are probably exaggerated due to unquantifiable shading uncertainties (e.g. vegetation, clouds, dirt) adding to the inherently low accuracy of geolocators.

According to longitude data, the post-nuptial migration took place during the second half of September and early October, and lasted $c. 5 \pm 1$ days ($n = 3$). The pre-nuptial migration took place during the first half of February and late March (Fig. 2), and lasted $c. 24.3 \pm 10$ days ($n = 3$) (Appendix S2). The length of pre-nuptial migration was 4.2 times longer and 3.5 times more variable in time than the post-nuptial one.

DISCUSSION

Despite the constraints inherent to light level geolocation, this study shows for the first time the wintering areas of Lesser Kestrels with a known origin (i.e. a colony in the south of the Iberian peninsula), as well as the first details of timing and rate of their migrations. So far, Lesser Kestrels had been widely recorded in West Africa, but not consistently (Moreau, 1972; Pilard et al., 2004, 2005). Specifically in Senegal, large flocks of Lesser Kestrels had been sighted in the deltas of the Senegal (Triplet et al., 1993; Triplet & Yésou, 1995) and Saloum rivers

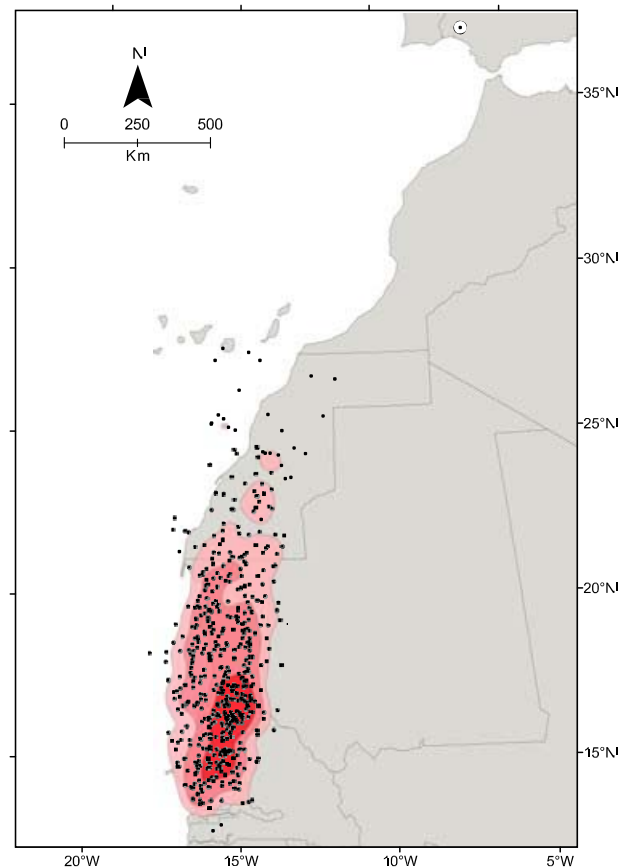


Figure 1 Validated locations and activity ranges derived from kernel analyses (encompassing 95, 75 and 50% of the locations) in the wintering areas of three adult Lesser Kestrels during a winter period (November, December 2007 and January 2008). The white circle with a black point shows the location of the breeding colony of the individuals at La Palma del Condado (Huelva Province, Spain).

(Isenmann, 2005; LPO, 2008; see Appendix S1B). These observations had been carried out during January or February, and it was believed that the birds were in active migration (Pilard et al., 2004). Our data show that Lesser Kestrels may spend the whole winter in those areas. Possibly, the observed large flocks reflect pre-migratory aggregations, as well as the use of communal roosts at times when migratory locusts are the staple prey (Triplet et al., 1993; Triplet & Yésou, 1995; Isenmann, 2005). Ringing of Lesser Kestrels has provided only five recoveries in the presumptive winter quarters (Appendixes), two corresponding to western European birds (see below) and three to Asian birds that wintered in South Africa. In the case of Spain, more than 37,000 Lesser Kestrels have been ringed during the period 1973–2006, and only two recoveries of corpses in unusual dates (20 June 1992 and 23 April 1996) have been obtained in the Western African presumptive winter quarters. The scarcity of recoveries may be associated to the low presence of ornithologists, bird-watchers or even tourists in the Sahel area, at least compared with other African regions.

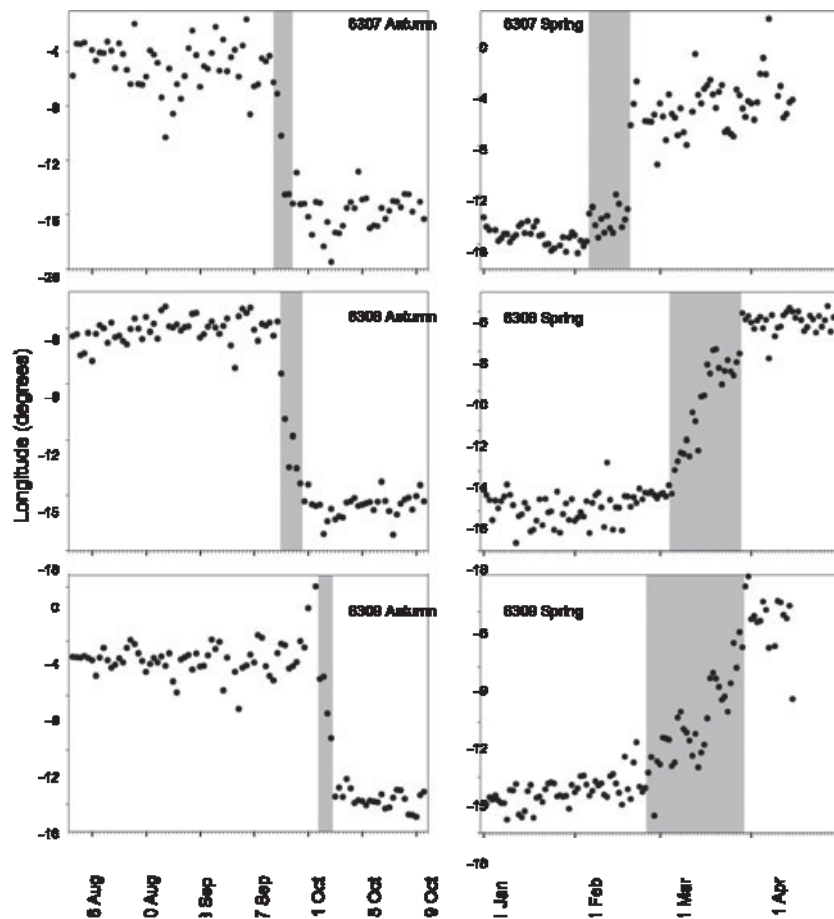


Figure 2 Longitude variations during post- and pre-nuptial migration of Lesser Kestrels. Shade area indicates the estimated duration of migration. Each point corresponds to the average longitude of the date (two locations per day).

The proportion of individuals which migrated was similar (75 or 85% if we take into account the darvic ring data loggers with poor data) to that reported for the species in the same population (19% of adults are residents in southern Spain; Negro et al., 1991; Negro, 1997). The fact that Lesser Kestrel migration coincided approximately with the equinoxes, and in proximity to the tropics, precluded the ability to include latitude in the plotting of migratory routes (Hill, 1994). The longer pre-nuptial migration in comparison to the post-nuptial migration contrasts with the typical pattern shown by other birds (Curry-Lindahl, 1981; Alerstam et al., 2006; Stutchbury et al., 2009). In migratory birds, early arrivals on the breeding grounds entail advantages in terms of high-quality site occupancy. Several facts, including the active defence of nest holes during a 3-month period before egg-laying (February, March and April) or the sequential arrival of adult males, adult females and yearlings to the breeding colonies (Negro et al., 1991; Negro, 1997), would predict a migratory pattern contrary to the observed one (see also Sergio et al., 2007). Northern-east directions of dominant trade winds through the migratory routes could be responsible for the observed pattern with tail-winds aiding the post-nuptial migration (Liechti, 2006). Another plausible and non-mutually exclusive explanation for our results is the ringlet migration proposed by Heim de Balsac & Mayaud (1962). Thus, the rapid rate of change in longitude during

post-nuptial migration could indicate that the birds migrate in a straight southerly direction crossing the Sahara desert, and ending the migration in a relatively short travel through the Sahel until the arrival to the winter areas. On the other hand, during the pre-nuptial migration, Lesser Kestrels may flock together and come back to the breeding grounds through Western Sahara, and thus a gentler longitude slope would be drawn (Fig. 2). The mean velocity of post-nuptial migrations reported here (range 4–6 days and 417–625 km day⁻¹) is higher than the estimated for other *Falco* species (McGrady et al., 2002; Ganusevich et al., 2004; Strandberg et al., 2009b) or raptors in general (maximum speed of about 200 km, see Strandberg et al., 2009a) and similar to two songbirds (Stutchbury et al., 2009). This may be related to the fact that the Sahara desert constitutes almost entirely the route until the wintering grounds. It is well known that birds cross the Sahara desert in a shorter time period than other safer and more suitable zones (Meyburg et al., 2004; Klaassen et al., 2008). In the case of Lesser Kestrel, it has been proposed that birds make a continuous flight of some 2500 km in post-nuptial migration (Moreau, 1972). In this sense, Eurasian Hobby *Falco subbuteo* is able to make a non-stop flight over a distance of 740 km across the Mediterranean Sea during 27 hours (Strandberg et al., 2009b). If we accept the loop migration hypothesis, the pre-nuptial migratory route will cross a smaller area of desert, and

consequently birds could fly over a safer terrain. However, we have only used longitude data, and therefore, our conclusions may be biased.

The fitted geolocators did not appear to have severely affected the birds in any significant way. Breeding success during tagging year and survival did not vary between tagged and un-tagged individuals (Rodríguez et al., 2009). We will therefore assume that data obtained are representative for breeding birds of our study colony. Given that the geolocators fitted on darvic bands failed to provide usable data due to damage caused by the birds themselves, we recommend the use of back-mounted geolocators, at least for raptors or species with strong beaks. Furthermore, leg mounting may be unsuitable for geolocators on many terrestrial species due to the accumulation of dirt over the light sensor; to date, most success with leg mounting geolocators has been with seabirds (e.g. Guilford et al., 2009). In the case of back-mounted geolocators, the light sensor is kept cleaner and less accessible to the beak and talons than in the leg mounts.

According to mostly anecdotal observations, the winter ecology of the Lesser Kestrel appears to be similar to that of other resident or long-distance migratory raptors such as the Black Kite *Milvus migrans* or the African Swallow-tailed Kite *Chelictinia riocourii* in the same area, roosting in large communal roosts and feeding on locusts and grasshoppers (Triplet & Yésou, 1995; Pilard et al., 2004, 2005; Isenmann, 2005; LPO, 2008). It has been reported by satellite telemetry that other Western European raptors such as the Marsh Harrier *Circus aeruginosus* (Strandberg et al., 2008), Montagu's Harrier *Circus pygargus* (Limiñana et al., 2007) or Egyptian Vulture *Neophron percnopterus* (Meyburg et al., 2004), winter also in the Sahel zone. Some of them, mainly locust and grasshopper consumers, have suffered severe declines in recent decades, possibly related to droughts and pesticide use to control insects (Newton, 2004; Sánchez-Zapata et al., 2007). Due to the gregarious behaviour of kestrels, specific and localized conservation measures may help conserve almost the entire wintering European population (LPO, 2008).

While the banding of thousands of Lesser Kestrels throughout the Western European breeding range for more than 30 years has failed to provide conclusive data on wintering and migration, inexpensive geolocators have solved a crucial question in only 1 year of study. As migratory kestrels spend a considerable time on the wintering grounds, this valuable information should serve to focus conservation efforts both in time and space. Specifically, the large aggregations of kestrels previously observed in northern Senegal and southern Mauritania in the winter months may now be attributed to genuine wintering individuals that may stay in the area for several months. A single roost site found in Senegal gathering about 24,000 individuals in 2007, and that may have been used by the kestrels for years, holds every season more than the equivalent of one-third of the western European lesser kestrel population and deserves specific protection in conjunction with local authorities (see LPO, 2008).

It is now clear that there are at least two main wintering grounds for lesser kestrels in Africa: the one reported here in Western Africa that appears to recruit birds from the Western Palearctic; and South Africa, the first destination for Lesser Kestrel recognized years ago, and that seems to hold birds of Asian origin exclusively (Wink et al., 2004). The western route is considerably shorter (2500–3500 km) than the eastern one (8000–10,000 km), raising interesting questions on energetic constraints and adaptations for medium- or long-distance migration in birds travelling one or the other migration route.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1 (A) Band recoveries of migratory Lesser Kestrels in wintering areas and (B) locations of Senegal and Saloum rivers.

Appendix S2 States at recovery of geolocators and migration characteristics.

Appendix S3 Individualized home ranges for each Lesser Kestrel.

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BIOSKETCHES

Airam Rodríguez is carrying out his PhD thesis on phenotypic and genotypic indices of individual quality using the Lesser Kestrel as a model.

Juan J. Negro is currently investigating the evolution of colourful ornaments and also deals with molecular ecology of birds.

Javier Bustamante is interested in raptor ecology, species distribution models and the use of remote sensing in conservation biology.

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