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BIODIVERSITY RESEARCH

# 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, geolocator, Lesser Kestrels, migration, sub-Saharan region, wintering quarters.**

## 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


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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°23′N, 6°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° 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:

$$V_i = \sqrt{\frac{1}{4}\sum_{j=-2, j\neq 0}^{j=2} (v_{i,j+i})^2}$$

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 ± 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 ± 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.

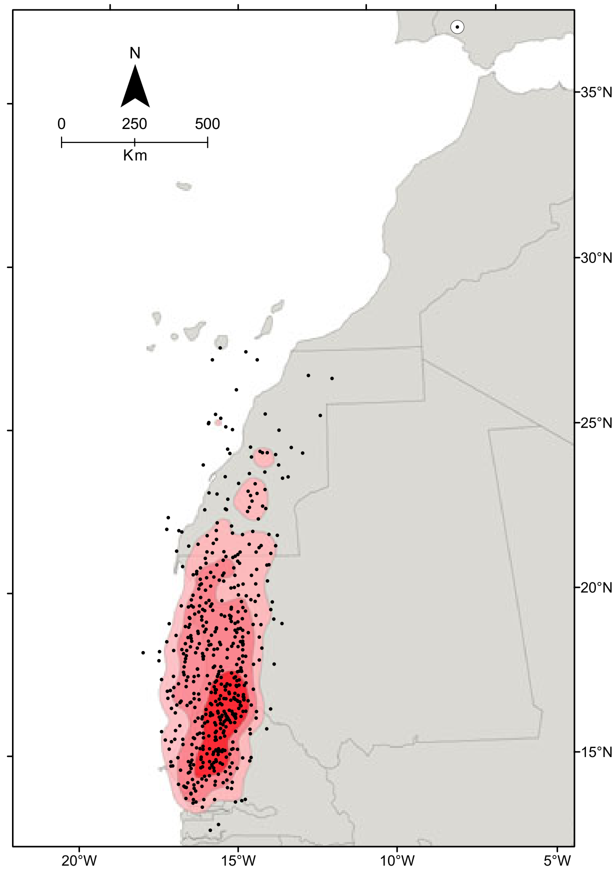


Figure 1 Validated locations and activity ranges derived from kernel analyses (encompassing 95, 75 and 50% of the locations) in the wintering areas of three adult Lesser Kestrels during a winter period (November, December 2007 and January 2008). The white circle with a black point shows the location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

## 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 (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, birdwatchers or even tourists in the Sahel area, at least compared with other African regions.

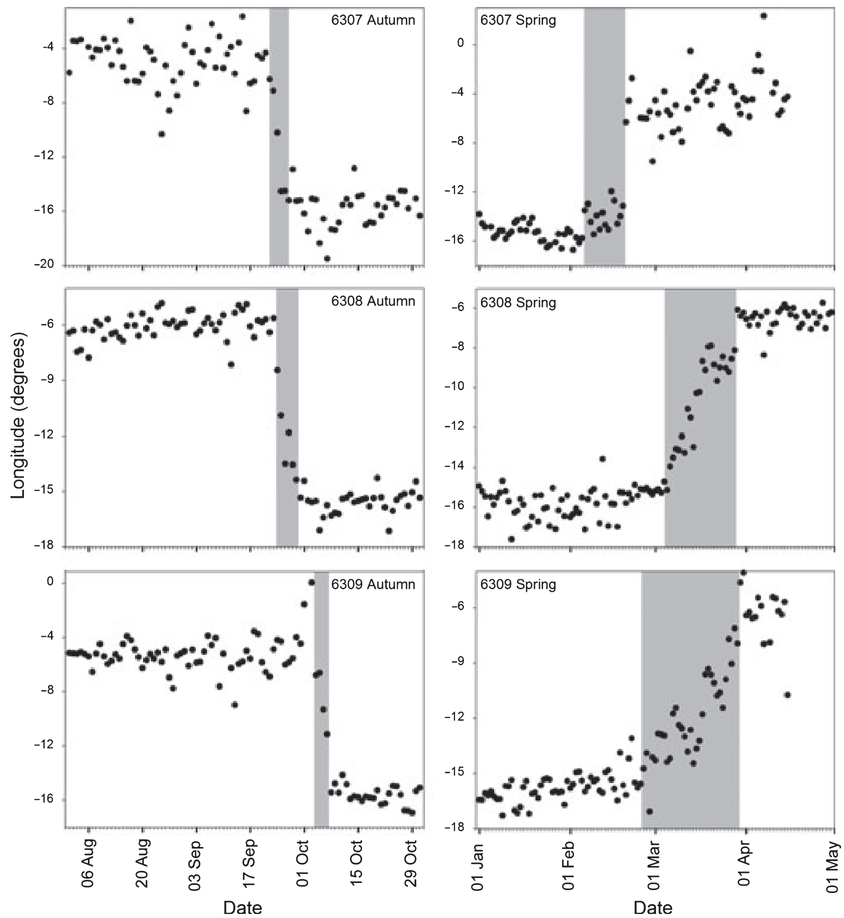


Figure 2 Longitude variations during post- and pre-nuptial migration of Lesser Kestrels. Shade area indicates the estimated duration of migration. Each point corresponds to the average longitude of the date (two locations per day).

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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## REFERENCES

Afanasyev, V. (2004) A miniature daylight level and activity data recorder for tracking animals over long periods. *Memoirs of National Institute of Polar Research*, **58**, 227–233.

Alerstam, T., Hake, M. & Kjellén, N. (2006) Temporal and spatial pattern of repeated migratory journeys by ospreys. *Animal Behaviour*, **71**, 555–566.

British Antarctic Survey (2008) Migrating bird tracking logger. In: *BAS research: instruments and techniques*. Cambridge, UK. Available at: http://www.antarctica.ac.uk (accessed 18 November 2008).

BirdLife International (2008) Falco naumanni. In: *Birdlife species factsheet*. Available at: http://www.birdlife.org (accessed 6 May 2009).

Curry-Lindahl, K. (1981) *Bird migration in Africa: movements between six continents*. Vols 1 & 2. Academia Press, London.

De Solla, S.R., Bonduriansky, R. & Brooks, R.J. (1999) Eliminating autocorrelation reduces biological relevance of home range estimates. *Journal of Animal Ecology*, **68**, 221–234.

Eichhorn, G., Afasnasyev, V., Drent, R.H. & van der Jeud, J.P. (2006) Spring stopover routines in Russian Barnacle Geese *Branta leucopsis* tracked by resightings and geolocation. *Ardea*, **94**, 667–678.

Ferguson-Lees, J. & Christie, D.A. (2001) *Raptors of the world*. Christopher Helm, London.

Ganusevich, S.A., Maechtle, T.L., Seegar, W.S., Yates, M.A., McGrady, M.J., Fuller, M., Schueck, L., Dayton, J. & Henny, C.J. (2004) Autumn migration and wintering areas of Peregrine Falcons *Falco peregrinus* nesting on the Kola Peninsula, northern Russia. *Ibis*, **146**, 291–297.

Guilford, T., Meade, J., Willis, J., Phillips, R.A., Boyle, D., Roberts, S., Collett, M., Freeman, R. & Perrins, C.M. (2009) Migration and stopover in a small pelagic seabird, the Manx shearwater *Puffinus puffinus*: insights from machine learning. *Proceedings of the Royal Society of London B*, **276**, 1215–1223.

Heim de Balsac, H. & Mayaud, N. (1962) *Les Oiseaux du Nord-Ouest de L'Afrique: Distribution geográphique, Ecologie, Migrations, reproduction*. Ed. Paul Lechavalier, Paris.

Hill, R.D. (1994) Theory of geolocation by light levels. *Elephant seals, population, ecology, behaviour and physiology* (ed. by B.J. Le Boeuf and R.M. Laws), pp. 227–236, University of California Press, Berkeley.

Isenmann, P. (2005) Nouvelles observations de faucons crécerellettes *Falco naumanni* dans leur quartier d'hiver en Afrique de l'ouest (Sénégal). *Alauda*, **73**, 141.

Klaassen, R.G.H., Strandberg, R., Hake, M. & Alerstam, T. (2008) Flexibility in daily travel routines causes regional variation in bird migration speed. *Behavioral Ecology and Sociobiology*, **62**, 1427–1432.

Liechti, F. (2006) Birds: blowin' by the wind? *Journal of Ornithology*, **147**, 202–211.

Limiñana, R., Soutullo, A. & Urios, V. (2007) Autumn migration of Montagu's harriers *Circus pygargus* tracked by satellite telemetry. *Journal of Ornithology*, **148**, 517–523.

Lopes, R.J., Hortas, F. & Wennerberg, L. (2008) Geographical segregation in Dunlin *Calidris alpina* populations wintering along the East Atlantic migratory flyway – evidence from mitochondrial DNA analysis. *Diversity and Distributions*, **14**, 732–741.

LPO (2008) Dernieres nouvelles des faucons crecerellettes au Senegal. In: *Faucon crecerellette*. Ligue pour la Protection des Oiseaux. Available at: http://www.crecerellette.lpo.fr (accessed 18 November 2008).

McGrady, M.J., Maechtle, T.L., Vargas, J.J., Seegar, W.S. & Peña, M.C.P. (2002) Movements of Peregrine Falcons Falco peregrinus wintering on the Gulf Coast of Mexico 1996–1998. *Condor*, **104**, 39–48.

Meyburg, B.-U., Gallardo, M., Meyburg, C. & Dimitrova, E. (2004) Migrations and sojourn in Africa of Egyptian vultures (*Neophron percnopterus*) tracked by satellite. *Journal of Ornithology*, **145**, 273–280.

Moreau, R.E. (1972) *The Palearctic-African bird migration systems*. Academic Press, London.

Negro, J.J. (1997) Lesser kestrel *Falco naumanni*. *BWP Update*, **1**, 49–56.

Negro, J.J., de la Riva, M. & Bustamante, J. (1991) Patterns of winter distribution and abundance of the Lesser Kestrel (*Falco naumanni*) in Spain. *Journal of Raptor Research*, **25**, 30–35.

Newton, I. (2004) Population limitation in migrants. *Ibis*, **146**, 197–226.

Ottosson, U., Waldenstrom, J., Hjort, C. & McGregor, R. (2005) Garden Warbler *Sylvia borin* migration in sub-Saharan West Africa: phenology and body mass changes. *Ibis*, **147**, 750–757.

Phillips, R.A., Silk, J.R.D., Croxall, J.P., Afanasyev, V. & Briggs, D.R. (2004) Accuracy of geolocation estimates for flying seabirds. *Marine Ecology Progress Series*, **266**, 265–272.

Pilard, P., Thiollay, J.M. & Rondeau, G. (2004) Données sur l'hivernage du faucon crécerellette *Falco naumanni* en Afrique de l'ouest. *Alauda*, **72**, 323–328.

Pilard, P., Corveler, T., Roche, H.P. & Girard, C. (2005) Données sur l'hivernage du faucon crécerellette *Falco naumanni* au Niger. *Alauda*, **73**, 137–140.

Rodríguez, A., Negro, J.J., Fox, J.W. & Afanasyev, V. (2009) Effects of geolocator attachments on breeding parameters of Lesser Kestrels *Falco naumanni*. *Journal of Field Ornithology* (in press).

Sánchez-Zapata, J.A., Donázar, J.A., Delgado, A., Forero, M.G., Ceballos, O. & Hiraldo, F. (2007) Desert locust outbreaks in the Sahel: resource competition, predation and ecological effects of pest control. *Journal of Applied Ecology*, **44**, 323–329.

Sarasola, J.H., Negro, J.J., Hobson, K.A., Bortolotti, G. & Bildstein, K.L. (2008) Can a 'wintering area effect' explain population status of Swainson's hawks? A stable isotope approach. *Diversity and Distributions*, **14**, 686–691.

Sergio, F., Blas, J., Forero, M.G., Donázar, J.A. & Hiraldo, F. (2007) Sequential settlement and site dependence in a migratory raptor. *Behavioral Ecology*, **18**, 811–821.

Strandberg, R., Klaassen, R.H.G., Hake, M., Olofsson, P., Thorup, K. & Alerstam, T. (2008) Complex timing of Marsh Harrier *Circus aeruginosus* migration due to pre- and post-migratory movements. *Ardea*, **96**, 159–171.

Strandberg, R., Alerstam, T., Hake, M. & Kjellén, N. (2009a) Short-distance migration of the Common Buzzard *Buteo buteo* recorded by satellite tracking. *Ibis*, **151**, 200–206.

Strandberg, R., Klaassen, R.H.G., Hake, M., Olofsson, P. & Alerstam, T. (2009b) Converging migration routes of Eurasian hobbies *Falco subbuteo* crossing the African equatorial rain forest. *Proceedings of the Royal Society of London B*, **276**, 727–733.

Stutchbury, B.J.M., Tarof, S.A., Done, T., Gow, E., Kramer, P.M., Tautin, J., Fox, J.W. & Afanasyev, V. (2009) Tracking Long-Distance Songbird Migration by Using Geolocators. *Science*, **323**, 896.

Triplet, P. & Yésou, P. (1995) Concetrations inhabituelles d'oiseaux consommateurs de croquets dans le delta du fleuve Sénégal. *Alauda*, **63**, 236.

Triplet, P., Tréca, B. & Schricke, V. (1993) Oiseaux consommateurs de *Schistocerca gregari*a. *L'Oiseau et la Revue Française D'Ornitholgie*, **63**, 224–225.

Wink, M. (2006) Use of DNA markers to study bird migration. *Journal of Ornithology*, **147**, 234–244.

Wink, M., Sauer-Gürth, H. & Pepler, D. (2004) Phylogeographic relationships of the Lesser Kestrel (*Falco naumanni*) in breeding and wintering quarters inferred from nucleotide sequences of the mitochondrial cytochrome b gene. *Raptors Worldwide* (ed. by R.D. Chancelor and B.-U. Meyburg), pp. 505–510, WWGBP, Berlin.

## 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.



## 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.

**James W. Fox** and **Vsevolod Afanasyev** are research engineers at the British Antarctic Survey, leaders in developing miniaturised light level geolocation technology for bird migration study. This paper results from a research project funded by the Junta de Andalucía (Spain) ''Automatic long-term monitoring of a Lesser Kestrel colony'' (HORUS project) and a collaboration with the British Antarctic Survey (Natural Environment Research Council).

Author contributions: A.R., J.J.N. and J.B. conceived the ideas; J.W.F. and V.A. developed the method and tools to gather and analyse the data; A.R. and J.J.N. collected and analysed the data; A.R., J.J.N. and J.B. led the writing.''

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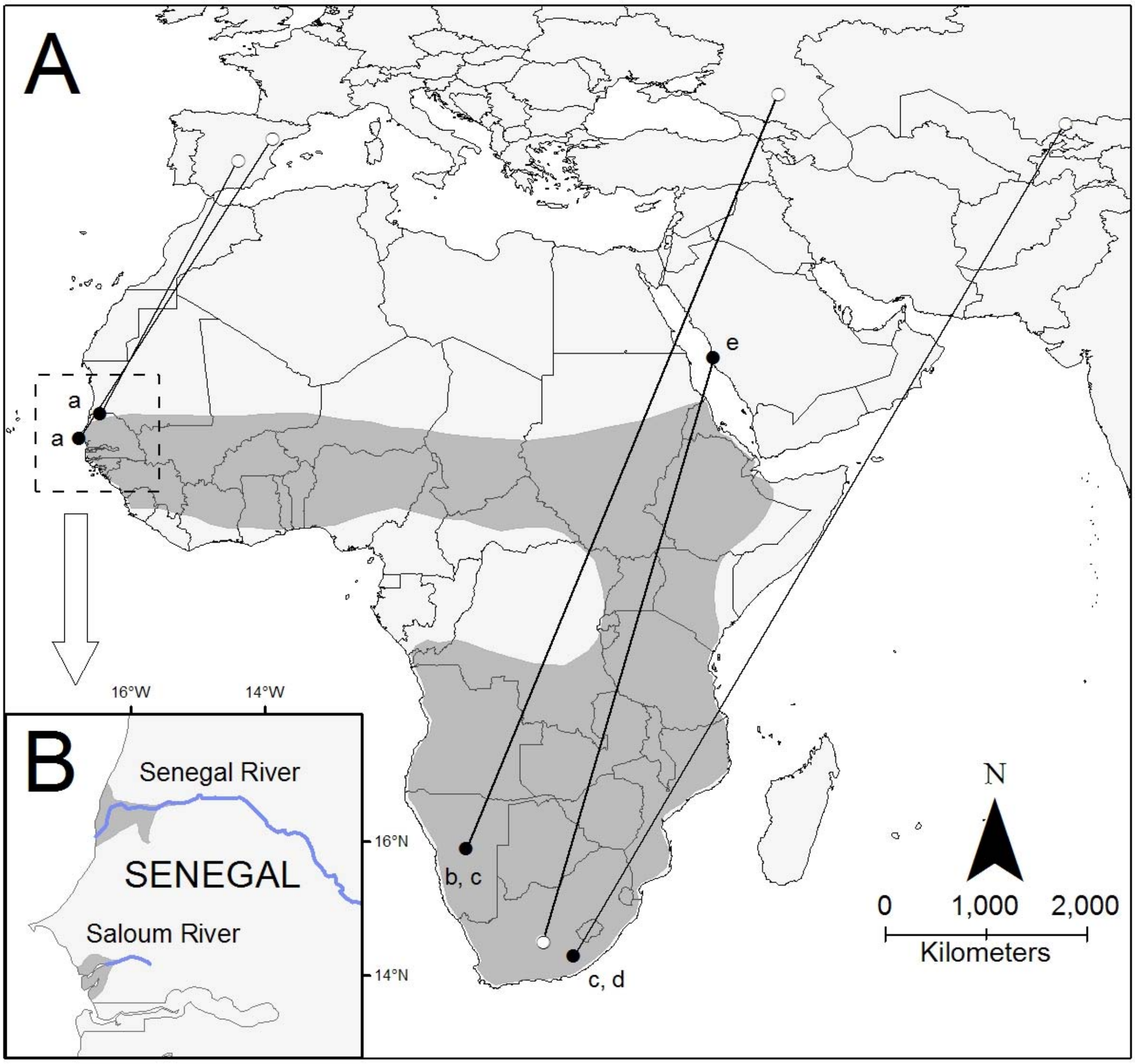
Editor: David Richardson

# Supporting Information

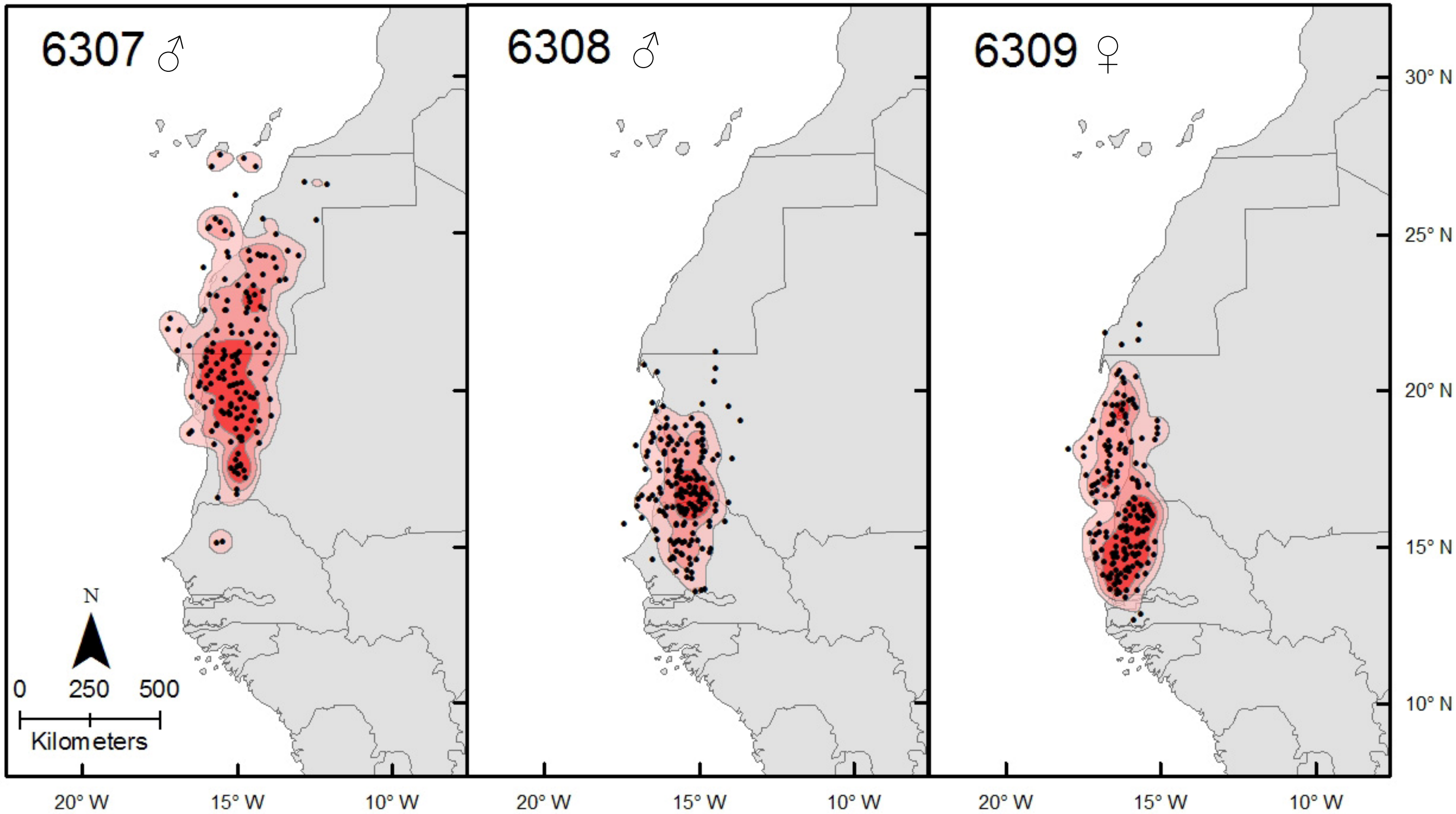
**Appendix S1** (A) Band recoveries of migratory Lesser Kestrels *Falco naumanni* in wintering areas. White and black dots indicate ringing and recovery locations, respectively. Grey area shows putative wintering areas of migratory Lesser Kestrels according to Ferguson-Lees and Christie (2001). Data from the Migratory Species Office[a] (Spanish Ministry of Environment), EURING data bank[b], SAFRING[c] (South African Bird Ringing Unit), Preston[d] (1976) and Anonymous[e] (1997). (B) Locations of Senegal and Saloum rivers (blue) and deltas (grey).



**Appendix S2** Distances and duration of pre- and post-nuptial migration of Lesser Kestrels. Type, state at recovery and ID of the geolocators is included, as well as sex of the bearer.

| ID | Type | Sex | State | Mode | Data | Migration | Post-nuptial migration duration (days) | Pre-nuptial migration duration (days) | Post-nuptial migration speed (km/day) | Pre-nuptial migration speed (km/day) |
|---|---|---|---|---|---|---|---|---|---|---|
| 6302 | harness | F | Damaged | Asleep | - | - | - | - | - | - |
| 6306 | harness | M | ok | Collecting data | Good | No | - | - | - | - |
| 6307 | harness | M | ok | Collecting data | Good | Yes | 5 | 14 | 500 | 179 |
| 6308 | harness | M | ok | Collecting data | Good | Yes | 6 | 25 | 417 | 100 |
| 6309 | harness | F | ok | Collecting data | Good | Yes | 4 | 34 | 625 | 74 |
| 6310 | harness | M | Damaged | Asleep | - | - | - | - | - | - |
| 6349 | ring | M | Dirty | Asleep | - | - | - | - | - | - |
| 6351 | ring | M | ok | Asleep | - | - | - | - | - | - |
| 6353 | ring | M | Scratched and dirty | Collecting data | Bad | Yes | - | - | - | - |
| 6355 | ring | F | Scratched and dirty | Collecting data | Bad | Yes | - | - | - | - |
| 6356 | ring | F | Damaged and dirty | Asleep | - | - | - | - | - | - |
| 6357 | ring | F | Damaged and dirty | Asleep | - | - | - | - | - | - |
| 6358 | ring | F | Scratched and dirty | Collecting data | Bad | Yes | - | - | - | - |

**Appendix S3** Validated locations and activity ranges derived from kernel analyses (encompassing 95%, 75% and 50% of the locations) for each individual in the winter areas of three Lesser Kestrels during a winter period (November 2007 to January 2008).



## References

Anonymous. (1997) Safring news: Lesser kestrel migration route. *Africa Birds & Birding*, **2**, 16.

Ferguson-Lees, J. & Christie, D.A. (2001) *Raptors of the World*. Christopher Helm, London.

Preston, J. (1976) Lesser Kestrel *Falco naumanni*. *Bokmakierie*, **28**, 68-69.