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SHORT NOTE

Unravelling migration routes and wintering grounds of European rollers using light-level geolocators

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Abstract We used light-level geolocators to track the migratory journey of a globally near-threatened trans-Saharan migrant, the European roller *Coracias garrulus,* from its breeding grounds in Iberia to its wintering grounds in southern Africa. During autumn migration, birds followed the western African coast with lengthy stopovers within sub-Saharan countries before crossing the equatorial rainforests towards the wintering areas, mainly in Angola. Although based in only two tracked birds, comparison of our results with other studies suggests that western European rollers use distinct migration routes and stopover sites towards shared wintering grounds. Time spent in widely separated and ecologically disparate countries highlights the vulnerability of the species facing the cumulative risks of each area used along their journey.

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Zusammenfassung

Aufklärung der Zugwege und Überwinterungsgebiete von Blauracken mittels Hell-Dunkel-Geolokatoren

Mithilfe von Hell-Dunkel-Geolokatoren verfolgten wir die Zugroute eines weltweit potentiell gefährdeten Transsahraziehers, der Blauracke Coracias garrulus, von ihren Brutgebieten auf der Iberischen Halbinsel zu ihren Winterquartieren im südlichen Afrika. Auf dem Herbstzug folgten die Vögel der westafrikanischen Küste, wobei sie längere Rastpausen in subsaharischen Ländern einlegten, um dann die äquatorialen Regenwälder zu überqueren und in die vor allem in Angola gelegenen Überwinterungsgebiete zu fliegen. Obwohl nur zwei Vögel verfolgt wurden, legen Vergleiche mit anderen Studien nahe, dass westeuropäische Blauracken auf dem Weg in die gemeinsamen Winterquartiere klar abgegrenzte Zugrouten und Rastgebiete nutzen. Es unterstreicht die Anfälligkeit dieser Vogelart, dass sie dabei Zeit in weit auseinander liegenden und ökologisch ganz verschiedenartigen Ländern verbringt und somit den geballten Risiken aller Gegenden ausgesetzt ist, die sie auf ihrer Reise aufsucht.

Introduction

Alarming long-term declines of Afro-Palearctic migratory birds are heightening the urgency of mapping migration routes and wintering locations of poorly known species

(Sanderson et al. 2006). Recently, the use of miniaturized geolocators has revealed new information on migration routes, key stopover locations, and wintering grounds of many long-distance migratory birds (e.g. Catry et al. 2011; Åkesson et al. 2012; Salewski et al. 2013), highlighting the role of this technology in tracking migratory species, even when sample sizes are small (McKinnon et al. 2013).

The European roller *Coracias garrulus* (hereafter “roller”) is a long-distance migratory Coraciiform classified as globally near-threatened due to rapid population declines across the Palearctic region (BirdLife International 2012). In Europe, declines exceeded 30 % in three generations (15 years), leading to its current classification as vulnerable (BirdLife International 2004). Whilst the species is known to overwinter in open habitats of sub-Saharan Africa (del Hoyo et al. 2001), the links between breeding and wintering populations and particularly the wintering range of western European populations remain largely unknown. The aim of this study was to investigate migration routes, stopover sites, and wintering grounds of rollers breeding in the Iberian Peninsula.

Methods

Geolocator deployment

Fieldwork was carried out in the Castro Verde Special Protection Area (37°43′N, 7°57′W), southern Portugal. Birds were captured inside their nests in June 2012, during the chick rearing period. Ten MK5790C GLS loggers (Biotrack, England) were deployed on adult rollers using a leg-loop harness made of 4 mm Teflon ribbon (Stutchbury et al. 2009). The light sensor was mounted on a stalk (length = 13 mm and angle = 30°) in order to minimize feather shading. Devices weighed 2.4 g including the harness, representing less than 2 % of the body mass of deployed birds (123–164 g, mean = 136.5 g ± 12.5, $n = 10$). Prior to deployment, geolocators were placed for calibration in the area during a 7-day period.

Data analysis

GLS loggers measure the light level every minute, and record the maximum light level at each 2 min. Light data from the retrieved geolocators were processed using the *BASTrack* software (British Antarctic Survey 2010). First, data was corrected for internal clock drift. Sunset and sunrise times were then determined using the *TransEdit* program (using a light threshold value of 10), and all further processing was based on functions available in R-package GeoLight (details in Lisovsky and Hahn 2012). Latitude and longitude of each bird was estimated (twice a day) from, respectively, day (night) length and the time of local apparent noon/midnight relative to Greenwich Mean Time (GMT). Using known positions obtained during the breeding period, i.e., either before or after migration, the sun elevation angle was estimated at −3.2° (using the *getElevation* function based in 102 and 109 twilight events for birds A and B, respectively). Two filtering procedures were used to remove unrealistic positions. First we removed outliers in sunrise and sunset times (using the *loessFilter* function; $n = 28$ and $n = 12$ positions removed for birds A and B, respectively). We then used a speed filter (the *distanceFilter* function) by setting a maximum speed of 30 km h^{-1} between consecutive positions (excluding 237 and 272 data points for birds A and B, respectively). Finally, coordinates were smoothed twice (by calculating mid-positions in between consecutive locations following Philips et al. (Phillips et al. 2004) and projected in a map using a Lambert Equal Area Projection centred at 10°N and 10°W. Latitudes were not calculated for 21 days before and after the vernal and autumnal equinoxes (Hill 1994). Error of positions averaged (±SD) 101.6 ± 36.0 km ($n = 26$ positions) and 256.1 ± 115.5 km ($n = 24$ positions) for calibration (i.e. fixed-position) and bird-born data obtained during pre-migratory periods, respectively.

Given that autumn and spring migrations of rollers largely coincide with equinox periods, migratory phenology of rollers could not be accurately estimated exclusively by positioning data. Movements and stopovers were thus identified using combined information from stationary periods determined by the *changeLight* function (probability of change = 0.09, minimum stationary period = 5 days) and positional data (mainly longitude values within equinoxes). Wintering and stopover grounds were portrayed by kernel densities encompassing 50 and 75 % of the positions which were calculated using the R package ‘adehabitatHR’ with the smoothing factor estimated by least square cross validation. Due to the inaccuracy of positioning data during equinoxes (Phillips et al. 2004), the complete routes could not be accurately estimated, particularly during the spring migration.

All analyses were carried out using R v.2.11.1 (R Development Core Team 2010).

Results

Two out of ten rollers (20 %) fitted with geolocators were recaptured in May 2013 (one male and one female). A third bird carrying a geolocator was resighted but was not captured. Although the return rate of tracked birds seems rather low (see Emmenegger et al. 2013), we have no information on annual survival of rollers in this population. By the time of recapture, tagged birds showed no device-

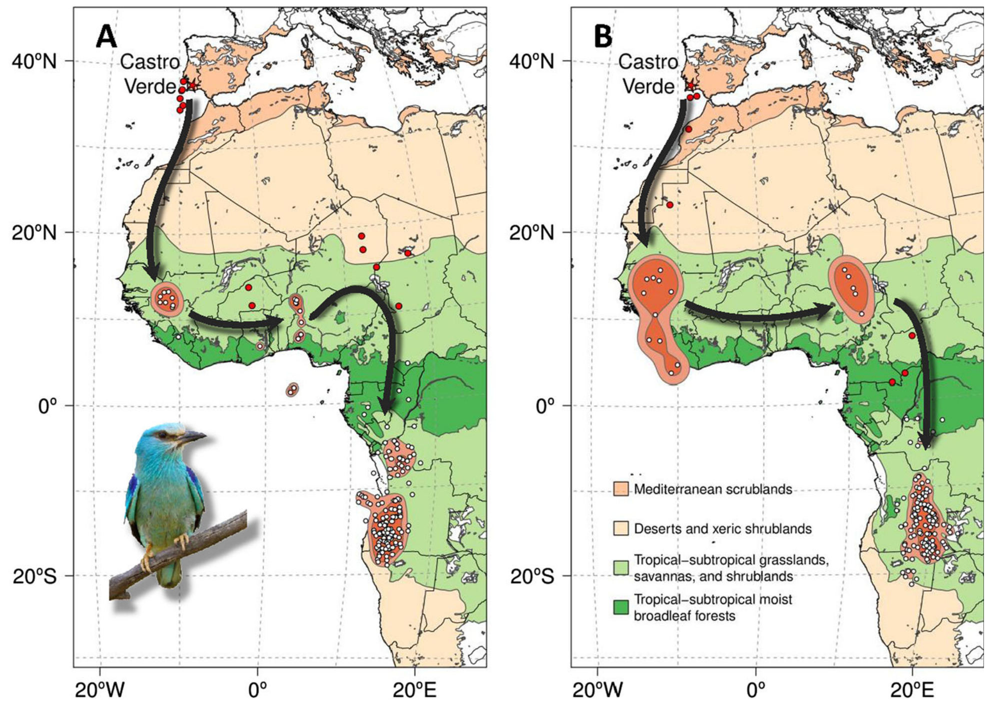

Fig. 1 Migration routes, stopover sites and wintering grounds of two European rollers, *Coracias garrulus*. The base map represents the major habitat types (available at http://maps.tnc.org/gis_data.html); the breeding site in Castro Verde (Portugal) is represented by a *red star*. Small *white circles* correspond to individual locations at stopover and wintering sites, and core areas within these periods are represented by 50 and 75 % kernel density contours. *Red circles* represent individual locations during active autumn migration. *Solid arrows* indicate approximate autumn migration routes derived from positioning data. **a** Bird A (female) and **b** bird B (male) (color figure online)

related injuries, and their body condition was not lower than that of their partners (mass/wing = 0.71 for logged birds vs. 0.65 and 0.61 for their mates).

The two birds showed similar migration routes and wintering areas (Fig. 1). Autumn migration started in August: bird B (male) and bird A (female) crossed the Mediterranean on 30 July and 3 August, respectively, and followed a western route crossing Morocco and Mauritania (Figs. 1, 2). After leaving the breeding area both birds made a first stopover (ca. 8 and 16 days for birds A and B, respectively) in West Africa (latitudes 4°39′N, 13°44′N, Fig. 1). Bird A made a second and longer stopover (22 August to 14 October) around Nigeria and likely migrated through southeastern Niger/western Chad before crossing the equatorial rainforest and reaching its wintering grounds (around 24 October) mainly in Angola (Figs. 1, 2). Bird B stopped around Lake Chad (11 days) and arrived at its wintering grounds also in late October (26 October). Overall, autumn migration took around 85 days covering up to 9,000 km between breeding and wintering areas. Bird B wintered mainly in Angola about 500 km farther east from bird A (Fig. 1), but both birds might have reached Namibia during the winter. The wintering period lasted from late October to mid February, with birds likely reaching the southernmost areas in early December (Fig. 2). Spring departure from wintering grounds occurred almost simultaneously for the two birds, around February 16 and 14 for birds A and B, respectively (Fig. 2). Most of the spring migration coincided with the vernal equinox, and therefore, the migration routes and stopovers are rather uncertain. Overall, the spring migration took around 2 months, being shorter than the autumn migration: birds A and B were first sighted at their breeding grounds on April 17 and 13, respectively (breeding areas were systematically surveyed every 5 days, Fig. 2).

Discussion

Rollers have been described to overwinter in two distinct regions of Africa, from Senegal east to Cameroon, and from Ethiopia west to Congo and south to South Africa (del Hoyo et al. 2001). Nonetheless, the migratory connectivity of different breeding populations is still poorly known (del Hoyo et al. 2001). Although supported by a small sample size, our results, along with recent data on rollers tracked in Spain (http://www.migraciondeaves.org) and France (Emmenegger et al. 2013), indicate that western European roller communities use distinct migration routes and stopover sites towards their overlapped wintering grounds, mainly in Angola and Namibia. Individuals from France and north Iberia crossed the Sahara in a straight north-southward direction (crossing Algeria and Niger), while those from central and south Iberia progressed across the western coast of Africa. The western autumn migration route through northwestern Africa has been described in other recently tracked species (Åkesson et al. 2012; Kristensen et al. 2013; BTO 2014). Contrarily to French birds (Emmenegger et al. 2013), Portuguese rollers crossed the Mediterranean and the Sahara desert in a non-stop flight,

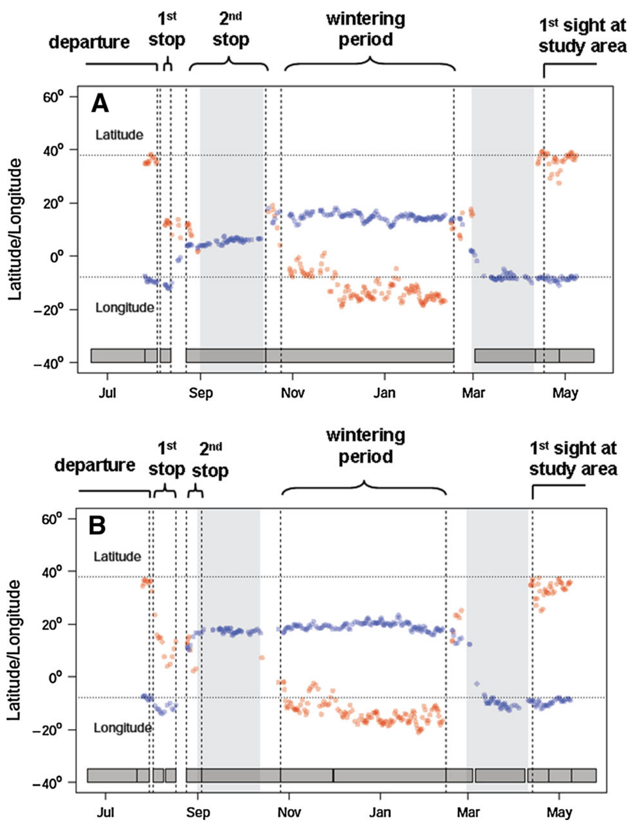

Fig. 2 Variation in geolocator-derived latitude and longitude data of two European rollers, *Coracias garrulus*, and identification of major phenological events during the annual cycle (*vertical dashed lines*). *Grey boxes* at the bottom of each figure represent stationary periods as estimated by the GeoLight package. Phenological events classified in the figure only include those identified by the GeoLight package that were also supported by latitude and/or longitude values (see "Methods"). Periods of 21 days before and after the vernal equinoxes are highlighted in *grey*

making lengthy stopovers in the Gulf of Guinea as they travelled east. Curiously, regardless of their breeding origin, most birds seem to have stopped at (or flown over) the Lake Chad basin before proceeding towards southern latitudes, supporting the idea that this region presents good foraging opportunities for migratory rollers at this time (Emmenegger et al. 2013). Further south, the rainforest likely represents an ecological barrier (with unsuitable foraging and weather conditions) before they reach the dry wooded savanna and bushy plains in Angola (del Hoyo et al. 2001). The southernmost wintering grounds of tracked rollers from Spain encompass the north of Namibia and Botswana, while our two birds (as well as the French birds) seemed to use a slightly northern wintering area, though they might have reached Namibia. During the autumn migration, French birds covered a total distance of 6,500–7,000 km, while Portuguese birds crossed more than ten countries, flying up to 9,000–9,500 km towards their wintering grounds. Departure dates from the breeding grounds and arrival dates to the wintering grounds were very similar to those reported by Emmenegger et al. (2013), and both studies recorded substantially shorter spring migrations.

While rollers spent only 4 months at their European breeding grounds, most research and conservation efforts are concentrated in these areas (del Hoyo et al. 2001). This migratory behaviour makes rollers vulnerable, as they rely on spatially separated sites and habitats during their annual cycle and may face the cumulative risks for each site used along their migratory journey. In the future, increasing the number of tracked individuals from multiple breeding sites can bring new insights on migratory connectivity and can reveal potential threats during the non-breeding season.

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