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SHORT REPORT

Turtle Dove *Streptopelia turtur* migration routes and wintering areas revealed using satellite telemetry

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ABSTRACT
Satellite telemetry of two European Turtle Doves *Streptopelia turtur* confirmed the broad patterns suggested by earlier work using geologgers but also revealed that they migrated by night and used four distinct stopover and two wintering sites. Winter habitat used by one bird covered less than 100 km^2 per site, much smaller than previously assumed.

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The European Turtle Dove *Streptopelia turtur* has shown one of the most dramatic population declines among all farmland bird species breeding in Western Europe. Abundance has been reduced by 74% over the 1980–2013 period (PECBMS 2013) and, accordingly, the species was recently listed as 'vulnerable' on the IUCN Red list (Birdlife International European Red List of Birds 2015).

Changes in agricultural practices and the consecutive degradation of breeding conditions have been suggested as playing a role in population decline, through a reduction in breeding productivity (Browne & Aebischer 2004). This trans-Saharan migrant species spends two-thirds of its annual cycle either along migration routes or in its sub-Sahelian wintering quarters. Consequently, the species may also face additional environmental threats with significant consequences for its population dynamics (Newton 2004). For instance, apparent survival of adult Turtle Doves was shown to be correlated with crude measures of food availability in the West African wintering grounds (Eraud *et al.* 2009). In this context, the identification of migration routes, major stopover sites and wintering habitats is a crucial issue to predict the consequences of changes in land use on population dynamics and for developing appropriate conservation measures (Kirby *et al.* 2008), particularly in the sub-Saharan region where agricultural landscapes are changing rapidly (Cour 2001, Cresswell *et al.* 2007).

Recently, Eraud *et al.* (2013) have provided a comprehensive overview of migratory journeys and winter destinations of adult Turtle Doves fitted with geologgers (GLS). Their results suggested that birds originating from western France followed a loop migration pattern, wintered mainly in an area overlapping southern Mauritania, western Mali and the inner Niger delta, and used spring stopover sites, presumably located in Morocco and Algeria. Although this work represents an important advance in our understanding of the migration pattern in this species, the GLS technique has potentially limited accuracy and the equinoxes inhibit latitudinal positioning (Phillips *et al.* 2004); consequently, several aspects of migration remain undetermined and others need to be clarified using a more accurate tracking technique.

Taking advantage of the recent miniaturization of Argos satellite transmitters (PTT), we report here tracking data obtained in the course of a pioneering study on Turtle Doves originating from western France.

Between 31 May and 19 June 2013, we captured three Turtle Doves (under licence from the *Office National de la Chasse et de la Faune Sauvage*) in the Chizé Forest, France (46.12°N 0.42°W) using drop traps baited with a mix of cereal seeds. Determination of sex by molecular analysis and plumage examination (Cramp 1985, Baker 1993) confirmed that all birds were adult males (thereafter named *Jacky, Jean-Marie* and *Marcel*). Birds (range in body mass: 149–177 g) were fitted with a 5-g solar powered PTT-100 satellite transmitter (Microwave Telemetry Inc., Colombia, MD, USA), fixed as a backpack using a 2-mm width Teflon ribbon harness. The whole device weighed 3.3–4% of each bird's body mass and was below the 5% upper limit recommended by Gaunt *et al.* (1997).

Satellite transmitters were programmed with a standard 10 h ON/48 h OFF duty cycle. We used all

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locations whatever their accuracy (classes: LC 3, 2, 1, 0, A, B), but applied a speed filter to exclude data corresponding to biologically aberrant travelling speeds between successive locations. Dorst (1956) reported a range in flight speed for migrating Turtle Doves of 61–82 km h^{-1}. Hence, data associated with a flight speed above 90 km h^{-1} were discarded. For all locations, geographical coordinates were retrieved in their original projection (WGS84) and thereafter mapped using ArcMap 9.2 (ESRI) on a UTM29N projection for further analyses.

For each bird, the annual cycle was broken down into the following phases: breeding, active migration and stopover, and wintering. The onset and end of each phase was defined as abrupt changes in the pattern of displacements and locations. When changes occurred during the OFF phase of the duty cycle, the date of change was set as the midpoint between the two consecutive distinct patterns. We considered that birds used a staging site when two consecutive sets of locations (separated by one OFF phase) were spatially overlapping, meaning that birds stayed on the site for at least 3 days. Estimates of the area covered by birds at their stopover and wintering sites were derived from 95% and 50% minimal convex polygons (MCP; Tools Extension for ARCVIEW 9.2; Rodgers *et al.* 2007).

Autumn migration

Jacky was tracked for 108 days until the PTT stopped emitting on 20 September 2013, just before the start of autumn migration. *Jean-Marie* and *Marcel* left the breeding grounds on 7 and 8 September, respectively, and from 9 to 10 September made a one-week stop in southern Spain (37°40′N 4°46′W and 38°10′N 5°34′W; Figure 1). Thereafter, *Jean-Marie* travelled to the south of the Western Sahara (21°18′N 13°04′W), arriving on 20 September. From that date, the bird did not show any movements although the PTT still emitted regularly, so it was considered to have died. Overall, *Jean-Marie* travelled about 3028 km in 14 days. On 19 September, *Marcel* was located at the southern limit of the Sahara, reaching a second stopover site in southern Mauritania (17°03′N 13°17′W) where he stayed for about 10 days before arriving on the first wintering quarter by 29 September. *Marcel* travelled approximately 4167 km in 22 days.

Wintering period

Marcel used two distinct wintering sites (Figure 1): the first one for 65 days until 1 December was in the northeast of Senegal, along the Senegal river (14°46′N 12°12′W); the second for 138 days, from 3 December 2013 to 21 April 2014, was southwest of Bamako, along the Niger river (12°10′N 8°15′W). The whole wintering period lasted 204 days.

Spring migration

Marcel left its wintering quarters on 23 April, performed a 12-hour diurnal stop in the Sahara Desert (21°35′N 4°35′W) and reached a first stopover site on 25 April in the Beni Mellal region of northern Morocco (32°31′N 6°47′W; Figure 1). After 10 days, the bird left Morocco on 5 May, performed a short 3-day stopover in southern Spain (37°14′N 4°59′W) and finally came back to its breeding site in the Chizé Forest on 11 May. Overall, *Marcel* travelled 3986 km in 20–21 days.

Migration characteristics

PTT data showed that Turtle Doves migrated nocturnally: 87.5% of the 64 locations obtained during active migration were nocturnal, while 9% were obtained in the late afternoon or early morning, when birds presumably started or ended a migration bout. Taking into account periods when both birds were actively migrating ($n = 8$ bouts), the mean (±se) flight speed was 52.6 ± 0.5 km h^{-1}.

Area and habitats used in staging areas

PTT locations at stopover sites were all distributed over areas of less than 92 km^2 (see legend of Figure 1), with one exception: the Moroccan stopover site used by *Marcel* during the spring migration (195 km^2). Spanish and Moroccan stopover sites corresponded to arable farmland landscapes with predominantly cereal crops, while no particular cropland was apparent in the Mauritanian stopover site used by *Marcel*. On each wintering site, locations were distributed over areas of, respectively, 60 and 87 km^2 and core areas (50% MCPs) reached 3 and 2 km^2. Both wintering sites used by *Marcel* were close to rivers (respectively Senegal and Niger rivers) and encompassed irrigated agricultural landscapes including cereal crops such as rice, sorghum and millet.

This work demonstrates the feasibility of equipping Turtle Doves with PTT transmitters and the benefits for gathering conservation evidence. Overall, our results confirm the broad migration patterns described in earlier works using geologgers (Eraud *et al.* 2013): an autumn migration starting in late August/early September; a 3-week postnuptial trip crossing Spain,

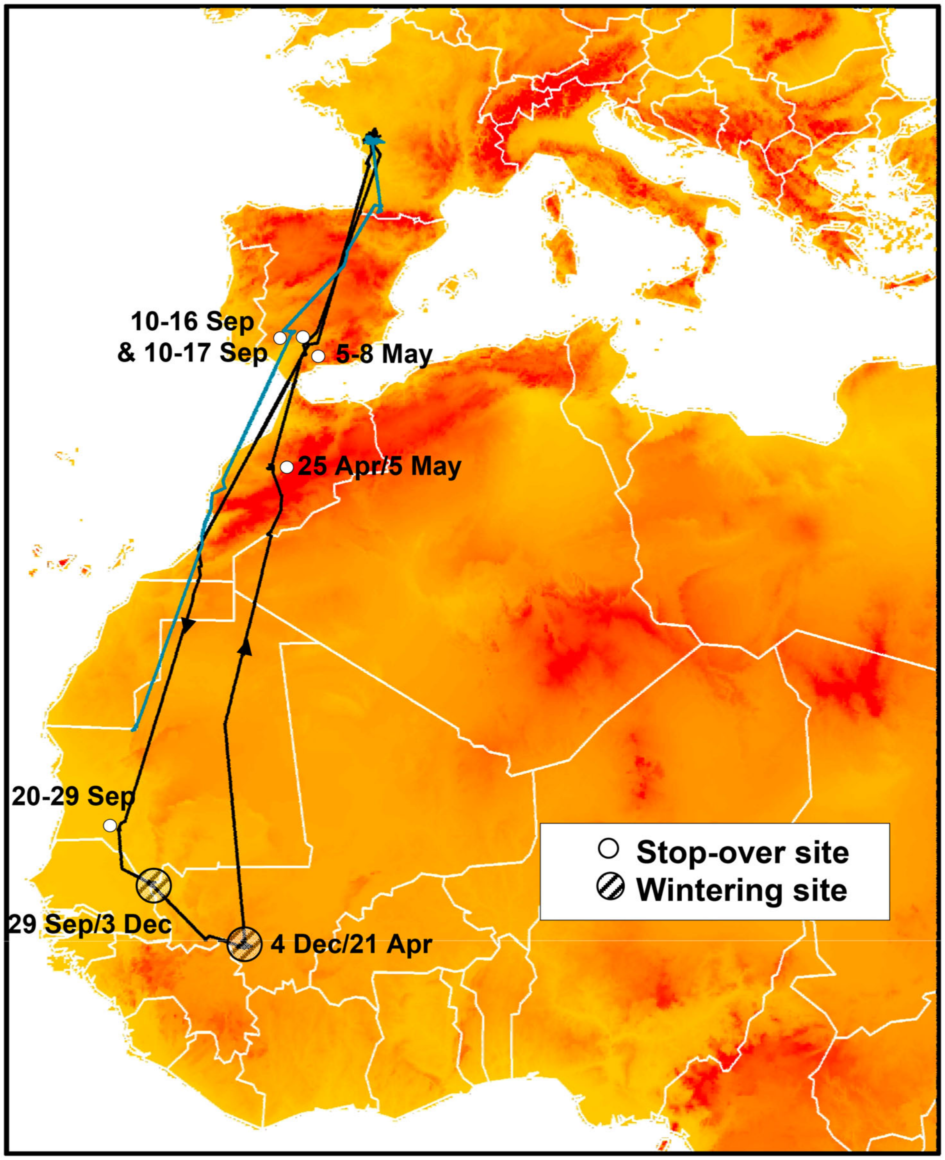

Figure 1. Satellite tracks of two Turtle Doves (*Marcel* – black track, *Jean-Marie* – blue track) during migration between Europe and Africa. Open circles correspond to stopover sites (n = two birds) and dashed circles to wintering sites (*Marcel* only). Background colours indicate altitude and white lines indicate national borders. Area of stopover and wintering sites were estimated in km^2 using 95% MCP for stopover sites, 95% and 50% MCP for wintering sites. The stopover site used by *Jean-Marie* in Spain covered 91 km^2. For *Marcel*, the area of autumn stopovers used in Spain and south of Mauritania were, respectively, 18.3 and 49.9 km^2. The first and second wintering sites covered 57.9 and 87.3 km^2, respectively (with 50% MCP area reaching 3 and 2.3 km^2). *Marcel* spring stopover sites in Morocco and Spain covered, respectively, 195 and 44 km^2.

Morocco and Mauritania to reach wintering quarters located in western Mali; a shift in wintering quarters in November/early December; and a 3–4-week spring migration starting in the second half of April and taking a more easterly route.

Data from satellite transmitters overcome the low accuracy associated with light-level geolocation and provided a much more comprehensive and detailed overview of the migration pattern. Firstly, PTT data allowed us to trace more precisely the timing and route followed from Spain to the sub-Saharan region: the two birds migrated through central Spain and then followed the Atlantic Moroccan coasts until the northern limit of Western Sahara. *Marcel* crossed the desert at its narrowest part, in the Atar region which is an area crossed by mountain chains (Akchâr desert). This migration corridor could result from an optimal use of prevailing local winds in order to minimize flight energetic costs (Erni *et al.* 2005) and the need for Turtle Doves to find some water at oases located along the mountain chains. On the way back to Europe, *Marcel* rapidly crossed the Sahara desert and seemed to apparently stop to rest in the desert only during the daytime. It has been shown that migrant passerines with relatively high fuel loads were able to rest during the day in the desert far from oases and continue the migration during the following night (Salewski *et al.* 2010).

Interestingly, PTT data clearly suggest that Turtle Doves might favour nocturnal flights during the migration. Murton (1968) had already suggested that Turtle Doves could migrate nocturnally and Guyomarc'h (1998) observed that juvenile Turtle Doves kept in captivity showed an increase of their nocturnal activity in the first hours of the night in September–October. Diurnal spring migration of Turtle Doves was reported commonly during the 20th century, (Marchant 1969) and is still reported in the southwest of France in spring but, as a whole, the diurnal fraction of migration seems to have shrunk dramatically in the last few decades (Zwarts *et al.* 2009). It is possible that this change reflects the Turtle Dove population decline, but the extent of nocturnal migration within the rest of the population remains to be demonstrated.

A valuable result highlighted by our study is that Turtle Doves use several stopover sites both during autumn and spring migration. These stopover periods constituted quite an important part of the time spent in migration, with respectively 72% and 65% of the autumn and spring migration duration. This highlights the need for this migrating species to have access to refuelling sites, particularly just before and after crossing an ecological barrier such as the Sahara Desert. Current results also confirm the suggestion made by Eraud *et al.* (2013) that stopover sites located in northern Morocco are essentially used during spring migration, while in autumn, birds might use stopovers in Spain and at the southern edges of the Sahara. All these stopover sites but one (located in Mauritania) were in farmland habitats where cereal crops predominate and water is readily accessible. It should be stressed that from late April to early May, both in Morocco and southern Spain, barley harvests have started and it is likely that mature seeds are therefore available for birds.

The area covered by the two PTT tagged birds at the staging sites was much less extensive that might have been assumed on the basis of data from geologgers (Eraud *et al.* 2013). Moreover, we stress that the area is likely to be even smaller, as our calculations included all locations irrespective of their accuracy. This is in agreement with field observations showing that for long periods birds forage only a few kilometres around the same roost, as long as water is available locally (Jarry & Baillon 1991).

Habitat used on wintering sites consisted predominantly of cultivated areas of millet, sorghum and rice on which Turtle Doves feed (Morel 1987, Jarry & Baillon 1991, Jarry 1994; local crops were identified through data downloaded at: http://www.geog.mcgill.ca/landuse/pub/Data/175crops2000/ArcASCII-Zip/). Our results confirm the use of two successive sites during winter. Examination of local calendar crops (see http://www.fao.org/agriculture/seed/cropcalendar/searchbycountry.do) suggests that such movements could be linked to availability of food resources (Eraud *et al.* 2013). For instance, birds might take advantage of stubble of millet and sorghum which are already available from early September in northern Senegal (Morel 1987) and then move in early December after the local depletion of the resource. In the Sudanese region of Mali, rice fields are harvested more than one month earlier than in the Senegal valley. Accordingly, bird movement towards this region might reflect the emergence of plentiful food resources, through the occurrence of spilt rice seeds occurring following harvest (Morel 1987, Jarry & Baillon 1991). Water availability is unlikely to be involved in such movements as both wintering sites were located close to permanent rivers.

Finally, our results show that southern Spain was used as a stopover site both during autumn and spring migration, suggesting that this region might be a key area to rest and refuel. All Spanish stopover sites identified in this study were relatively close to each other (<50 km apart) and concentrated in central Andalusia. Hunting bag statistics indicate that the Andalusia region harvests more Turtle Doves that any other Spanish province (2011–12 hunting season: 421 000 Turtle Doves; http://www.magrama.gob.es/es/biodiversidad/estadisticas/forestal_produccion_2011.aspx). Spanish hunters generally hunt Turtle Doves around landscaped sites consisting of a pond surrounded by seed crops (wheat and sunflower), which might be very attractive for birds making their migratory halts (Rocha & Quillfeldt 2015). Because of the very limited sample size of our study, our aim was not to demonstrate any impact from Spanish hunting on the Turtle Dove population breeding in western France. However, as a high hunting pressure occurs on this species in this apparently key region during migration, further studies should be encouraged to identify which Turtle Dove populations are targeted by hunting during autumn migration in the south of Spain.

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