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*Published in:*
Journal of Avian Biology

*Publication date:*
2019

# Non-breeding areas and timing of migration in relation to weather of Scottish-breeding common sandpipers *Actitis hypoleucos*

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Keywords: Common sandpiper, FlightR, geolocator. Guinea-Bissau, mangrove, migration strategy, West Africa.

The number of breeding common sandpipers has declined in Britain due to poorer return rates from non-breeding areas. To investigate little known aspects of their annual cycle, breeding common sandpipers were fitted with geolocators to track their migrations and determine their non-breeding areas. Ten tagged birds left Scotland on 9 July (median dates and durations are given throughout the abstract). Short-term staging was carried out by some birds in England and Ireland, then for longer by most birds in Iberia before continuing to West Africa, arriving on 28 July. Six birds spent most of the non-breeding season (October–February) on the coast of Guinea-Bissau, suggesting that this is a key area. Single birds occurred in Sierra Leone, Guinea, the Canary Islands and Western Sahara. The southward migration from Scotland took 17.5 days (range 1.5-24 days), excluding the initial fuelling period. The first northward movement from Africa was on 12 April. Staging occurred in either Morocco, Iberia or France. Arrival in Scotland was on 2 May. The northward migration took 16 days (range 13.5-20.5 days). The main migration strategy involved short- and medium-range flights, using tail-winds in most cases. Variation in strategy was associated with departure date; birds that left later staged for shorter durations. Coastal West Africa provides two major habitats for common sandpipers: mudflats associated with mangroves and rice fields. Although the area of mangrove has been depleted, the scale of loss has probably been insufficient to account for the decline in sandpiper numbers. Rice fields are expanding, providing feeding areas for water-birds. Meteorological data during the migrations suggest that the weather during the southward migration is unlikely to contribute to a population decline but strong cross-winds or head-winds during the northward migration to the breeding grounds may do so.

There is increasing concern about the decline in numbers of Afro-Palaearctic migrant birds that breed in Britain (Balmer et al. 2013). In the 1960s and 1970s, declines were seen mainly in migrants that spend the non-breeding season in the arid Sahelian zone (Winstanley et al. 1974), but since the 1980s, those species that occur in the humid tropics and Guinea forest zone have also declined (Vickery et al. 2014). It is generally accepted that our knowledge about declining species is better for the breeding than the non-breeding parts of the annual cycle, though some studies have obtained more information about the lives of these migrants during the non-breeding season (Jones et al. 1996, Zwarts et al. 2009, Stevens et al. 2010). Part of this involves describing migratory tracks and determining the locations of the non-breeding areas using data-loggers that are now small enough for many medium-sized birds; e.g. European nightjars *Caprimulgus europaeus* (Cresswell and Edwards 2013), common swifts *Apus apus* (Åkesson et al. 2012) and great snipes *Gallinago media* (Lindström et al. 2016).

The common sandpiper *Actitis hypoleucos* is a Palearctic migrant wader that breeds around lakes and along fast-running rivers from the British Isles in the west to Kamchatka in the east. The non-breeding range includes Africa, India, Southeast Asia and Australia (Cramp and Simmons 1983). The Pan-European population declined by 21% during 1980-2009 (Vickery et al. 2014), a trend which has also been seen in Britain (Ockendon et al. 2012). As with many migrant species, there have been population studies on the breeding grounds (Holland et al. 1982, Dougall et al. 2010). An analysis of demographic data indicated that the long-term decline in a small population (mean of 13.6 territories) in northern England was not due to low breeding success but to a low return rate of adults, which was negatively associated with the winter North Atlantic Oscillation (NAO) (Pearce-Higgins et al. 2009). How the NAO influences the survival of common sandpipers is unclear, so Pearce-Higgins et al. (2009) stressed the need to understand more about their migration and non-breeding areas.

Despite ringing over 22,000 common sandpipers in the UK to 2015 (Walker et al. 2016), little is known about the migratory route and non-breeding areas once UK birds leave Europe (Wernham et al. 2002). By contrast, recoveries of common sandpipers ringed elsewhere in Europe show that the non-breeding area extends from southern Europe to West Africa (Fransson et al. 2008, Saurola et al. 2013). Ringing recoveries show that UK birds occur in France and Spain during southward and northward migrations and this is reflected in studies of birds caught on migration in Spain (Arcas 1999, Balmori 2005, de Elgea and Arizaga 2016). There are several recoveries of British-ringed birds in Morocco but only two records south of the Sahara. One referred to a bird ringed in September in southeast England, so may have been a migrant from continental Europe (Wernham et al. 2002). The other was a Scottish-breeding common sandpiper on the non-breeding grounds from our initial work using geolocators (Bates et al. 2012). This initial study identified Morocco as a staging site on migration and coastal West Africa as its non-breeding area (Bates et al. 2012).

The present study extends our initial study (Bates et al. 2012), to describe the migrations and non-breeding areas of Scottish-breeding common sandpipers. The weather patterns in West Africa are partly determined by variations in the position of the Inter-Tropical Convergence Zone and its influence on the northeast trade winds blowing along the coast of northwest Africa (Lockwood 1974). We examined the weather conditions that the birds experienced during migration and speculate on the cause of the decline in breeding numbers in Britain.

## Methods

### Study area

Study areas included the River Spey, downstream from Grantown-on-Spey (57°21′N, 3°32′W), Loch Loyal (58°24′N, 4°21′W) and a small lake near Tongue (58°31′N, 4°20′W) in north Sutherland, Scotland. The banks and islands of the River Spey are lightly wooded with alder *Alnus glutinosa*, birch *Betula* spp. and Scots pine *Pinus sylvestris*. Small grassy islands and bars of river shingle provide breeding and feeding habitats, respectively, for common sandpipers. By contrast, the Sutherland lakes has stony edges, grading into grassy or heather *Calluna vulgaris* banks with occasional birches.

### Field work

During 2011 to 2015, breeding common sandpipers were mist-netted or trapped at the nest (Pienkowski 1976). Birds were sexed either on behaviour (males singing) or molecularly from a feather's DNA (Fridolfsson and Ellegren 1999). Mass was recorded to 0.1 g on an electronic balance. Twenty-eight sandpipers were fitted with unique permutations of colour rings and a 1 g (Mk 10S) British Antarctic Survey geolocator on leg-loops (5 birds) (Rappole and Tipton 1991, R.E. Green pers. comm.), or a 0.65 g (W65) Migrate Technology Intigeo geolocator on a leg-flag attached to the tibia (23 birds). The leg-loops were made from fixed lengths of soft "Silastic" tubing through which ran elasticated thread, allowing the loops to expand or contract according to any change in the birds' shape during the accumulation and use of migratory fuel. Once a bird returned and was re-trapped, the geolocator was removed and the data were downloaded using BASTrak or IntigeoIF software.

**Analysis**

Geolocator data were analysed in R software (R Core Team 2016) using the FlightR package (Rakhimberdiev et al. 2015), following the procedures outlined by Rakhimberdiev et al. (2016). FlightR provides estimates of location (geolocations) at twilight (dusk and dawn), based on a template fit across these twilight periods, rather than on the "threshold method" such the Geolight package (Lisovski & Hahn 2012). Data for individual twilights were excluded if the pattern of change in light levels during transitions between light and dark was erratic two hours either side of the twilights. This could happen due to varying cloud conditions. However, we re-ran the analyses without twilight deletions to check on the timing of key events, such as arrivals and departures. We used the following behavioural masks: birds could not be static more than 50 km from land, and were constrained to between 60°W-50°E and 20°S-70°N. Distances measured between geolocations were along great circles.

The geolocation estimates were approximately 12 hours apart. Therefore, it was not possible to determine the actual time of departure and arrival at locations during migration. To account for uncertainty, the start time of a movement was taken as half way between the last record before the movement and first during the movement. Arrival time was taken as between the last record prior to arrival and the first record at a destination. A movement was deemed to have taken place if there was a difference of at least one degree of latitude (c.111 km) between twilights. A change in latitude rather than longitude seemed appropriate given that the migrations were largely north-south.

Meteorological data during the migration periods were examined to account for potential influences of weather on the migrations. These included surface and upper air data, synoptic analyses and geostationary satellite imagery, accessed from professional websites: www.ogimet.com/index.phtml.en, www.sat.dundee.ac.uk, www earth.nullschool.net, www.wetterzentrale.de/topkarten/ and http://weather.uwyo.edu/upperair/sounding.html. During the investigation into meteorological conditions, visual interpolation of data (by studying synoptic charts and satellite images) was frequently necessary due to data-sparse areas along the birds' routes (especially prior to 2014 in northwest Africa). Wind speeds and directions are those at the most likely altitudes, given the lack of data regarding the birds' flight levels.

Wind directions follow meteorological convention, i.e. the direction from which the wind is blowing. The term 'weather' includes visibility, temperature and precipitation, as well as other severe phenomena described in the text. All may impact upon a migrant's progress to a greater or lesser degree. Synoptic analyses provided overall representations of the conditions during migration. Altitudes are given in metres above sea level.

Indices for the NAO from 1948 to 2016 were obtained from (https://crudata.uea.ac.uk/~timo/datapages/naoi.htm) and (www.metoffice.gov.uk/research/climate/seasonal-to-decadal/gpc-outlooks/ens-mean/naodescription). These data were obtained to test whether there had been any long-term trend, which might support the findings by Pearce-Higgins et al. (2009) that declining return rates by common sandpipers were related to the NAO.

## Results

### The migrations

Ten geolocators were retrieved, two from Speyside and eight from Sutherland. These provided data for ten southward migrations but only eight northward, due to two geolocators failing before northward migration. The mean mass of the 10 birds was 51.3 g (sd = 4.0) at marking, and 50.1 g (sd = 3.6) at recapture. There was no significant difference in the masses between marking and recapture (paired t-test = 1.06, n = 10, $P = 0.32$).

***Southward migration***

The median last date in Scotland was 9 July (inter-quartile range, IQR 5-24 July, range 2 July-5 August). Initial movements by five birds were to staging sites in England or Ireland where they stayed for short periods; median of 6.5 days (range 1.5-14 days) (Fig. 1, Table 1). The other birds departed from Scotland.

Eight birds staged in Iberia (Fig. 1, Table 1). The median arrival date was 12 July (IQR 10-19 July) and the median length of stay was 10.8 days (range 2-15 days). One bird staged at an additional site in Morocco, but only for 3.5 days. The median number of staging sites used was 1.5 (IQR 1-2, range 0-3) and the median for the total number of days staging was 13 days (IQR 11.5-15 days, range 0-21.5 days). There was a significant negative correlation between the number of days staging and the last day in Scotland; birds that left earlier staged for longer ($r = -0.66$, $n = 10$, $P < 0.05$).

Most then flew without further staging to West Africa, arriving by 28 July (IQR 24 July-7 August, range 24 July-13 August) (Fig. 1). The total time to migrate from Scotland to West Africa, including staging periods, but not the initial fuelling period, was 17.5 days (IQR 15-21 days, range 1.5-24). There was uncertainty about latitude during the autumn equinox, but after this period, most shifted further south by 480 km (range 380-1300 km). Thereafter, there were no trends in either latitude or longitude from October to February, indicating that the birds were sedentary over this period. Six of the birds spent this period on the coast of Guinea-Bissau, and one each in Guinea, Sierra Leone, the Canary Islands and Western Sahara (Fig. 1, Table 1, Supplementary Material). The median distance between the non-breeding sites during October to February and breeding areas was 5,300 km (range 3,500-5,400 km) (Table 1).

***Northward migration***

Departure from West Africa overlapped with the spring equinox when estimates for latitude are less reliable for geolocators. The median date on which there was a major northerly movement that exceeded the 95% CLs for previous latitudes took place was 12 April (IQR 8-17 April, range 3-20 April). The northward crossing of Africa was followed by staging in Morocco (three birds), Spain (five), France (three) and England (three) (Table 1). The median length of stay in Morocco

/ Iberia was 7.5 days (range 5-10 days), but only for 3.8 days (range 2.5-16 days) for France / England. The median number of staging sites used was 2 (IQR 1.5-2, range 1-3) and the median for the total number of days staging was 11.5 days (IQR 9.3-13 days, range 6-16.5). This was not significantly different from the total time spent staging during the southward migration (Mann-Whitney U = 51.5, n = 10, 8, P = 0.31).

The median arrival date in Scotland was on 2 May (IQR 24 April-4 May, range 19 April-6 May). Therefore, the northward migration, excluding the initial fuelling period prior to leaving West Africa, took a median length of 16 days (IQR 13.8-19 days, range 13-20.5 days). This was not significantly different from the southward migration time (Mann-Whitney U = 50, n = 10, 8, P = 0.37).

The migration routes for each individual bird are presented in the supplementary material.

**Weather during the migrations**

***Southward migration***

There were no weather-related conditions that might be considered to present difficulties in any of the birds' southward migrations. Most migration began in July with high or weak pressure patterns over or to the west of the British Isles, giving north-easterly tail-winds to the main staging area in southwest Iberia (Fig. 1, Supplementary Material). Six birds departed from the breeding sites almost immediately as adverse wind and weather conditions were clearing, while four did not depart until two to six days after the weather had improved. Onward migration utilised northerly or northeast winds in the trade-wind zone, with one bird stopping briefly in Morocco.

Exceptions to this general migration pattern were birds 7 and 9, which departed from Britain later in the season than the other birds. Bird 7 departed from its breeding grounds on 5 August 2013, perhaps delayed by a succession of low pressure systems. Bird 9 staged in England in late July and early August (2015), likely being delayed by a similar weather pattern as bird 7, and departed from Britain on 7 August (2015), arriving in Senegal 9 August (2015). It then flew back north in late August to winter in the Canary Islands. Head-winds on this return north may have been avoided if the bird flew above 1,000 m.

***Northward migration***

The first part of the return passage from West Africa for most birds began in fine weather although one experienced low-level head-winds. Thereafter, the fortunes of each bird were dependent on the timing of migration in relation to the passage of weather systems over northwest Africa, Iberia and France (Fig. 1).

The weather during the migration of bird 1 has already been described (Bates et al. 2012), although our current refinement of the data showed a route some 350 km further west over Iberia than originally indicated. Nevertheless, strong head-winds over the staging area in southern Spain were still likely to have delayed onward migration.

In 2014, winds in mid-April were light northerly in West Africa, whence bird 5 departed on 6 April, bird 3 on 15 April and bird 4 on 18 April. None encountered adverse winds or weather during the initial flight over northwest Africa. Bird 6 may have been delayed by a strengthening north-easterly wind of 10-15 m per s, before departing on 20 April. Its eventual northward movement could have been at a higher altitude where the wind became south-westerly. This tail-wind strengthened further north, ahead of a strong upper trough (associated with part of the sub-tropical jet stream) and resulted in marked drift over the Sahara to take the bird into eastern Morocco by 22 April (Fig. 2). An accompanying surface trough brought low level northerly winds gusting to 15-30 m per s. Associated weather included blowing sand, thunderstorms, hail and local tornados, but the poor conditions lasted for only hours at any one place and the bird had moved into eastern Spain by 27 April. By 20 April, bird 5 was in France, followed by bird 3 on 26 April and bird 6 on 1 May. Birds 3 and 6 both encountered unfavourable winds and rain over France but birds 3 and 5 were aided by southeast winds on reaching the UK in late April and early May. Bird 4 made short stopovers in Western Sahara and Morocco, finally leaving its Spanish staging area on 5 May and making rapid progress through the UK on 6 May.

In 2015, bird 8 was the earliest to depart and moved through Morocco between 4 and 7 April. This coincided with low pressure and troughs, but winds were light. The bird crossed into Spain on 8 April during strong easterly winds (the Levanter) with low level winds of up to 25 m per s. For the whole of April 2015, easterly winds blew on a high percentage (70%) of days (Garcia 2016). After staging in Spain for five days, the final return to the UK took place west of France where strong east to southeast winds forced an overseas route, after which rising pressure allowed a steady onward passage to Scotland *via* a short stopover in England.

In 2016, bird 9 returned south to Western Sahara from the Canary Islands in late March 2016, in fresh north to northeast winds. It staged here until 11 April, whence it departed. Passage north was rapid in southwest winds, and it reached France by 14 April *via* the western Mediterranean, where it staged for 16 days in variable weather conditions. By contrast, bird 10 moved only slowly through Morocco, staging there until 23 April. It overtook bird 9 by 26 April but was delayed in northern France and southern England by a succession of weather fronts with changeable winds (Fig. 3). Both birds then returned to northern Scotland in freshening south-westerly winds, with bird 9 arriving one day ahead of bird 10.

We examined long-term data (1948-2016) for the NAO indices for April and winter, and did not find significant trends: April $r_s = -0.12$, January $r_s = 0.13$, February $r_s = 0.13$, $n = 70$ for all tests.

**Discussion**

The above results from the analyses of geolocator data (including weather experienced) plus recoveries of ringed common sandpipers allow us to summarise the migration patterns of Scottish common sandpipers.

**Southward migration**

Holland (2009) predicted that common sandpipers with a departure mass of 84 g and lean mass of 45 g would be able to undertake a 4,000 km flight from England. Another estimate based on Pennycuick's (2008) equation predicted a flight range of 5,893 km (Yalden 2012). Similarly long flight ranges were predicted by Iwajomo and Hedenström (2011) for birds with the highest fuel loads in Sweden: 5,902 km for juveniles and 6,102 km for adults. It would therefore seem that common sandpipers have the potential to accomplish their migration from northern Europe to West Africa in a single flight, but our findings from geolocators show that this is not usually the case. Further, ringing recoveries in France and Spain of birds from Britain and elsewhere in northern Europe indicated that many stage in southern Europe, rather than accomplish the migration in a single flight (Arcas 1999, Wernham et al. 2002, Iwajomo and Hedenström 2011). If birds had only average fuel loads, then shorter flights to staging sites in southern Europe were predicted: juveniles 2,182 km; adults 2,324 km (Iwajomo and Hedenström 2011). Our data from birds with geolocators showed that most staged in Iberia for 10 days (range 2-14.5 days).

After staging in Iberia (eight birds) and Morocco (one bird), the rest of the migration to West Africa involved a longer flight (c. 3,000 km). One bird was late in departing and migrated without staging, thereby revealing variation in migration strategy. Generally, late departing common sandpipers staged for shorter periods, a pattern that has also been seen in great snipes (Lindström et al. 2016). This variation in strategy is consistent with the observation that a range of fuel loads are stored prior to departure from northern Europe (Iwajomo and Hedenström 2011, Bates et al. 2012).

All tagged birds departed from the breeding grounds in weather conditions that were suitable for migration, such as high visibility and little cloud cover, and when wind directions were generally favourable (tail-winds).

**The non-breeding area**

Ringing recoveries of common sandpipers ringed in Sweden (Fransson et al. 2008) and Finland (Saurola et al. 2013), our initial study with geolocators (Bates *et al*. 2012) and this study showed that coastal West Africa is an important non-breeding area for common sandpipers that breed in northern Europe. The majority of our tagged birds spent most of the non-breeding season (October – February) in the coastal regions of Guinea-Bissau, and thereby were associated with mudflats bordered by mangrove woodland (Feka and Ajonina 2011), presumably in the Archipélago dos Bijagós. Thus, our study pinpoints this area as the most important site for Scottish-breeding common sandpipers. The estimated number of waders wintering on the intertidal flats of Guinea-Bissau is one million, including tens of thousands (mostly whimbrels and common sandpipers) in the mangroves (Zwarts 1988).

**Northward migration**

Initial tracks of the northward migration were over the north-western edge of the Sahara. Whereas the northeast trade winds are advantageous in late summer, they act as head-winds in spring (Table 4). In many circumstances, waders make use of tail-winds, but may be forced to migrate in head-winds when tail-winds are rare (Grönroos et al. 2012). Fortunately, the trade winds are weaker in spring and tail-winds are often present at higher altitudes (above 2,000 m), to which migrants may find it expedient to climb (Alerstam 1990, Newton 2008). Flight levels exceeding 2,000 m would be necessary on some inland routes, for example when crossing the Atlas Mountains of Morocco.

As in late summer, Iberia was a staging area during northward migration, though some used, or were forced to use Western Sahara and Morocco as the first opportunity to refuel.

Weather systems crossing routes between latitudes 30° and 40° N clearly affect returning sub-Saharan migrants because there are instances of mass mortality of small migrants (Smith 1968, Elkins 2004). Further, Smith (1968) recorded a fall of 20 common sandpipers in eastern Morocco in April 1963 in northerly gales, showing that migration had been curtailed. Such weather conditions were similar to those described above for bird 6. However, there is no evidence of a trend for an increase in short-term adverse wind and weather events in this region, such as extreme rainfall (Tramblay et al. 2012).

Some birds also made short stops in France or England before reaching their breeding grounds. Birds 3, 6 and 10 were possibly delayed in France or England due to adverse winds (Fig. 1). The common theme of strong head-winds and cross-winds in spring was associated with weather systems moving east or southeast across northwest Africa, Iberia and/or France. The degree to which such weather events significantly influence the route or duration of staging periods is not known, although can perhaps cause delays or drift. Any delays must have been of short duration because there was no significant difference between the time spent on the southward and northward migrations.

The tracks of the tagged birds were consistent with ringing recoveries of British breeders during northward migration, with birds in Morocco, Spain, Portugal and France during March-April (Wernham et al. 2002), and Scottish-ringed birds recovered in southwest, central and northern England, and Wales (Dougall 1999, 2005).

In summary, the data from ringing and geolocators show that most common sandpipers from Scotland migrate to and from West Africa in medium-range flights *via* staging areas, largely in Iberia. The other strategy was to carry out a single flight, but to a closer non-breeding site. Several studies of wader migration using geolocators have involved birds whose strategy has been constrained by the need to make long flights over oceans; *e.g*. Pacific golden-plovers *Pluvialis fulva* and ruddy turnstones *Arenaria interpres* migrating across the Pacific (Johnson et al. 2011, Minton et al. 2010), and purple sandpipers *Calidris maritima* crossing the Atlantic (Summers et al. 2014). By contrast, the little ringed plover *Charadrius dubius* (Hederström et al. 2013) and Temminck's stint *Calidris temminckii* (Lislevand and Hahn 2015) migrate largely over land, and have shorter flights punctuated by staging. Likewise, the migration of common sandpipers is largely over land where there are opportunities to stop, rest, and refuel, and allow birds to select the wind direction for the next stage of the migration. Migrants crossing oceans can only select winds within different altitude bands once they have departed. Nevertheless, the Sahara is still regarded as an obstacle, requiring at least one long flight for Afro-Palearctic waders; e.g. great snipe *Gallinago media* (Lindström et al. 2016).

**Possible causes of the population decline**

The decline of a breeding population of common sandpipers in northern England was negatively correlated with the North Atlantic Oscillation (NAO); the return rate to the breeding grounds was lower when the weather was cool and dry in northwest Africa in winter (Pearce-Higgins et al. 2009). The NAO relates to the global wind pattern occurring over the North Atlantic Ocean, mainly during October to March and in mid to high latitudes. Although Barandiaran and Wang (2012) found a correlation between rainfall in West Africa and the NAO, such a link to rainfall where most of the common sandpipers spend the non-breeding season is unclear, especially as common sandpipers are largely associated with intertidal habitats (Zwarts 1988). There are no detailed data on long-term changes in winds or rain over the migration routes, so the NAO indices are the only relevant data available. However, we did not detect any long-term (70 years) trends for either the April NAO indices (when the birds are on northward migration) or the winter indices (as used by Pearce-Higgins et al. 2009).

It is well known that staging areas are vital to migrants (Alerstam 1990, Newton 2008). In late summer, common sandpipers staging in southwest Iberia and/or Morocco during the southward migration do so during the hottest and driest season. Recent rising temperatures and intensifying droughts in Spain (Meteorological Office 2011) have been implicated in the decline of some migrant species (e.g. Halupka et al. 2017), but there is no current evidence of any significant degradation of the wetland habitats that common sandpipers utilise (E.F.J. Garcia pers. comm.) and it thus seems unlikely that this would cause a population decline. However, birds also staged in Morocco, which has also undergone increasing drought (USAID 2016) and has fewer wetlands than Iberia, so this could have affected common sandpipers.

Our study showed that most of the tagged common sandpipers spent the northern winter on coastal mudflats and associated mangrove woodland in Guinea-Bissau. The mangrove woodland in West Africa occurs largely in southern Senegal, The Gambia, Guinea-Bissau, Guinea, Sierra Leone and Nigeria. From 1975 to 2013, the area of mangrove declined by 4.8% (984 km$^2$), with the greatest losses in Nigeria (432 km$^2$), whereas Senegal and Guinea-Bissau lost 288 and 220 km$^2$, respectively (USAID 2017). The main losses were due to deforestation for wood fuel and conversion to land for agriculture (Feka and Ajoina 2011, USAID 2017). The amount lost (4.8%) is probably insufficient to have had a major effect on the population size of common sandpipers. Some of the loss of mangrove has been due to the creation of rice fields, which will have offset some of the loss of feeding habitat for waders, at least when the fields are wet (Wymenga and Zwarts 2010, Elphick et al. 2010). The area of rice cultivation within the coastal mangrove zone extended over 1,128 km$^2$ in 2000-2005 (Bos et al. 2006) and the coastal rice fields support 1.17 million wetland birds during the northern winter (Wymenga and Zwarts 2010). Thus, it seems unlikely that loss of habitat in the non-breeding quarters is the reason for the decline in the numbers of common sandpipers in Britain.

In terms of explaining the decline in the numbers of common sandpipers, it seems that the northward migration is the only time when they experience unfavourable weather and winds that could possibly lead to higher mortality. Even although some common sandpipers migrate close to the coast (supplementary material), where there are more stop-over opportunities than for trans-Saharan migrants crossing the central Sahara, staging sites may have become increasingly untenable during both spring and autumn migration as drought intensifies in northwest Africa (USAID 2016). Increased mortality among common sandpipers during the northward migration in April would be consistent with results from a study of the Spoonbills *Platalea leucorodia* that breed in The Netherlands and spend the non-breeding season in West Africa. They suffer their highest mortality when crossing the western part of the Sahara during the northward migration (Lok et al. 2015). Although it is plausible that this part of the annual cycle is also a bottleneck for common sandpipers, confirming this would require tags that can track the fate of all birds rather than just for those that return.

Our study dealt only with adult birds. It is possible that, rather than a change in adult mortality causing the decline, it is juvenile common sandpipers that are suffering a higher mortality when crossing the Sahara, as found for raptor species during their first autumn migration (Strandberg et al. 2009).

*Acknowledgememts* **-** Our study is a Highland Ringing Group project for which geolocators were bought from money raised by the group. The *British Birds* Charitable Trust and the Endowment Fund of the Scottish Ornithologists' Club also kindly provided funds to cover some of the costs of the project. Rhys Green provided the design for the leg harness and Clive Minton and Ron Porter advised on flag construction for leg-mounted geolocators. Snæbjörn Pálsson from the University of Iceland carried out the molecular sexing. The Speyside Estate kindly provided permission to trap birds on the River Spey. We thank Teresa Catry, Oliver Fox, Yvonne Verkuil and Leo Zwarts for information about West Africa and Ernest Garcia for information about wetlands in Spain. We are grateful to Tom Dougall, Phil Holland and Åke Lindström who commented on the draft. We plan to deposit our data in Movebank.

*Declarations* – There were no conflicts of interest. Field work was carried out by BB, BE and RS, and analyses and writing by BB, NE, LdR and RS.

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Table 1. The timing of key events during the southward (autumn) and northward (spring) migrations of common sandpipers marked with geolocators in Highland Scotland as breeding adults. Sex (M = male, F = female) is given beside the bird code. The first two refer to birds breeding in Strathspey, whilst the rest were from Sutherland. The migration duration does not include the initial period of fuelling and only to the July-August locations. The great circle distances are from breeding grounds to October-February locations.

Southward migration

| Bird code (sex) | Last day in Scotland | Staging details | First day in West Africa | Migration duration (days) | Location (Jul-Aug) | Location (Oct-Feb) | Distance (km) |
|---|---|---|---|---|---|---|---|
| 1. (M) | 8 July | England (8-20 July)<br>Spain (22-23 July)<br>Morocco (24-27 July | 29 July | 21 | Senegal | Guinea-Bissau | 5,200 |
| 2. (M) | 2 July | England (3-10 July)<br>Portugal (12-25 July) | 27 July | 24 | Mauritania | Sierra Leone | 5,400 |
| 3. (F) | 5 July | Portugal (8-19 July) | 24 July | 18 | Senegal | Guinea-Bissau | 5,300 |
| 4. (F) | 4 July | Spain (8-22 July) | 26 July | 21.5 | Senegal | Guinea-Bissau | 5,300 |
| 5. (M) | 9 July | Spain (11-20 July) | 24 July | 14 | Senegal | Guinea-Bissau | 5,300 |
| 6. (M) | 12 July | Ireland (13-14 July)<br>Portugal (16-25 July) | 28 July | 15 | Senegal | Guinea-Bissau | 5,300 |
| 7. (M) | 5 August | None | 7 August | 1.5 | Morocco | Western Sahara | 3,600 |
| 8. (M) | 6 July | France (8-10 July)<br>Spain (11-20 July) | 24 July | 17 | Liberia | Guinea | 5,400 |
| 9. (F) | 24 July | England (24 July-7 August) | 9 Aug | 16 | Senegal | Canary Islands | 3,500 |
| 10. (M) | 25 July | England (26-27 July)<br>Portugal (30 July-11 August) | 13 August | 18.5 | Mauritania | Guinea-Bissau | 5,300 |

| | | | | |
|---|---|---|---|---|
| Median | 9 July | 28 Jul | 18 | 5,300 |

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Northward migration

| Bird code (sex) | Last day in West Africa | Staging details | First day in Scotland | Migration duration (days) |
|---|---|---|---|---|
| 1. (M) | 10 April | Spain (12-18 April)<br>England (19-23 April) | 24 April | 13.5 |
| 3. (F) | 15 April | Spain (20-25 April) | 1 May | 15.5 |
| 4. (F) | 18 April | Western Sahara (23-26 April)<br>Morocco (27-29 April)<br>Spain (30 April-5 May) | 6 May | 18 |
| 5. (M) | 6 April | Morocco (8-17 April)<br>France (20-22 April) | 23 April | 16.5 |
| 6. (M) | 20 April | Spain (23-30 April)<br>France (1-4 May) | 4 May | 14 |
| 8. (M) | 3 April | Spain (8-13 April)<br>England (14-16 April) | 19 April | 15 |
| 9. (F) | 11 April | France (14-30 April) | 2 May | 20 |
| 10. (M) | 12 April | Morocco (14-23 April)<br>England (28 April-2 May) | 3 May | 20.5 |
| Median | 12 April | | 2 May | 16 |

Legends for figures

Figure 1. (a) Southward migration and (b) northward migration of common sandpipers with marking locations (stars), southward and northward staging areas (southward and northward facing triangles), locations during July-August (squares) (Figure 1a) and locations during October to February (circles). Symbols for two birds overlap with others in Guinea-Bissau, making six birds in total. Wind roses for Britain, France, Spain/Iberia and West-Africa (from top to bottom) show the number of birds experiencing low/moderate wind speeds (<5 m per s) (grey) and high wind speeds (>5 m per s) (black) during their migration, whereby each ring represents one bird (e.g. in Figure 1a, during southward migration in Spain/Iberia [third wind rose from the top], one bird experienced low/moderate north-westerly winds, two birds experienced low/moderate northerly winds and one bird experienced high northerly winds, and two birds experienced low/moderate north-easterly winds and two birds experienced high north-easterly winds).

Figure 2. Synoptic chart for 00hrs, 22 April 2014. The troughs of low pressure over Algeria and Morocco brought surface wind gusts up to 30 m per s with local thunderstorms and tornados, affecting the track of bird 6. Its location is shown as a cross (see also Fig. 3). (http://www.wetterzentrale.de/reanalysis.php?uur=0000&var=45&nmaps=24&map=1&model=nws&jaar=2014&maand=04&dag=22

Figure 3. Synoptic chart for 00hr, 29 April 2016. Bird 10 (its location shown as a cross) was possibly delayed by the passage of fronts in northern France and southeast Britain, before reaching northern Scotland on 3 May in clearing weather. Reproduced by permission of the Meteorological Office.

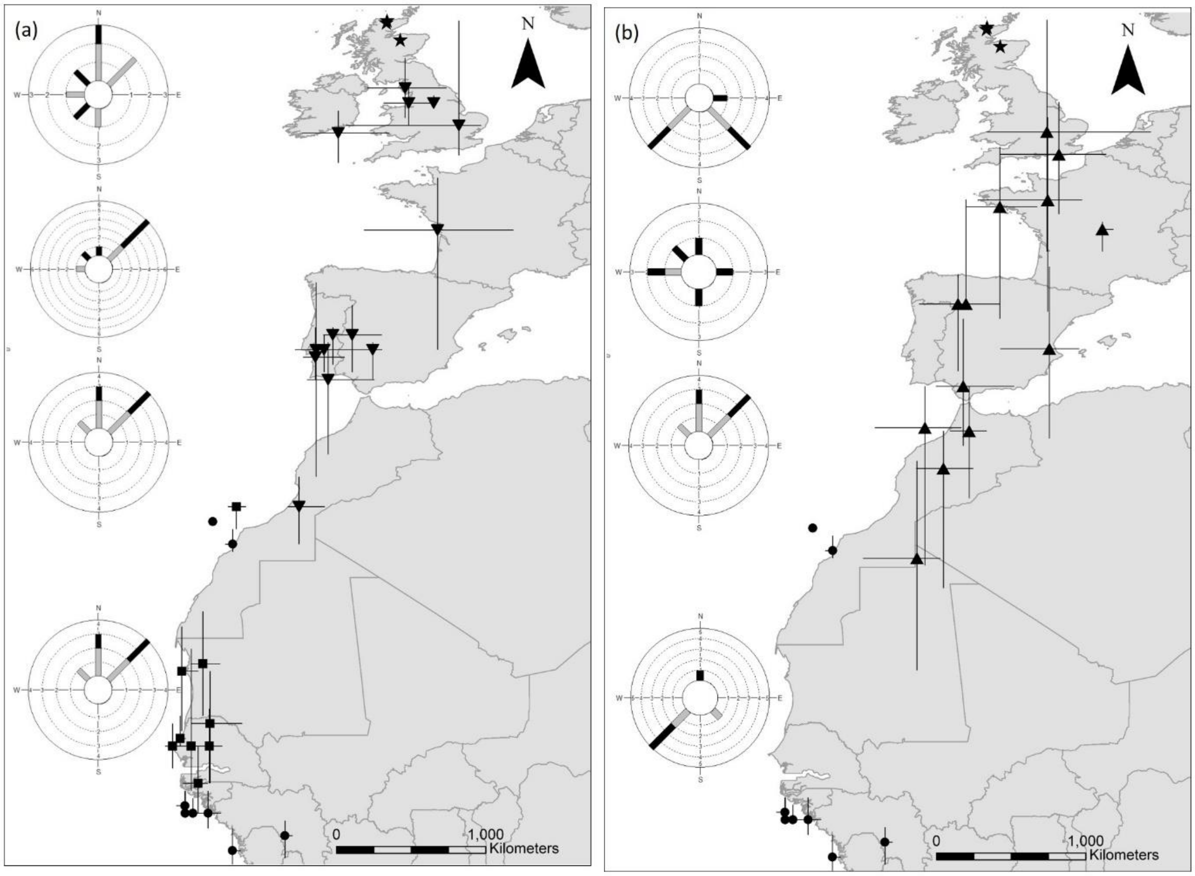


Fig. 1

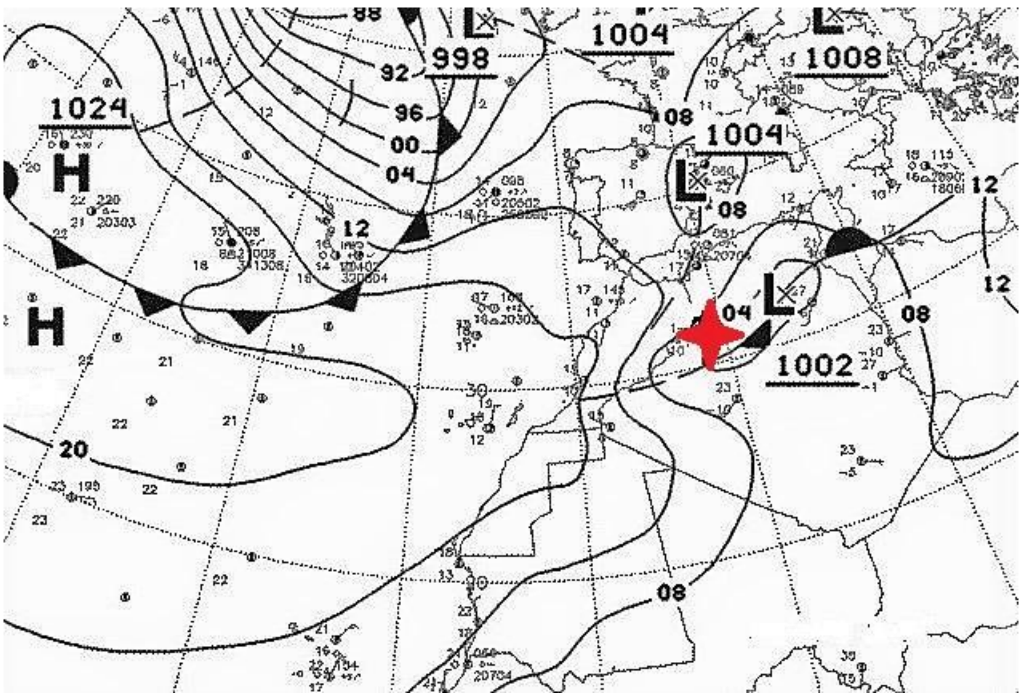
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Fig.2

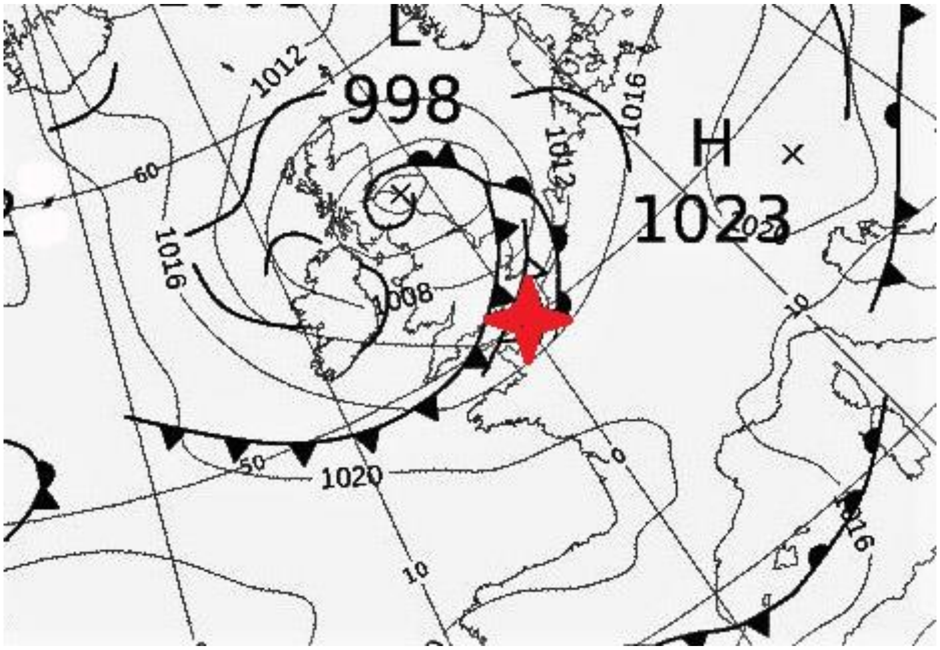


Fig. 3