Running head: Spoon-billed Sandpiper migration

Post-breeding migration of adult Spoon-billed Sandpipers

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ABSTRACT

Critically Endangered Spoon-billed Sandpipers *Calidris pygmaea* migrate from their breeding grounds in arctic and subarctic Russia along the East Asian-Australasian Flyway to winter in coastal habitats in south-east Asia. To describe the use of migration stopover and wintering sites during the post-breeding migration, we tracked six adults equipped with solar-powered Platform Transmitting Terminals (PTTs) on the breeding grounds and a further seven adults tagged at a post-breeding moulting site in Jiangsu Province, China. We identified 28 clusters of sites in all, of which nine appeared to be of special importance for

refuelling for onward migration, or the post-breeding moult of flight feathers. In particular, we identified three sites in Russia that were used by tagged birds for prolonged periods of time prior to long migratory movements to the moulting grounds (Perevalochni Bay, Moroshechnaya River and Tyk Bay), three sites used during the period of flight feather moult (Rongmae Mudflat in DPRK; Tiaozini and Yangkou in Jiangsu Province, China) and three stopover sites used for long periods followed by long onward flights after the moult of flight feathers (Shanghai Chongming Donglin and Nandu Estuary, Leizhou in China and Ha Nam Island in Vietnam). In addition, wintering areas of eight tagged birds were identified, of which three were in China (Xitou Yangxi, Guankoudu Zhaoan and Xichang Hepu), one in Vietnam (Ha Nam Island), one in Myanmar (Gulf of Mottama), two in Bangladesh (Jahajja Char North and an area nearby) and one in Indonesia (Northern Sumatra). Ten of the 28 stopover and wintering sites identified have statutory protection.

Keywords: migratory stages, wintering grounds, stopover site, *Calidris pygmaea*, satellite-tagging

INTRODUCTION

The Spoon-billed Sandpiper *Calidris pygmaea* is listed as Critically Endangered in the IUCN Red List (BirdLife International 2018). It is a long-distance migrant that breeds on coastal tundra in the north-east Arctic and subarctic zones of the Russian Federation, hereafter "Russia" (Chukotka Autonomous Okrug and northern Kamchatka Kraj). The geographical range of the species outside the breeding season is known from ornithological records and counts (Zöckler *et al.* 2016). During autumn passage, adult Spoon-billed Sandpipers are seen around the Yellow Sea (People's Republic of China, Democratic People's Republic of Korea and Republic of Korea), where they moult their flight feathers and replace most of the contour feathers of the reddish-brown breeding plumage with those of the grey and white winter plumage. After the moult, they move to wintering grounds in southeast Asia, between south China and Bangladesh, which are occupied during November–February (Zöckler *et al.* 2016). Coastal mudflats, including estuaries, are the main foraging habitat in the non-breeding season. We refer to this movement from the breeding grounds to wintering areas as the *post-breeding migration*. There is little information on the timing and duration of site use by individual birds during this migration.

Spoon-billed Sandpipers are threatened by the loss of non-breeding habitats, especially of intertidal mudflats, because of land-claim projects to create harbours, industry zones, wind and solar power generation farms, aquaculture ponds and ricefields (Yang *et al.* 2020). In addition, colonisation of mudflats in some coastal areas of China, the Republic of Korea and Japan by the cordgrass species *Spartina alterniflora* and *S. anglica* has rendered them unsuitable for foraging by most shorebird species (Zhang *et al.* 2004, Zuo *et al.* 2012, Kim et al. 2015, Kimura *et al.* 2016). Until recently, Spoon-billed Sandpipers were killed frequently at an important wintering site in Myanmar by hunters intending to catch larger shorebird species for food (Zöckler *et al*. 2010). There are also reports of mortality caused by hunting and accidental entanglement in fishing nets at other sites in Myanmar and China (Martinez & Lewthwaite 2013, Martinez 2016). Recent conservation actions may have reduced habitat loss and mortality at these sites and others mentioned later in this paper (Clark *et al.* 2014, Chang *et al.* 2019, Aung *et al.* 2020), but better information on the location and timing of use of stopover and wintering sites is essential if conservation measures to prevent hunting and further losses of intertidal habitat are to be applied evenly across the range.

In this paper, we describe the post-breeding migration of adult Spoon-billed Sandpipers in detail, based upon locations of 13 birds tracked using solar-powered Platform Transmitting Terminals (PTTs) and report on the timing of the migration, the duration of stay at stopover sites, and the length of movements between stopovers.

METHODS

Satellite tagging and marking

In 2016–2019, we captured 13 adult Spoon-billed Sandpipers and fitted each bird with a solar-powered PTT (type PTT-100/5/ZE, Microwave Telemetry, Inc., Columbia, MD, USA). Six birds (five males and one female) were captured using funnel cage traps on nests containing dummy eggs at Meinypil'gyno in Chukotka, Russia. Their eggs had been taken for artificial hatching and rearing as part of a head-starting programme and none of the birds reared young in the wild in the year of tagging. Dummy eggs were removed at the end of the expected incubation period, based upon observing the beginning of incubation. We determined the birds' sexes based upon differences in plumage . The red colouration of the breeding plumage of males is deeper and brighter than that of females. Although the sex of some individuals is difficult to determine when they are seen alone, the difference is clear when a mated pair are seen together. In addition, seven adult birds were captured for tagging using mistnets, cannon nets and whoosh nets during their post-breeding moult period at Tiaozini in Jiangsu Province, China. We do not know the sexes of these birds. Tagging dates and locations are shown in Table 1.

Each tag weighed 1.6 g, measured 18 x 11 x 6 mm (length, width, height) and had a 210 mm-long antenna. The PTTs transmitted continuously, rather than operating on a programmed on/off duty cycle. Transmissions shut down if the battery voltage became low. The mean number of useable fixes per day was 5.4 (Table 1). The combined weight of the tag and attachment was 1.9–2.0 g, which is approximately 6% of the bird's body weight. Because of this high relative weight, we chose to attach the tags temporarily with glue, rather than using a harness (Fig. 1). We assumed that this would reduce the risk of negative impacts on the birds' welfare both because they would carry the tag for a few months, rather than throughout the rest of their lives, and because the mechanical effects of harness attachments sometimes cause harm (Peniche *et al.* 2011). We attached each tag to the bird's back via a patch of woven fabric glued to the skin and feathering over the synsacrum with cyanoacrylate glue (Loctite Superglue 3, Henkel AG & Co.), having first clipped the contour feathers in the area of attachment to about 3 mm in length and washed the skin and feather stubs with acetone to remove oils. We also marked the birds with a numbered metal ring on one tibia (weight 0.07 g) and a uPVC leg flag (weight 0.09 g; colours: lime green, yellow or white) engraved with a unique combination of two black alphanumeric characters on the other tibia (Clark *et al.* 2005). Leg flags were read through telescopes or by digital photography by fieldworkers and birdwatchers opportunistically and during counts and surveys at a few locations in the Russian breeding range and, more widely, in the non-breeding range in China, Thailand, Myanmar and Bangladesh. Observers sent resightings to the co-ordinators of the East Asian-Australasian Flyway Partnership Spoon-billed Sandpiper Task Force database of mark reads for checking and storage (Lee *et al.* 2016). We used resightings contributed to this database up to 20 August 2020. We refer to individuals by their two-character flag inscription, prefixed by the flag colour (L, Y, or W). Hence, the bird with yellow flag HU is YHU. All tagging was performed with appropriate permits. Prior ethical approval was obtained from the (Animal Welfare) Ethics Advisory Committee of the Royal Society for the Protection of Birds.

In late winter and spring, adult Spoon-billed Sandpipers moult some of their contour feathers to acquire their breeding plumage, starting in February. This includes the contour feathers on the rump, which is the area to which the tags were glued. We therefore expected that any tags still in place at this time would be shed during this moult. As expected, we obtained no information from the tags about the spring migration from the wintering areas back towards the breeding grounds. However, all eight individuals tracked after leaving the area used for their autumn flight feather moult in August-October were tracked at least until November. We follow Zöckler *et al.* (2016) in regarding November-February as the period when Spoon-billed Sandpipers are on their wintering grounds. Three of these individuals were tracked until the expected body moult period in February, March and April (YCT, YET and YHU respectively).

Pre-processing of satellite fixes

Location fixes from the 13 tagged individuals were obtained via the Argos satellite. For each bird, all fixes with Argos location classes 0, 1, 2, 3, A, B were used. Class Z fixes (no quantitative accuracy data available) were excluded. Numbers of fixes meeting this criterion and the duration of the periods over which they were obtained are shown in Table 1. Useable fixes were not obtained at intervals of constant duration, for reasons given above.

Identification of stopover sites

The number of useable fixes obtained from each bird per day was insufficient to separate periods when it was flying continuously in one direction from short intervening stopover periods when it was foraging, resting and moving around on intertidal habitats in response to tidal cycles. We instead identified each stopover site of an individual tagged Spoon-billed Sandpiper by identifying each series of its consecutive PTT fixes that were confined to an area with root-mean-square (r.m.s.) geodesic distance separating fixes from the site centroid <10 km and time elapsed between the first and last fix of the series >2 days. To do this, we listed the records for each bird in chronological order and processed the list using the following method. Starting at the beginning of the list, we calculated the geodesic centroid of a *set* of consecutive fixes, the r.m.s. of the geodesic distances between the fixes in the set and the set centroid and the time between the first and last fix in the set (set duration). We began with the smallest set of the first fixes in the list whose duration exceeded 2 days. If the r.m.s. distance was less than a distance threshold of 10 km, we expanded the set by adding one new fix from the list and performed the calculations again. If the r.m.s. distance remained less than 10 km as each fix was added, we continued the procedure of adding successive fixes until it exceeded 10 km. At that point, we attributed all the fixes, except the last, to a stopover *site* and began the procedure again with a new set, starting with the next fix. If the duration of a set of fixes exceeded 2 days and its r.m.s. distance exceeded 10 km, we regarded the set as being not attributable to a stopover and began a new set with the next fix. Using this procedure repeatedly, we defined further stopover sites for all subsequent consecutive sets with r.m.s. distance <10 km and set duration >2 days. Each time a stopover site had been defined according to these rules, we started the procedure again with the next fix in the list. This procedure identified 78 sites.

We defined the location and extent of a site as the area lying within the edges of an ellipse containing 95% of the summed bivariate probability density distribution the central part of the bivariate normal probability distribution fitted to latitudes and longitudes of the fixes attributed to the site. We note that this is not the confidence ellipse for the location of the centroid of the fixes assigned to the site. We mapped ellipses for all of the sites defined for each Spoon-billed Sandpiper. For sites for the same individual whose ellipses overlapped one another, we pooled the fix data for their sets and used them to calculate a new 95% ellipse, which we took to define a *site-group*. In all cases, site-groups comprised data from sets of fixes for sites used successively by a single tagged individual. As a result of applying this procedure, we pooled 36 sites into 12 site-groups that consisted of multiple sites and 42 site-groups consisted of just one site to give a total of 54 site-groups.

Clusters of stopover site-groups

Some site-groups used by different individuals were close to each other. When 95% ellipses for site-groups of two or more individuals overlapped, we defined all the site-groups with overlap as being members of the same site-group cluster. However, we did not pool fix data from different birds to calculate new 95% ellipses for a site-group cluster, but instead took the outer edges of the overlapping site-group ellipses comprising the cluster to define its boundary. The resulting clusters each comprised overlapping site-groups for one or more individuals, comprising site-groups from up to seven of the 13 tagged individuals. The clustering procedure identified 28 site-group-clusters which we labelled C1 to C28 from the north-east to the south-west of the flyway (Fig. 2; Table 2).

Duration of stay at stopovers and the distances moved between them

We calculated the known minimum duration of stay of each tagged individual in each stopover site-group as the time between the first and last fixes assigned to the site-group. For each of the 13 individuals, we excluded from analysis of stopover durations the site-group where an individual was captured for tagging and the site-group where the bird's tag ceased to provide data, because the times of arrival and departure respectively at these sites were unknown. We took the geodesic distance between the centroids of a pair of site-groups used in succession by an individual to be the minimum distance covered in moving between those two site-groups.

Habitat and protection status of site-group-clusters

To characterise the habitats present at site-group clusters, we superimposed the 95% bivariate normal ellipses for each site-group onto a background map of imagery from Sentinel 2 (European Space Agency 2020), with a short wavelength infrared colour scheme (bands 12, 8A and 4 as red, green and blue) and a 2.5 standard deviation stretch. The majority of images were from December 2018, although those at higher latitudes were from earlier in the year to avoid snow and ice. All images were captured between June 2018 and March 2019. Field observations in the non-breeding season have identified intertidal mudflats as the main foraging habitat of the Spoon-billed Sandpiper (Zöckler *et al.* 2016). We superimposed areas of intertidal mudflats mapped by Murray *et al.* (2019) onto the satellite images to establish whether that habitat occurred within the ellipses used by tagged Spoon-billed Sandpipers. The species sometimes forages on saltpans (Round 2006) and partially-drained ponds used for aquaculture of fish and prawns (Putra *et al.* 2019). We used the satellite images to identify these habitats within the ellipses, assisted by ground observations of their locations at some sites (e.g. fishponds at C28 visited by Putra *et al.* (2019)) to establish characteristics of their appearance on the images.

To determine the extent to which sites were protected legally or recognised internationally, we superimposed boundaries of World Database on Protected Areas sites, Ramsar sites, National Nature Reserves (China), National Wetland Parks (China), World Heritage Sites, East Asian-Australasian Flyway Network Sites (EAAF Partnership) and Key Biodiversity Areas. Democratic People's Republic of Korea Wetland Inventory sites were taken from Sim *et al.* (2018). If the site-group ellipse for any bird overlapped one of these sites and the boundary of the designated area included at least some Spoon-billed Sandpiper habitat, we scored it as being at least partially covered by the designation. We considered that a site-group-cluster was afforded some legal protection if its ellipse overlapped a site with suitable habitat which had protection under national laws or international treaties, such as the Ramsar Treaty and the UNESCO World Heritage Convention. We regarded sites which overlapped private reserves or had international recognition as East Asian-Australasian Flyway Network Sites or Key Biodiversity Areas as not having statutory protection by virtue of that status alone.

RESULTS

Route and timing of post-breeding migration

The stopover sites used by this sample of adult Spoon-billed Sandpipers spanned the species' current known world distribution (Fig. 2). Site-group-cluster C28 in Sumatra, Indonesia, which was used as a wintering area by individual L07, lies outside the species' known range. The post-breeding migration was characterised by stopovers of a wide range of durations (n = 28, median 4.3 days, range 2.0–67.4 days, interquartile range 2.7–7.9 days). The stages between successive stopovers, defined according to the procedure given in the Methods section, comprised a mixture of directional movements with stops shorter than two days between them (n = 41, median stage duration 2.8 days, range 0.5–14.7 days, interquartile range 1.7–3.9 days), but the temporal resolution and fix accuracy of our data were not sufficient to give detailed information about this mixture. The geodesic distance between successive stopovers ranged between 44 km and 3,051 km (n = 41, median 1,079 km, interquartile range 432 km–1,351 km).

The six adults tagged in the breeding area in Chukotka, Russia, left in July and moved west and south by short migration stages through Kamchatka in July and early August (Fig. 3). This was followed in late July and August by a long flight (> 1,000 km) across the Sea of Okhotsk to Sakhalin Island. There, a bay on the western side of the island (site-group-cluster C8) was used by all four of the tagged individuals which reached that stage of the journey with functioning tags (Fig. 3, Table 2). After staying for 5.5–15.4 days at this site, all four birds moved long distances (1,237–1,981 km) in August to sites further south in Russia and in the Democratic People's Republic of Korea (Fig. 2, Fig. 3). All four of the birds monitored on this stage of the migration also paused at site-group-cluster C12 in the Democratic People's Republic of Korea. Two of these tagged adults (L07 and L21) paused for sufficiently long (67 days and a minimum of 37 days respectively) that they almost certainly underwent their flight feather moult at this site during August–October. The tag on L21 ceased to provide data after the bird had been at the site for 37 days, when its tag may have been shed during the flight feather moult, which coincides with the replacement of most tracts of contour feathers. The other two birds (L32 and L43) that paused at site-group-cluster C12, did so only briefly (2.0–2.3 days) and then moved on to site-group-clusters C13 and C14, which are close together in Jiangsu Province, China. These individuals almost certainly underwent their flight feather moult in Jiangsu because they were present there for at least 39 days (L43) and 49 days (L32) before their tags ceased to provide data, which probably occurred when the tags detached during the moult. The four individuals that were tracked from the breeding area at Meinypil'gyno to the site they used for the post-breeding flight feather moult stopped for 2 days or more at 3 sites (L07, L21 and L32) or 7 sites (L43) between the breeding and moulting areas, an average of 4.0 stopover sites per journey.

Information on the part of the migration after the post-breeding flight feather moult was provided by results from eight adults: the seven tagged late in their moult period in site-group-cluster C13 (YHU, YCT, YET, YKT, YKY, YJY, YEH) at Tiaozini in Jiangsu Province and L07, which retained its tag after its moult period at site-group-cluster C12. All eight of these birds moved west and south in October or early November (Fig. 3). Three of them (YCT, YHU and YJY) moved to wintering sites in southern China (site-group-clusters C18, C19, C21), where they remained until their tags ceased to provide data. The other five birds visited stopover sites in China before moving on to their wintering areas. Three birds moved from southern China to wintering sites in Vietnam (bird YKY; site-group-cluster C22), Myanmar (bird YET; site-group-clusters C24 and C25) and Sumatra (bird L07; site-group-cluster C28) without any further stopovers. Bird YKT moved to its wintering site in Bangladesh (site-group-cluster C27) having paused *en route* at stopover sites in Vietnam (C22) and Myanmar (C26). Bird YEH moved from the post-breeding moult area in China (C13) to a stopover site in the Gulf of Thailand (C23). It then flew northwest, crossing Malaysia, Myanmar, and the Bay of Bengal and was approaching an area in Bangladesh close to the wintering site used by bird YKT (site-group-cluster C27) when the signal from its tag was lost on 22 November 2019. The eight individuals that were tracked from the moulting area in the DPRK or northern China to their wintering site, or near to it in the case of YEH, stopped for 2 days or more at no sites (YCT, YJY), 1 site (L07, YEH, YHU), 2 sites (YKY) or 3 sites (YET, YKT) between the moulting and wintering areas, an average of 1.4 stopovers per journey.

Distance between successive stopovers in relation to preceding duration of stay at a stopover

We knew both the geodesic distance between the centroids of pairs of stopover site-groups used in succession by individual Spoon-billed Sandpipers and the duration of stay of the individual at the first-used site-group of the pair for 28 such migration stages. There was a significant tendency for long-distance migratory stages to follow stopovers of long duration (Fig. 4; Spearman rank correlation coefficient $r_S = 0.491$, two-tailed $P < 0.01$). For short stopovers of less than five days duration, only 20% (3/15) were followed by movements exceeding 1,000 km, whereas 77% (10/13) of movements exceeded this length following stopovers of more than five days.

Fidelity to sites in subsequent seasons

Leg flag inscriptions of six of the tagged individuals were read after their tags had detached (Table 1). This revealed cases of fidelity in later years to sites used for breeding, autumn moult, and wintering. Individual YHU was seen to return to site-group-cluster C13 in Jiangsu Province, China in the autumn moult periods of both 2017 and 2018, the site where it was tagged in the autumn of 2016. Individuals YCT and YET also returned to site-group-cluster C13, the site where they had been tagged in the autumn of 2016, in the autumn of 2017. Individual YHU was seen again in both the 2017–2018 and 2018–2019 winters at site-group-cluster C19 in Guangdong Province, southern China, having first been tracked to this site in the 2016–2017 winter. Individuals L07, L32, and L43 were resighted breeding at Meinypil'gyno, Russia (C1), in breeding seasons after they had been tagged at the site.

Habitats and protection status of site-group-clusters

The stopover-site-clusters were all located on or near coasts, except for one (C26) on sandbanks in the Irrawaddy River, Myanmar. Most clusters included areas of intertidal mudflats, especially on estuaries. However, a few included other habitats, including saltpans and fishponds in impounded areas which had previously been intertidal (Table 2).

Few of the sites identified by our study have statutory protection. Ten of the 28 clusters have some protection under national legislation or international agreements recognised by governments, such as Ramsar and World Heritage sites. Eleven of the remaining 18 clusters without such legal protection are recognised as important for birds by being listed as Key Biodiversity Areas and/or East Asian-Australasian Flyway Network Sites, but seven clusters appear to have neither protection nor international recognition (Table 2).

DISCUSSION

Our study has identified an extensive chain of coastal sites that are used by adult Spoon-billed Sandpipers during their post-breeding migration and for wintering. Our list of stopover sites is not comprehensive because of the small number of birds tagged and the duration of stay criterion we used. Of the 28 site-group-clusters identified, 17 (61%) were only visited by one of our tagged individuals, suggesting that we would probably have identified more stopover sites if we had tagged more birds. Some sites not used by our tagged birds are known from sight records and counts to hold Spoon-billed Sandpipers regularly (Tomkovich 1992, Zöckler *et al.* 2016). In addition to being incomplete because of small sample size, we also recognise that the characteristics of the journeys from the breeding grounds to moulting areas might not be fully representative because, in Russia, we selected more males than females and birds that did not breed successfully. We expect the timing of migration of unsuccessful breeders to be earlier than that of birds which reared young and they might therefore have migrated more slowly than average on their way to the areas used for the autumn flight feather moult. Successful breeders may also make longer flights between stopovers than the unsuccessful birds we tagged. The sexes might also migrate differently.

Any quantitative definition of stopover or staging sites based upon tracking data is bound to use arbitrary thresholds (Chan *et al.* 2019). We chose a minimum period of two days of little movement for the duration criterion for identifying sites where individuals paused. Using a shorter time threshold would have led to more sites used only for short stops being identified, but with low accuracy for their real duration of stay. Most long-distance movements (>1,000 km) between stopovers followed periods at stopovers of five days or more. This suggests that our two-day duration threshold probably identified the sites most important to the tagged birds for refuelling for long-distance onward movements.

During the post-breeding migration, several sites appeared to be of special importance. Long mean durations of stay (>5 days) and long mean distances (>1,000 km) moved to the next stopover occurred together at seven site-group-clusters (C5, C6, C8, C12, C15, C20, C22), suggesting that these stopovers might be particularly valuable for refuelling. Two of these site-clusters (C8- Tyk Bay, Russia and C12 - Ryongmae Mudflat, DPRK) were used as stopovers by all the tagged birds that passed beyond the sites. There was no evidence before this tracking study that these sites were of special importance to the species. However, this is not to say that sites used during migration for periods shorter than 2 days or by fewer individuals are of little or no importance. The use of sites for the post-breeding flight feather moult is another criterion affecting their relative importance. Site-group-clusters C12 (Ryongmae Mudflat), C13 (Tiaozini, China) and C14 (Yangkou, China) are of special importance in this regard (Green *et al.* 2018, Chang *et al.* 2019, Yang *et al.* 2020). The importance of these sites would be underestimated by prioritisation using observed duration of stay alone, because shedding of tags during moult and/or capture of birds for tagging part-way through their stay prevented valid estimation of duration of stay.

Tracking revealed the wintering sites, in November or later, of seven individuals, according to our stopover site criteria. The approximate wintering area in Bangladesh of another bird (YEH) was determined, but its site was not established precisely. Of the seven birds with known winter sites, only two, YHU at Xitou Yangxi and YET at Gulf of Mottama North, were at sites counted during the period November to February in 2005–2013 included in the compilation of winter counts reported by Zöckler *et al.* (2016). The sites used by the other five birds were 17–490 km away from the nearest of those winter count sites. Comparison of our Fig. 2 with the map of winter count locations in Figure 1 of Zöckler *et al.* (2016), shows that there were no sites used by tagged Spoon-billed Sandpipers in two large areas where the species is known to be present in winter from counts. These are the southern coast of Bangladesh, especially Sonadia Island, and the coast of Myanmar to the north and west of the Gulf of Mottama. According to the winter count data, these areas held 12 to 27 (Bangladesh) and 28 to 40 (Myanmar) birds, 40 to 67 birds in total, which is approximately 17% of the world count in winter. The absence of tagged birds from these areas is probably due to the small number of individuals tracked to wintering areas. Zöckler *et al.* (2016) concluded, based upon their counts, that 19 to 33 Spoon-billed Sandpipers (8–9% of their world winter count) wintered in southern China. Of the eight tagged birds whose wintering area we located, three of them (38%; 95% exact binomial confidence interval 9-76%) wintered in China, which suggests that the number of birds wintering in China may be higher than what recent winter counts indicated. This conclusion is supported by a survey in January 2020 which found 49 birds in southern China, including four birds at two of the sites where satellite-tagged birds wintered (3 at C19 and 1 at C21) (Spoon-billed Sandpiper Conservation Alliance 2020). In addition, 28 birds were recorded at and near stopover site C20 (Nandu Estuary, Leizhou Peninsula). One of the tagged birds that wintered in southern China returned to its wintering site there in the two subsequent winters after its tag detached. Hence, the short distance covered, relative to the other observed migrations to Bangladesh, Myanmar and Sumatra, seems unlikely to have been an artefact of tag attachment. This sample size is too small for a firm conclusion to be drawn, but our results justify further systematic counts in southern China and more tagging to clarify this point.

We found that only about one-third of the stopover sites identified by our study had any protection under national conservation laws or international agreements. This lack of protection is of concern because of continuing threats to Spoon-billed Sandpipers and their habitats referred to in the *Introduction*. Hunting of Spoon-billed Sandpipers remains a problem. During a visit to site C18 (Guankoudu Zhaoan, Fujian Province, China) in December 2016, occasioned by the tracking of bird YCT to the area, many mistnets, more than 2 km in total length, were found, some of which held entangled live and dead shorebirds. This site has no legal protection, but this illegal bird-trapping was reported to local government agencies, whose staff quickly began the removal and destruction of the nets. The local forestry bureau arranged for a surveyor to inspect the area subsequently and large signs saying "Protect migrant birds. Illegal hunting is prohibited" were erected. Mortality of shorebirds caused by illegal hunting has been identified as a threat to Spoon-billed Sandpipers previously in Myanmar and China (Zöckler *et al*. 2010, Martinez & Lewthwaite 2013, Martinez 2016) and illegal nets were identified at several sites used by wintering Spoon-billed Sandpipers in southern China in January 2020 (Spoon-billed Sandpiper Conservation Alliance 2020). Continued efforts are needed to locate sites used by Spoon-billed Sandpipers throughout their vast migratory flyway and then counter the threats to them by minimising habitat loss and degradation through statutory site protection and habitat management and by implementation of measures to reduce illegal and accidental killing.

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Table 1. Dates, locations and body weights at tagging of 13 adult Spoon-billed Sandpipers tracked using satellite PTTs. Also shown are the duration of tracking, number of useable tag fixes and the date of the last leg flag resighting after the end of tag operation. Superscripts on the leg flag codes show the sex (m = male, f = female) of the six individuals for which the sex was determined.

Leg flag code	Date of tagging	Tagging location	Body weight (g)	Tracking duration (d)	Number of fixes	Date of last resighting
L43^{m}	16 Jun 2017	Meinypil’gyno, Russia	30.0	116	925	18 Oct 2018
L44^{f}	16 Jun 2017	Meinypil’gyno, Russia	34.5	44	413	Not seen
L32^{m}	16 Jun 2017	Meinypil’gyno, Russia	30.0	103	670	22 Jun 2019
L07^{m}	7 Jul 2018	Meinypil’gyno, Russia	32.2	163	963	30 Jul 2019
L21^{m}	7 Jul 2018	Meinypil’gyno, Russia	29.6	86	704	Not seen
W1P^{m}	7 Jul 2018	Meinypil’gyno, Russia	31.0	19	215	Not seen
YHU	4 Oct 2016	Tiaozini, China	34.8	187	203	14 Aug 2020
YET	4 Oct 2016	Tiaozini, China	31.9	161	503	10 Oct 2017
YCT	6 Oct 2016	Tiaozini, China	29.7	141	152	10 Oct 2017
YKT	5 Oct 2017	Tiaozini, China	36.8	74	411	Not seen
YEH	30 Sep 2019	Tiaozini, China	28.2	53	149	Not seen
YKY	28 Sep 2019	Tiaozini, China	28.2	110	450	Not seen
YJY	28 Sep 2019	Tiaozini, China	34.6	62	176	2 Aug 2020

Table 2. Site-group-clusters identified from analysis of satellite tag fixes from 13 adult Spoon-billed Sandpipers. Site numbers are given in the Designations column for Ramsar and East Asian - Australasian Flyway Partnership sites. Sites with legal protection are indicated in bold. The mean duration of stay and mean move length after moving on from the cluster are geometric means of stay durations and moves for all individuals using the cluster. The fraction of birds stopping is the number of individuals using a focal cluster relative to the number of birds with functioning tags that moved to or beyond that cluster in the sequence shown.

Code	Cluster name	Country[1]	Latitude °N	Longitude °E	Habitats[2]	Designations[3]	Mean duration (d)	Mean move length (km)	Fraction of birds pausing	Bird identities
C1	Meinypil'gyno	Russia	62.545	177.052	CT	KBA	-	994	-	L07, L21, L32, L43, L44, W1P
C2	Pakhacha River mouth	Russia	60.582	169.302	ITF	KBA	2.6	314	1/6	W1P
C3	Zaliv Anapka	Russia	59.991	164.047	ITF	-	2.5	220	2/6	L43, W1P
C4	Palana	Russia	59.545	160.534	ITF	-	2.4	395	1/5	L43
C5	**Perevalochni Bay**	Russia	59.48	154.155	ITF	KBA	6.6	1052	2/5	L07, L21
C6	**Moroshechnaya River**	Russia	56.815	156.186	ITF	KBA, Ramsar 695, EAAF001	5.1	1091	3/5	L32, L43, L44
C7	Northeast Sakhalin Lagoons	Russia	53.422	143.113	ITF	KBA	2.1	209	1/4	L07
C8	Tyk Bay	Russia	51.722	141.769	ITF	KBA	8.4	1596	4/4	L07, L21, L32, L43
C9	Islands in Peter the Great Bay	Russia	43.006	131.511	ITF	KBA	2.8	522	1/4	L43
C10	Lower Tumen River	Russia	42.3	130.722	ITF	KBA	2.9	643	1/4	L21
C11	Kumya Bay	DPRK	39.414	127.496	ITF, SP	DPRKWI, EAAF044	4.2	225	1/4	L43
C12	Ryongmae Mudflat	DPRK	37.801	125.952	ITF	-	6.8	1086	4/4	L07, L21, L32, L43
C13	**Tiaozini**	China	32.761	120.982	ITF	KBA, NNR, Phase I WHS, EAAF005	-	840	1/3	L43, YCT, YET, YHU, YKT, YJY, YEH
C14	**Yangkou**	China	32.555	121.120	ITF	Phase II WHS	-	-	1/9	L32
C15	**Shanghai Chongming Dongtan**	China	31.684	121.993	ITF	KBA, NNR, Ramsar 1144, EAAF002	7.8	1493	1/8	YKY
C16	**Hangzhou Wan**	China	30.369	121.368	ITF	NWP	4.1	1364	1/8	YHU
C17	Minjiang Estuary	China	26.018	119.674	ITF	KBA, NNR	3.7	348	1/8	YET
C18	Guankoudu Zhaoan	China	23.661	117.347	ITF	-	2.9	2235	2/8	YCT, YET
C19	Xitou Yangxi	China	21.633	111.766	ITF	-	7.9	549	2/7	YHU, YKY
C20	**Nandu Estuary, Leizhou Peninsula**	China	20.994	109.682	ITF	NNR, Ramsar 1157	8.6	2193	1/6	L07
C21	Xichang Hepu	China	21.598	108.977	ITF	KBA	18.0	235	2/6	YKT, YJY
C22	Ha Nam Island	Vietnam	20.839	106.860	ITF	KBA[$]	9.2	1240	2/5	YKT, YKY
C23	Pak Thale/ Laem Phak Bia	Thailand	13.117	100.080	ITF, SP	PR, EAAF121	-	-	1/4	YEH
C24	**Gulf of Mottama South**	Myanmar	16.836	97.214	ITF	KBA, Ramsar 2299, EAAF117	4.3	44	1/3	YET
C25	**Gulf of Mottama North**	Myanmar	17.137	96.93	ITF	KBA, Ramsar 2299, EAAF117	-	-	1/3	YET
C26	Irrawaddy Valley	Myanmar	19.086	95.139	FS	-	3.9	554	1/2	YKT
C27	Jahajja Char North	Bangladesh	22.479	91.234	ITF	KBA	-	-	1/2	YKT
C28	Northern Sumatra	Indonesia	5.224	97.478	FP	-	-	-	1/1	L07

[1]DPRK = Democratic People's Republic of Korea.

[2]CT = coastal tundra; ITF = intertidal mudflats; SP = saltpans; FS = fluvial sandbanks; FP = fishponds.

[3]KBA = Key Biodiversity Area; NNR = National Nature Reserve (China); NWP = National Wetland Park (China), PR = private reserve, WHS = World Heritage Site; DPRKWI = DPRK Wetland Inventory; EAAF = East Asian - Australasian Flyway Partnership site.

[$]Two UNESCO Man and Biosphere Reserves overlap this site, but neither includes any Spoon-billed Sandpiper habitats.

LEGENDS TO FIGURES

Fig. 1. An adult male Spoon-billed Sandpiper, Lime green 07, having a satellite PTT glued to its back on 7 July 2018 at Meinypil'gyno, Chukotka, Russia. This individual was tracked to its wintering site in Northern Sumatra, where it arrived on 30 October 2018, having moulted in the Democratic People's Republic of Korea between 11 August and 17 October. The signal from its tag was lost on 16 December 2018, but its leg flag was read in June and July 2019 back at Meinypil'gyno, where it bred. Photo: Pavel S. Tomkovich.

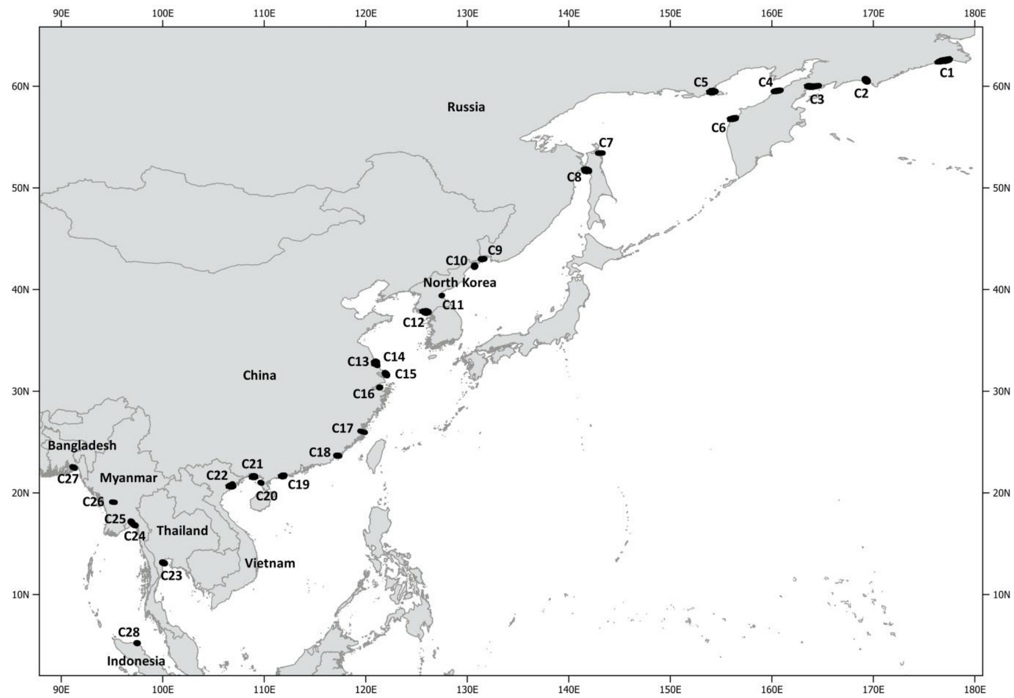
Fig. 2. Map showing the locations of 28 site-group-clusters (black shading) used by 13 Spoon-billed Sandpipers marked with satellite tags during their post-breeding migrations. Clusters, each of which is labelled with its code (see Table 2), comprise site-groups derived from 1–7 individuals, for which the site-group ellipses overlapped.

Fig. 3. Latitude (ºN) of site-group-clusters used by 13 satellite-tagged Spoon-billed Sandpipers in relation to time of year. Results for each bird are represented by a coloured line, with the identity of the bird (see Table 1) shown by a label with the same colour as the line. Black labels with a C prefix identify some of the principal site-group-clusters.

Fig. 4. Geodesic distance between the centroids of pairs of stopover site-groups used in succession by individual Spoon-billed Sandpipers and the duration of stay of the individual at the first- used site-group of the pair. Both axes are on logarithmic scales.

Fig. 1 SUGGESTED CROPPING OF THE IMAGE SHOWN IN YELLOW

Fig. 2


90E
100E
110E
120E
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140E
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170E
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60N
50N
40N
30N
20N
10N
Russia
China
North Korea
Bangladesh
Myanmar
Thailand
Vietnam
Indonesia
C1
C2
C3
C4
C5
C6
C7
C8
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C21
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C26
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Fig. 3.

Comment [JC1]: Please change y-axis label to: Latitude (°N)
And remove periods from x-axis labels

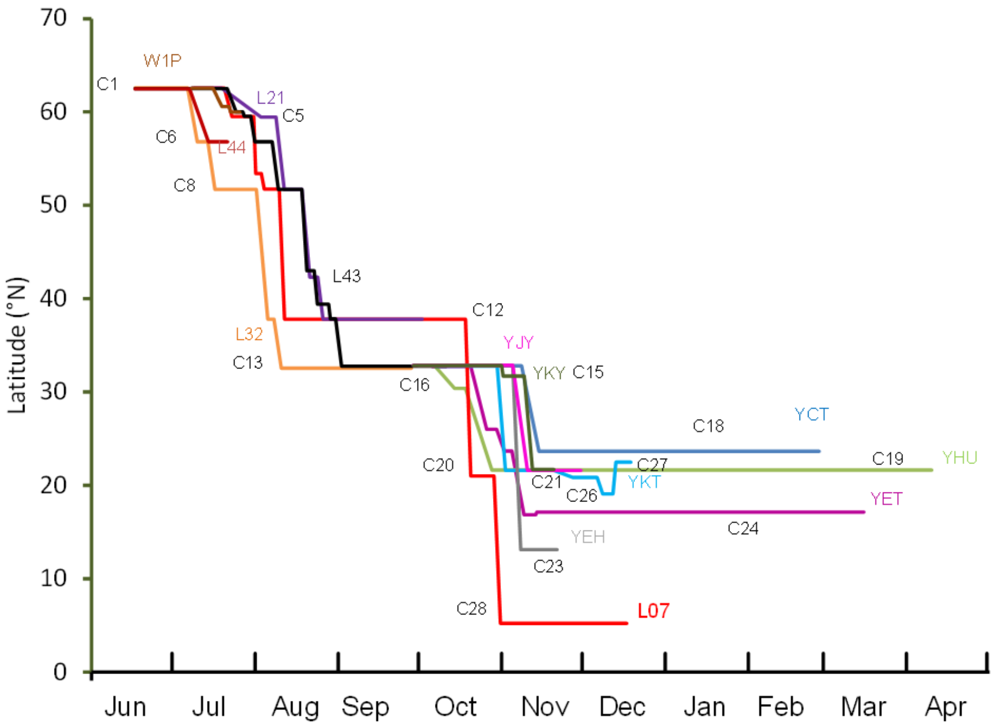
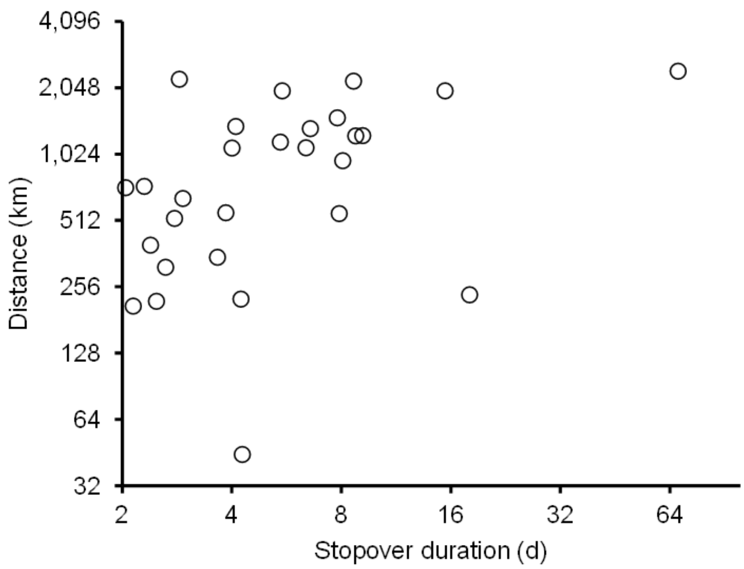


Fig. 4.


4,096
2,048
1,024
512
256
128
64
32
Distance (km)
2
4
8
16
32
64
Stopover duration (d)