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Summary

Declines in populations of the Critically Endangered Spoon-billed Sandpiper *Calidris pygmaeus* have been rapid, with the breeding population now perhaps numbering fewer than 120 pairs. The reasons for this decline remain unresolved. Whilst there is evidence that hunting in wintering areas is an important factor, loss of suitable habitat on passage and wintering areas is also of concern. While some key sites for the species are already documented, many of their wintering locations are described here for the first time. Their wintering range primarily stretches from Bangladesh to China. Comprehensive surveys of potential Spoon-billed Sandpiper wintering sites from 2005 to 2013 showed a wide distribution with three key concentrations in Myanmar and Bangladesh, but also regular sites in China, Vietnam and Thailand. The identification of all important non-breeding sites remains of high priority for the conservation of the species. Here, we present the results of field surveys of wintering Spoon-billed Sandpipers that took place in six countries between 2005 and 2013 and present species distribution models which map the potential wintering areas. These include known and currently unrecognised wintering locations. Our maximum entropy model did not identify any new extensive candidate areas within the winter distribution, suggesting that most key sites are already known, but it did identify small sites on the coast of eastern Bangladesh, western Myanmar, and the Guangxi and Guangdong regions of China that may merit further investigation. As no extensive areas of new potential habitat were identified, we suggest that the priorities for the conservation of this species are habitat protection in important wintering and passage areas and reducing hunting pressure on birds at these sites.

Introduction

The Spoon-billed Sandpiper *Calidris pygmaeus* is a 'Critically Endangered' species with a population now estimated at less than 120 pairs (BirdLife International 2015, Syroechkovskiy *et al.* in prep.). Its breeding range is restricted to Chukotka and Koryakya in the far north-east of Russia, where it nests along a 4,500-km discontinuous narrow strip of coastal tundra (Tomkovich *et al.* 2002, Zöckler and Lappo 2008, Zöckler *et al.* 2010a). From here, it migrates down the eastern coast of Asia, through the Russian Far East, Korean Peninsula and along the Yellow Sea coast of China, before wintering along the coasts of Bangladesh, Myanmar, the Inner Gulf of Thailand, Vietnam, south and east China, with occasional records from India, Sri Lanka and Malaysia (BirdLife International 2001, Chowdhury 2010, Zöckler *et al.* 2008, 2010b).

A major decline in the breeding population of Spoon-billed Sandpipers was detected between 1977 and 2000 (Tomkovich *et al.* 2002) and has continued, with the rate of decline estimated at 25% per annum (Zöckler *et al.* 2010a). Surveys indicate that although breeding pairs successfully fledge young, recruitment to the known breeding populations is low (Zöckler *et al.* 2010a). There is evidence that first year birds spend their first full summer in the non-breeding grounds (Tomkovich 1995, Zöckler *et al.* 2010a, Eiam-Ampai *et al.* 2011). Birds are apparently recruited to breeding populations near the areas in which they fledged. Low return rates of young birds to the breeding grounds suggest they suffer high mortality at this stage, or on passage (Zöckler *et al.* 2010a). However, observations indicate juveniles can in some rare incidences disperse from their birth sites (Zhang Lin and P. Tomkovich *in litt.*). Low recruitment of birds could explain part or all of the observed decline in the species. Although not studied in detail, it has been suggested that adult mortality is also most likely to occur on the non-breeding areas, both on wintering and stop-over areas (Tong *et al.* 2012).

A major threat on non-breeding areas appears to be to be hunting or trapping. Trapping for larger waders on wintering areas has been found to be prevalent, with Spoon-billed Sandpipers being caught or poisoned as by-catch (Zöckler *et al.* 2010b, Chowdhury *et al.* 2011, Tong *et al.* 2012, Martinez and Lewthwaite 2013). In the Gulf of Mottama, Myanmar, at least 53 hunters were active in winter and 20 hunters on the east coast claimed to have captured over 150 Spoon-billed Sandpipers between 2000 and 2010 (Zöckler *et al.* 2010b). On Sonadia Island, Bangladesh, at least 25 hunters were active in winter and eight hunters claimed to have captured 22 Spoon-billed Sandpipers between October 2009 and April 2010 (Chowdhury 2010). In China, hunting is ongoing and widespread. Martinez and Lewthwaite (2013) reported 460 mist nets between Zhuhai and Leizhou at mudflats in Guangdong Province. The prevalence of hunting along the remainder of the coast is unknown, but it has certainly been observed at a number of other sites. In addition to hunting, shorebirds and other coastal waterbirds are sometimes killed by poisoned bait, as has been observed in the Gulf of Mottama (Zöckler *et al.* 2010b), but also at sites in Jiangsu Province (Tong *et al.* 2012). Hunting mitigation measures and engagement with communities have been initiated at some sites, with some apparent early success (Zöckler *et al.* 2010b). Other potential or actual threats include habitat loss (mostly to coastal development) and increasing levels of pollution in non-breeding areas. Coastal development and reclamation of mudflats are taking place across the passage and wintering range, with analysis of satellite images showing widespread loss of intertidal habitat since the early 1980s (Ma *et al.* 2014, MacKinnon *et al.* 2012, Murray *et al.* 2014).

In order to target advocacy and protection efforts at conserving important habitats in important sites and reducing winter hunting pressures, a good knowledge of the areas used by non-breeding birds is required. To meet this need, between 2005 and 2013, field surveys in six countries were undertaken to improve knowledge of the non-breeding distribution of the Spoon-billed Sandpiper. While some sites are now well known, the species has such an extensive and poorly delineated non-breeding range that it is possible that important wintering sites remain undiscovered, hindering conservation efforts (Zöckler *et al.* 2010b).

It is impractical to survey the entire coastline in the species' wintering range. However, a species distribution model can be used to model the suitability of the coastline and identify potential wintering sites, allowing field surveys to be better targeted. Species distribution models (SDMs; Guisan and Zimmermann 2000) have proved to be highly useful in predicting new sites for poorly known species (e.g. Donald *et al.* 2010, Le Lay *et al.* 2010, Drew *et al.* 2011) and in making assessments for conservation management (e.g. Rödder *et al.* 2010, Cushman and Huettmann 2010). Comparing environmental conditions at sites where Spoon-billed Sandpipers have been recorded with conditions across the potential wintering range might enable us to detect areas that could support unknown wintering populations of the species.

Here, we describe recent surveys that have updated our knowledge of the winter distribution (November–February) of the Spoon-billed Sandpiper, describing counts and documenting

observations on the species' ecology. These were combined with previous records of the species in a database, with coordinates where available (Bunting and Zöckler 2006). We then used species distribution models, trained using the results of field surveys, with the aim of identifying unrecognised wintering areas, thereby helping to efficiently target conservation resources to the most important areas for the species. We provide a spatially geo-referenced GIS file of the predicted potential distribution to help target survey effort.

Methods

Field surveys

Field surveys were undertaken in six countries along the East Asian-Australasian flyway between 2005 and 2013. In January 2005, potential wintering sites in India were surveyed, followed by Bangladesh (January 2006), Thailand (December 2006) and Myanmar (six surveys between January 2008 and February 2013). Surveys also took place in Vietnam (Red River Delta in 2009 and the Mekong Delta in 2011). Since 2009, key sites on the southern Chinese coast have been surveyed. Regular winter surveys in Bangladesh began in October 2009 under the Bangladesh Spoon-billed Sandpiper Conservation Project (e.g. Bird *et al.* 2010, Chowdhury *et al.* 2011).

Areas for field surveys were selected using two sources of information. First, we collated records dating back to the 19th century (BirdLife International 2001) with more recent records supplied by visiting birdwatchers and local ornithologists. Second, visual assessment of Landsat Geocover Mosaic data (MDA Federal 2004), satellite images and aerial photos on Google Earth were used to identify areas of potentially suitable estuaries with large exposed mudflats and connected sandbars with little or no mangroves.

At each site, teams of surveyors looked for suitable habitats or flocks of small waders (calidrids and charadriids), whether feeding or roosting. Local knowledge collected from fishermen was often used to identify sites of shorebird concentrations, particularly temporary sand/mud flats offshore. Variation in the nature of sites meant that methods could not be standardised between sites, and there was variation in the amount of ground surveyed and number of surveys undertaken. Ideally, areas were surveyed at high tide when roosting birds could be carefully checked using a telescope. Training was given to surveyors to help them identify Spoon-billed Sandpipers. Surveys were mostly undertaken from boats with shallow draft that were able to rest level on intertidal substrates for long periods during low tide, providing observers with a stable platform from which to survey intertidal areas. An absence of boats in some areas prevented surveys from being undertaken.

In the Gulf of Mottoma, Myanmar, teams of surveyors fanned out across the tidal mudflats, when the tide receded. Each wader flock encountered was scanned with telescopes and the number of each species counted. Attention was paid to the behaviour of birds, especially feeding activities. Observations on prey items were recorded from many wintering sites, through direct observations using telescopes and based on photographs of feeding birds. Several scans could be made in the same area if multiple flocks were present. Surveyors also estimated the total number of small waders (calidrids and charadriids) seen during each survey. The proportion of Spoon-billed Sandpipers was estimated by fitting a generalised linear model with binomial errors (Zöckler *et al.* 2010b) to the flock scan data. The total number of Spoon-billed Sandpipers was estimated by multiplying the average proportion of Spoon-billed Sandpipers observed by an estimate of the total number of small waders on the mudflats (Zöckler *et al.* 2010b).

Records from these field surveys were compiled into a central database, together with *ad hoc* records documented in literature or sightings which authors were aware of, based on their own knowledge or connections (BirdLife International 2001, Bunting and Zöckler 2006). Information on site, date, coordinates and count were compiled where available. Additionally, surveyors assessed

current or potential threats to sites, identifying whether there was evidence of hunting, development, or ongoing habitat change. Proposed infrastructure developments on sites were identified from local sources and documented plans.

Species distribution modelling

We modelled the potential winter distribution of Spoon-billed Sandpipers using geo-referenced records from the database from the period 2000 to 2013. These were largely observations collected during the field surveys, but also contained *ad hoc* sightings. Records prior to 2000 were not considered due to the potential for sites to have changed considerably over time. We took presence in one year as a presence, meaning no account was taken on the number of years in which a bird was present at a site. Accurate records of which sites have been visited in each year are not available (observers are generally more likely to report presences). Models were built using maximum entropy implemented in Maxent (Phillips *et al.* 2006) to link records to environmental variables. Maxent uses a machine learning technique to estimate the predicted distribution (likelihood of occupancy between 0 and 1) that is most evenly spread out across the study area, given constraints set by the training data. It has been shown to perform well with low sample sizes (Franklin 2009).

Models were run at 1-km resolution and the modelled area was a 0.1° strip along the coastline of South-East Asia. Coastline was derived from the bounds of values of the SPOT VGT data on which the models were based (see below), with the coast being defined as where reflectance values occurred next to No Data values. An area within a bounding box of 86.6° to 111.7° E and 5.0° to 23.3° N (dotted line in Figure 1) was used for the models. The area selected for the model covered the majority of wintering sites that were in close proximity to each other (assessed visually). This was done to balance between capturing the majority of wintering records, while minimising the variation in environmental conditions. It resulted in the exclusion of some areas that were remote from the majority of other records (e.g. Wenzhou and Min Jiang in China). However, the inclusion of all wintering areas would potentially reduce the efficacy of any final models. Models used species records and environmental data from November to February. Of 414 Spoon-billed Sandpiper records, just 85 1-km squares were occupied, with many cases of multiple records from locations. Environmental conditions at these 85 cells were compared to those at 10,000 pseudo-absences.

Environmental data summarised climate, land cover, tidal and offshore conditions. Our variable selection was based on measures which were recorded in a consistent way across the entire extensive study area. We selected readily available variables that could be measured in an objective way, across the entire study area now and in the future. Two bioclimatic variables from Worldclim (<http://www.worldclim.org>), mean temperature of the coldest quarter and precipitation of the coldest quarter, were included. Land cover was described from SPOT VGT data (<http://www.vito-eodata.be/>), with each of five bands (B0, B2, B3, MIR and NDVI) used. B0 measures reflectance between 0.43 - 0.47 μm (blue light), B1 measures reflectance between 0.61 - 0.68 μm (red light), B2 measures 0.78 - 0.89 μm (near infra-red) and B3 measures 1.58–1.75 μm (mid or short wave infra-red). NDVI (Normalised Difference Vegetation Index) is derived from B3 and MIR, and is a measure of photosynthetic activity (<http://www.vgt.vito.be/>). For each band we extracted the maximal value in a middle 10-day period of each month for November 2008-February 2009, November 2009-February 2010 and November 2010-February 2011, and averaged these to produce a single value per band. Tide height (the average difference between high and low water) was extracted from topex calculations of tidal range (Ray *et al.* 1999). Offshore conditions were described by mean monthly average chlorophyll *a* concentration from Aqua MODIS ocean colour data at 4-km resolution (<http://oceancolor.gsfc.nasa.gov/cgi/l3>). Values were extrapolated to the adjacent land using Euclidean allocation. Distance to coastline (as defined above, and always positive as SPOT data were not available from areas on the seaward side of the coast) was also included as a variable.

This gave a total of 10 variables (two climatic, five land cover, ocean chlorophyll, tide height and distance to coast) in the initial model. Models were built by sequentially removing the variables that contributed the least to each model, based on percentage contribution values of $< 1\%$. The regularisation multiplier was altered as appropriate to produce smooth response functions to reduce over-fitting of the models. Once a final model had been obtained, 10 replicates were run for cross-validation. Model fit was assessed by ROC/AUC statistics (area under the receiver operating characteristic curve). The AUC is a continuous threshold independent statistic for which a value of 0.5 indicates random discrimination between presences and absences, and values of 1 indicating perfect discrimination. An imbalance in the number of absences compared to presences can inflate AUC values (Lobo *et al.* 2008), but a value ≥ 0.9 indicates a good model.

Results

Field surveys

Based on records from the 2005–2013 surveys, we estimate a minimum total of 242 and a maximum of 378 Spoon-billed Sandpipers across the entire winter distribution (Table 1 and Figure 1). This figure is based on absolute counts in some areas and extrapolations (using the methods described above) in other sites that were too extensive to survey in their entirety (Table 1). Totals for Myanmar and Bangladesh together account for up to 80% of the wintering Spoon-billed Sandpiper population (Table 1, Figure 1). Notable was the upper part of the Gulf of Mottama in Myanmar where the total population estimate based on flock counts in 2010 was 160–220, based on 191 sightings of Spoon-billed Sandpipers in scans of flocks totalling 33,562 small waders and a total of 35,000 small waders estimated to be in the area by observers. Absolute numbers

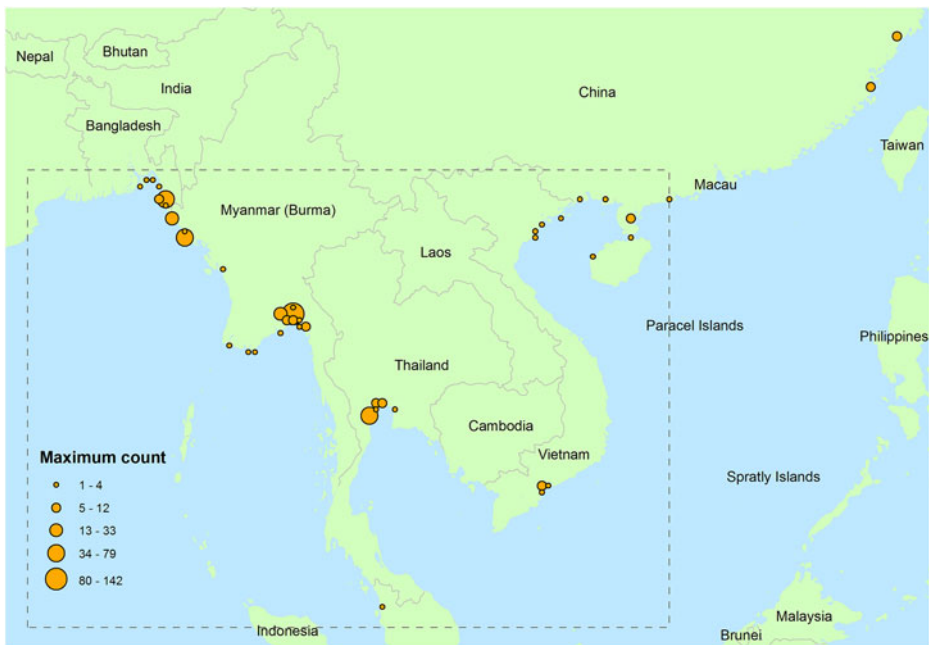


Figure 1. Winter distribution of Spoon-billed Sandpipers, based on records from 2005 to 2013. Size of dot indicates maximum number of birds seen in any single winter (Nov–Feb) in each 0.25 degree grid square. The dotted line depicts the area used for modelling (see Figure 2).

Table 1. Number of Spoon-billed Sandpipers observed at sites surveyed since 2005. Minimum and maximum counts from different years over the reporting period 2005–2013 except for * where total number of Spoon-billed Sandpiper in Gulf of Mottama has been extrapolated, based on flock counts in 2010–2012. Wintering population estimates are based on counts 2011–2013.

Country	Site	Min.	Max.	Main threats	Year of survey
China	Wenzhou	5	8	Development <i>Spartina</i> encroachment	2011–2013
China	Min Jiang	6	12	Reclamation	2008–2013
China	Lei Zhou	4	5	Hunting	2012, 2013
China	Beihai, Fangcheng and Hainan	4	8	Development, hunting	2011, 2012
Vietnam	Red River Delta	2	4	Habitat change, Hunting	2009, 2012, 2013
Vietnam	Mekong Delta	5	8	Habitat change	2011, 2013
Vietnam	Central Vietnam	1	1		2013
Thailand	Inner Gulf	10	15	Development	2005–2013
Thailand	South Thailand	1	2		2011, 2013
Myanmar	Gulf of Mottama	160*	220*	Hunting	2008–2012
Myanmar	Ahlat	4	8	Hunting, Development, hunting, sand abstraction	2009–2013
Myanmar	Nan Thar	20	25		2008–2013
Myanmar	Ayeyarwaddy Delta	2	2	Hunting	2010, 2013
Myanmar	Other sites in Rakhine	2	5		2009
Bangladesh	Sonadia	12	27	Development, hunting	2006–2013
Bangladesh	Teknaf	0	2	Development	2006–2013
Bangladesh	Nijhum Dweep	2	23		2006–2012
Bangladesh	Other Ganges Delta	1	2		2006–2012
Malaysia	Selangor	1	2		2010–2013
	Total	242	378		

wintering on the island of Nan Thar in the state of Rakhine (near the border with Bangladesh) fluctuated between 14 and 35 birds with 20–25 in recent years. The large Asian River deltas of the Ganges–Brahmaputra, Ayeyarwaddy, Red River and Mekong all held three or more birds on a regular basis. Sites in China, Vietnam, and Thailand all held relatively low numbers. A summary of all wintering sites is presented in Table 1 and Figure 1.

Species distribution models

The performance of the model was convincing according to the AUC of 0.946 ± 0.028 . Neither of the climate variables contributed more than 1% to the models, so were dropped from the model along with mid infra-red reflectance (Table 2). Offshore chlorophyll was of particular importance, and examination of the relationship (Figure S1 in the online supplementary material) suggests

Table 2. Variables retained in the final model with their permutation importance values and percentage contributions.

Variable	Percentage contribution	Permutation importance
Mean ocean chlorophyll concentration	31.4	4.2
Mean radiance in band 2	18.5	6
Mean NDVI	13.7	41.6
Mean radiance in band 3	10.1	28.5
Distance from coast	10	6.7
Mean radiance in Band 0	9.3	12.4
Tidal range	7	0.7

that birds were more likely to occur in areas where concentrations of chlorophyll offshore were higher. Relationships with reflectance from SPOT are more difficult to interpret, but the negative association with NDVI (Figure S1) might simply reflect areas of extensive unvegetated land (i.e. estuarine mud) being more likely to be occupied than vegetated areas inland. Areas in the top 5% of values for the model included the areas along the coast of Bangladesh, western Myanmar, the outer regions of the Gulf of Mottoma in Myanmar and the Inner Gulf of Thailand (Figure 2). Most of the larger areas identified as suitable are already known to be used by wintering Spoon-billed Sandpipers, but there would appear to be less extensive but still potentially suitable areas south of the Mekong delta. Small parts of the coast of western Myanmar, eastern Bangladesh and the Guangxi and Guangdong regions of China may also merit further investigation. Figure S2, a geo-referenced .tif file for GIS, is provided to allow detailed interrogation of the areas predicted to be potentially occupied.

Discussion

The species is widely distributed in winter over an area stretching from Bangladesh to Eastern China just south of the Yangtze River estuary. The majority of birds seem to winter in Myanmar, where 60% of the population has been observed. At least 80% of the entire global population appears to winter in Myanmar and Bangladesh. Surveys of wintering Spoon-billed Sandpipers were undertaken at sites in six of the flyway countries over a nine-year period. Collating records of these birds allows us to build up a database of areas used by wintering individuals, pointing to areas of conservation priority for the species. Difficulties in standardisation of



Figure 2. Modelled potential distribution of Spoon-billed Sandpiper habitat. Map shows the 5% of the study area with the highest predicted likelihood of occupancy. The predicted distribution of the Spoon-billed Sandpiper on which Figure 2 is based is available as a .tif for GIS in Figure S2. A indicates Gulf of Mottama, Myanmar, B is Inner Gulf of Thailand, C is south Mekong delta, D is Guangxi and E indicates Guangdong.

survey methodologies between and within sites, not least due to shifting sediments in estuaries, means that for many sites it is difficult to produce accurate population trends over multiple years. However, these surveys have allowed crude estimates of abundance to be calculated and broadly allow us to detect if populations continue to decline. From our surveys, the estimated population in the wintering areas surveyed is between 242 and 378 individuals. This is consistent with current estimates derived from the breeding area of fewer than 120 breeding pairs (Syroechkovskiy *et al.* in litt.).

Descriptive observations made during surveys and photos taken suggest that Spoon-billed Sandpipers fed on a broad variety of benthos, including small crabs, shrimps, polychaetes and amphipods, and often small flies. Birds were observed feeding in shallow waters or mudflats with puddles, but did not appear to visit or feed in the areas of deep and fine mud found in many shallow areas of estuaries.

Our species distribution model had a relatively high AUC value and correctly identified the majority of the known wintering areas as being highly suitable, suggesting that it provides a good description of the distribution of Spoon-billed Sandpipers. The model was built to assess the potential distribution of the species, rather than to interpret habitat associations, but the association with chlorophyll was notable. As we do not have geo-referenced data on where Spoon-billed Sandpipers do not occur, we were unable to undertake a thorough assessment of model performance and assess both specificity and sensitivity. The majority of suitable areas identified by our model were around sites at which birds are regularly recorded (Table 1), suggesting the main wintering areas are already known. This is supported by the scarcity of records away from major, known wintering grounds. However, since the species occurs in small numbers across extensive estuary systems, it may have been overlooked at some sites. For example, in 2013, just one individual each was reported from two sites in Malaysia (David Bakewell *in litt.*), one in the Eastern Ayeyarwaddy Delta in November 2013 (Moses and Zöckler 2013), two in 2014 at the same site (Saw Moses pers. comm.) and one in Cambodia in January 2014 (Simon Machmut pers. comm.). Substantial populations might remain in China: in 2008, local bird watchers and photographers mentioned wintering birds in the Min Jiang estuary in Fujian Province. Up to 14 birds have since been recorded at this site in winter (Bai *et al.* 2015), although none were seen in 2013. After intensive surveys in 2010 and 2011, further wintering sites were discovered west of Min Jiang (Fujian), in Beihai (Guangxi), on the island of Hainan and Fangchengang near the Vietnamese border. These mostly involved sightings of one or two individuals, but in Lei Zhou Peninsula towards Hainan (Guangdong), up to five were observed in December 2012 (Martinez and Lewthwaite 2013). Up to eight birds were recorded in 2013 in Wenzhou in Zhejiang Province (MT), making this both the most northerly and easterly known wintering site. The model highlighted a number of previously unsurveyed sites with small areas of potentially suitable habitat which may merit further investigation. These include parts of the coast of western Myanmar and eastern Bangladesh and the southern part of the Mekong delta. Potentially suitable areas were also indicated in the Guangxi and Guangdong regions, which coincide with areas identified as potentially suitable habitat from a visually interpretation of satellite images. Future field surveys should be targeted at these areas. Field surveys would ideally also be made at locations predicted to be unoccupied to test the veracity of the model. However, practicalities and expense means that the areas highlighted as potentially suitable should be prioritised.

Difficulties in survey methods, including the speed at which estuaries alter due to storms and the highly dynamic coastal tidal systems of some sites (authors' pers. obs.), means we cannot make an accurate assessment of population changes within most sites. However, the indications of declining populations in the breeding areas (Zöckler *et al.* 2010a) are supported by robust surveys. Apparent population declines have been noted across the wintering areas, although they appear to be less severe than those documented on the breeding grounds. For example, in Bangladesh the species was regularly recorded around Hatia Island in large numbers from the late 1980s to early 1990s, with the highest single count of 289 birds in 1989 from Moulevir Char (Howes and Parish 1989). Smaller numbers (three to c.30) were then recorded between the late 1990s and early 2000s, with the westernmost record of four birds on 24 February 1992 from Egg Island on the

edge of the Sundarbans (Thompson *et al.* 1993, Thompson and Johnson 2003). A survey on Egg Island and adjacent islands in January 2013 found no Spoon-billed Sandpipers (Chowdhury *et al.* 2014). On Sonadia Island, regular surveys began in 2009 and records reflect a consistent build up during northward migration: counts of 13 in January and 25 in March 2010 were followed by 15 and 11 in January and 27 and 24 in March 2011 and 2012. Up to eight birds were recorded at the tip of Teknaf peninsula in 2006, two in 2010 but no birds have been recorded there since at least 2012 (Thompson *et al.* 2014, Chowdhury *et al.* 2014). Wintering numbers from Nan Thar in Myanmar declined from 35 in 2008 to only 14 in 2009 and 2010 but increased to 20 in 2013 (Zöckler *et al.* 2014). In Vietnam, the Red River Delta was a regular wintering site with up to 17 birds recorded in the mid-1990s (Jonathan Eames pers. comm.), but no birds were found during a 10-day survey in January 2010 and only one bird in 2013, despite intensive searching. The ubiquity of the declines across all sites seems to indicate that the declines are genuine, rather than artefacts of variation in observer effort, especially as the species has had an increasing profile in recent years. Spoon-billed Sandpipers are surprisingly difficult to identify in flocks of waders especially when roosting, but the development of very high resolution telescopes and digital cameras for birdwatching has greatly increased the ability of general birdwatchers to identify the species with certainty. It has, however, required targeted surveys to find most of the new locations for the species. Chance findings of Spoon-billed Sandpipers cannot be relied upon to locate the remaining wintering areas and it must be assumed that they are not wintering in areas regularly visited by birdwatchers. Given the extremely difficult terrain in which most birds have been found, it is likely that the survey methods will need to be tailored for each site rather than there being a survey protocol that can be used across the wintering range.

Evidence of a link between changes in habitat and declines in Spoon-billed Sandpipers is lacking, not least because of the small number of detailed studies on the species. Habitat loss is a threat at a number of occupied sites (e.g. Chowdhury 2010, Chowdhury *et al.* 2011, Zöckler *et al.* 2014), and reclamation of crucial intertidal areas on the passage have rendered them unsuitable for waders (Murray *et al.* 2014). Therefore, sites which are currently occupied should be rigorously protected to prevent loss or alteration on a precautionary basis. The species distribution models did identify pockets of potentially suitable habitat that have not yet been surveyed. Targeting survey effort to these areas, whilst maintaining regular ongoing monitoring at other known sites, would be a priority. However, it would not appear that extensive areas of potentially suitable habitat still exist. Habitat loss on stop-over sites and wintering areas, together with hunting pressure (Zöckler *et al.* 2010b), might be the main driver for population declines in this species. It is also possible that some sites have become degraded in a way that is not easily detectable; e.g. the gradual reclamation by expanding shrimp farms, as observed in Thailand, Myanmar and Bangladesh (Zöckler *et al.* 2008), or that Spoon-billed Sandpiper distributions are driven by fine-scale factors in the environment or landscape that are not adequately captured by our model. Similarly, we cannot discount the role of habitat loss on passage sites and on the breeding grounds in causing declines, although loss on breeding areas might be less likely as a cause of decline, as breeding grounds have apparently largely remained unchanged and research from the breeding grounds (Zöckler *et al.* 2010a) points to threats along the migration route. The species might also be vulnerable to a range of other, less obvious, threats at passage and wintering sites, such as pollution or the impact of agricultural run-off: topics which also merit research.

Protection through site designations is much desired but alone is insufficient, and needs to be enforced. Hunting and trapping of birds is widespread and observed in almost all major sites. The species urgently requires stronger or better enforced protection in China and Vietnam. In China, Spoon-billed Sandpipers are on the “list of terrestrial wildlife under state protection, which are beneficial or of important economic or scientific value” under the Law of the People’s Republic of China on the Protection of Wildlife, but they are not listed as State Key Protected species. Hunting appears to be an important factor in the declines of Spoon-billed Sandpipers in many winter sites. In the Gulf of Mottama, at least 53 hunters were active in winter, having caught annually an estimated 20,000 birds (Zöckler *et al.* 2010b). On the East Coast of the Gulf, 20 hunters caught a

minimum of 150 Spoon-billed Sandpipers in total between 2001 and 2010 (BANCA 2011a) and 84 between 1989 and 2011 on the West coast of the Gulf (BANCA 2011b). On Sonadia Island, Bangladesh, at least 25 hunters were active in winter and eight hunters claimed to have captured a total of 22 Spoon-billed Sandpipers between October 2009 and April 2010 (Chowdhury 2010). This means actions will also need to be taken at the local or community scale, targeting damaging practices such as indiscriminate hunting and trapping of birds. In these areas, in addition to enforced legislative protection of sites, conservation efforts should be targeted towards reducing hunting pressure and supporting alternative livelihoods to the hunting of water birds for food. Mitigation and engagement with communities has been initiated at some sites, with early evidence of success (Zöckler *et al.* 2010b, BANCA 2011a). Expanding this action to other areas where Spoon-billed Sandpipers winter should be considered a priority for conservation, and our species distribution model could be used to guide survey efforts to identify any unknown populations. Law enforcement has been applied in South China, where hunting has been widespread (Martinez and Lewthwaite 2013).

Regular monitoring is recommended to closely watch the state of wintering populations. Over the past eight years, coordinated monitoring efforts have been carried out regularly at known sites with increasing efficiency, and searches for new areas focused on Myanmar (Zöckler *et al.* 2010b, 2014), Bangladesh (Chowdhury *et al.* 2010, 2013, Chowdhury and Foysal 2015), Thailand (Round 2006, Nimnuan and Daengpayon 2008, Sripanomyom *et al.* 2011) and Vietnam (this study). These surveys have been based around January counts in an attempt to minimise movement of birds between sites. Although we do not yet know enough about the species' movements, we observed little fluctuation in numbers of Spoon-billed Sandpipers and little movement between sites during this period.

A species distribution model described the known distribution of the species well, highlighting all major sites known to be used by wintering birds. A few new potential areas were identified in Bangladesh, China, Myanmar and Vietnam. Field surveys should be targeted at these locations urgently to determine if birds are present, and initiate conservation actions as required to mitigate any threats. The protection of sites that are found to be occupied should be encouraged, and is likely to benefit many other species in addition to Spoon-billed Sandpipers. Protection could also be applied to sites which have not yet been surveyed, based on the precautionary principle, especially if large numbers of shorebirds are known to occur there. This protection, whether legal or community based, should be extended to preventing hunting in addition to habitat loss.

Supplementary Material

The supplementary materials for this article can be found at journals.cambridge.org/bci

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