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REVIEW

Protecting stopover habitat for migratory shorebirds in East Asia

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Abstract Many migratory species depend on staging sites at which they refuel while on migration, and effective protection of such habitats is crucial to their conservation. Here we investigate the extent to which protected areas cover and ameliorate loss of tidal flats in East Asia, the key staging habitat for threatened and declining shorebirds migrating through the East Asian–Australasian Flyway. We discover rapid losses of the tidal flat ecosystem both inside (-0.42 % year^{-1}) and outside (-0.89 % year^{-1}) protected areas. In China, tidal flats are well represented within protected areas (22.9 % of current tidal flats occur within protected areas), but habitat loss continued despite protection (-0.55 % year^{-1} inside, -0.97 % year^{-1} outside). By contrast, in South Korea, where 12.1 % of remaining tidal flat is in protected areas, the rate of habitat loss outside protected areas was the highest in our study region (-1.83 % year^{-1}), yet inside protected areas there was tidal flat aggradation ($+1.13$ % year^{-1}), indicating either that protected area placement is biased away from vulnerable habitats, or protected areas are highly effective in South Korea. Tidal flats across our study area were lost most rapidly in internationally important sites for migratory shorebirds (-1.66 % year^{-1}), suggesting that transformative land use change of coastal areas is occurring disproportionately in regions that are important for migratory birds. We urge (1) improved management of existing protected areas in East Asia, particularly in China, (2) targeted designation of new protected areas in sites crucial for supporting migratory birds and (3) integrated decision-making that simultaneously plans for coastal development and coastal conservation.

Keywords Protected areas · Migratory species · China · South Korea · North Korea · Coastal development · Habitat loss

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Introduction

Migratory species depend on suitable habitats all along their migratory route to ensure their effective conservation (Martin et al. 2007; Runge et al. 2014), and habitat loss in particular regions can have a disproportionate population impact because of the location of that loss (Weber et al. 1999; Iwamura et al. 2013). A corollary of this is that the importance of habitat protection varies markedly over the geographic distribution of migratory species (Martin et al. 2007; Iwamura et al. 2014). Migratory shorebirds undertake some of the world's longest migrations and many species depend on very specific stopover sites in intertidal habitats, particularly tidal flats, while on migration (Colwell 2010). However, intertidal areas have rarely been mapped, and the extent to which protected areas adequately cover intertidal areas, or prevent the loss of tidal flats, remains poorly understood. Here we study this issue in the East Asian–Australasian Flyway (EAAF), where migratory shorebird populations are currently collapsing. Long-term monitoring at the terminus of the EAAF in Australia has revealed a 73 % decline in numbers of migratory shorebirds in eastern Australia between 1983 and 2006 (Nebel et al. 2008), and several regional analyses have documented significant local declines (Creed and Bailey 1998; Nebel et al. 2008; Rogers et al. 2009; Wilson et al. 2011; Dawes 2012; Kingsford and Porter 2009; Minton et al. 2012). Four migratory shorebird species endemic to the EAAF are listed as globally threatened on the IUCN Red List (Nordmann's Greenshank *Tringa guttifer*, Spoon-billed Sandpiper *Calidris pygmaea*, Eastern Curlew *Numenius madagascariensis* and Great Knot *Calidris tenuirostris*; IUCN 2014), and two have recently been nominated for threatened species listing in Australia (Curlew Sandpiper *Calidris ferruginea* and Eastern Curlew; Department of Environment 2014a, b).

Tidal flats in East Asia are a crucial refuelling point at which millions of migrating shorebirds in the EAAF stop to feed en route to and from the Arctic and subarctic (Barter 2002; Bamford et al. 2008; Hua et al. 2015). Analysis of satellite data has shown that two-thirds of this critical stopover habitat in the Yellow Sea has disappeared in the past 50 years from reclamation projects and sediment regime change (Murray et al. 2012, 2014). Moreover, species dependent on the Yellow Sea while on migration are declining more quickly in Japan (Amano et al. 2010), suggesting that habitat loss in the East Asian region has been at least in part driving the declines in migratory shorebirds. Australia has signed bilateral migratory bird agreements with Japan, China and South Korea to protect migratory shorebirds and their habitats, and the species are also protected under international treaties including the Convention on Biological Diversity, the Convention on Migratory Species, and the Ramsar Convention on Wetlands. These treaties commit countries to take special measures to protect birds migrating between them, yet catastrophic declines among migratory shorebirds have occurred during the lifetime of these agreements.

Given the rapid declines in stopover habitat for migrating shorebirds in the EAAF, a critical question is how well the remaining habitat is protected, and whether designation as a protected area is effective in arresting habitat loss. Protected areas encompass more than 15 % of the earth's land surface (Juffe-Bignoli et al. 2014) and are among the most widely implemented conservation measures aimed at slowing the loss of species and ecosystems (Gaston et al. 2008; Le Saout et al. 2013). For some ecosystems, such as tropical forests, the effectiveness of protected areas at abating threatening processes has been widely tested (Andam et al. 2008; Gaveau et al. 2009; Joppa and Pfaff 2011; Carranza et al. 2013; Green et al. 2013). However, for many ecosystems the ability of protected areas to reduce habitat conversion and ecosystem loss remains poorly evaluated (Watson et al. 2014). Coastal ecosystems, in particular, have been a primary focus of remote sensing and mapping efforts for decades (Green et al. 1996; Phinn et al. 2000), yet little information exists on coverage by protected areas, or the trajectory of habitat loss inside or outside protected areas (Spalding et al. 2008). Recognising their importance, preserving coastal ecosystems within "effectively managed, ecologically representative and well-connected systems of protected areas" is a global conservation priority under the Convention on Biological Diversity's (CBD) Aichi targets (Target 11; http://www.cbd.int/sp/targets). Clearly, understanding how protected areas perform for conserving coastlines and their ecosystem services is essential, and requires detailed information on the status of changing coastal environments, including the changing extent and distribution of coastal ecosystems, rates of coastal habitat loss, and measurements of the effectiveness of protected areas in abating threats (Sutherland et al. 2004; Keith et al. 2013).

In this study, we measure protected area coverage and rates of coastal habitat loss inside and outside protected areas along the mainland coast of East Asia. Along the coastlines of China, North Korea and South Korea (mainland East Asia), rapid migration of humans to the coastal zone over the past few decades has resulted in a coastal population of more than 160 million people in the low elevation coastal zone (less than 10 m ASL; after McGranahan et al. 2007). Moreover, by 2030, it is predicted that the growing coastal-urban corridor will extend across more than 1800 km of the region's coastline (Seto et al. 2012). To accommodate the rising coastal population, the governments of China, North Korea and South Korea have implemented large-scale development plans that are swiftly transforming natural coastal ecosystems to industrial, urban and agricultural land (UNEP 2003; UNDP/GEF 2007; CCICED 2010; MacKinnon et al. 2012; Murray et al. 2014; Ma et al. 2014). The primary remaining coastal ecosystem in the region, the tidal flat ecosystem, is rapidly disappearing in both quantity and quality and is having an enormous impact on the region's coastal biodiversity (UNDP/GEF 2007; MacKinnon et al. 2012; Murray et al. 2014, 2015). For example, the critically endangered Spoon-billed Sandpiper, which feeds in tidal flats along the China and Korean coastlines during migration, is thought to have a current global population of less than 200 breeding pairs (Zockler et al. 2010; MacKinnon et al. 2012). Similarly, declines in biodiversity due to widespread pollution, hunting, resource extraction, invasive species spread and land-use change are being widely reported (Choi et al. 2010; He et al. 2014; Murray et al. 2015), and the tidal flat ecosystem has recently been assessed as Endangered under the IUCN Red List of Ecosystems (Murray et al. 2015; Rodríguez et al. 2015). Despite these issues, the region (excepting North Korea) contains a well-established protected area system, providing a unique opportunity to evaluate the performance of protected areas in a region that is undergoing rapid coastal change.

We first describe how the region's primary coastal ecosystem, tidal flats, were mapped with a recently developed remote sensing method across more than 14,000 km of coastline, extending from the Vietnam–China border (21°32′N, 108°1′E) to the Russia–North Korea border (42°17′N, 130°42′E; Fig. 1). We outline the steps necessary to make robust comparisons of multi-source, multi-resolution data, overcoming the processing limitations of the satellite data for application to coastal ecosystems. Then we calculate the levels of protection for these ecosystems, and overlay rates of tidal flat loss onto the protected area system. We discuss the principal drivers of habitat loss inside and outside protected areas, and suggest potential pathways to recovery for intertidal habitats in East Asia and the migratory shorebirds that depend on them.

Methods

Our previously published remote sensing method (Murray et al. 2012) and Yellow Sea status analyses (Murray et al. 2014, 2015) provide the framework for determining the distribution and status of intertidal wetlands for any geographic region. Here we extend the geographic coverage of the change analyses and assess the extent to which protected areas cover tidal flat ecosystems.

Satellite analyses

We used maps of tidal flats over the study area coastline at two time periods (c. 1980s and c. 2000s) generated from Landsat Archive ETM+/TM imagery (see Murray et al. 2012, 2014 for detailed methods). Briefly, the method compares images acquired in the upper and lower 10 % of the tidal range for each Landsat footprint to delineate intertidal areas. Each classification was completed on a per-Landsat footprint basis; the classified raster outputs were post-processed to remove misclassifications, resampled to 100-m resolution and projected to the Albers equal area projection. The tidal flat class for each of the two time periods was mosaicked across the study area, resulting in

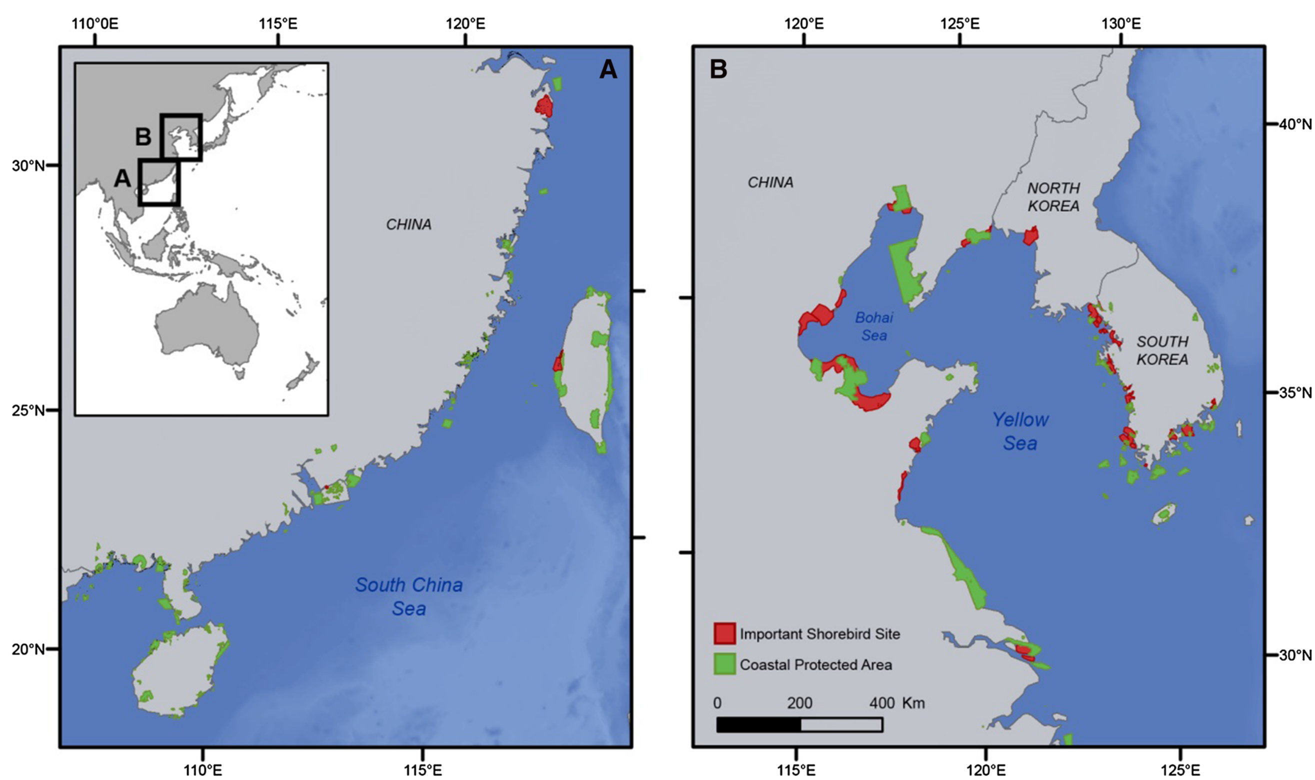

Fig. 1 Location map of the mainland coast of East Asia, south of the Yangtze River (**a**) and in the Yellow Sea region (**b**). The maps show the protected areas included in the analysis (*green*), and internationally important sites that hold more than 1 % of the EAAF population of migratory shorebirds (*red*). The study area included the whole coastline from the Vietnam–China border (21°32′N, 108°1′E) to the Russia–North Korea border (42°17′N, 130°42′E) (colour figure online)

comparable spatial data sets of tidal flat extent. Concurrently, raster mosaics of the mean year of acquisition of the input satellite imagery were produced, to allow for subsequent rates of change analyses. Areas that could not be mapped because of cloud, snow or ice cover, or pollution were masked over the two data sets. A technical fault on the Landsat 7 satellite in 2003 meant that about 22 % of data collected subsequent to this fault and prior to the launch of the Landsat 8 satellite in 2013 were missing in a striped pattern across the images. We dealt with this SLC-Off imagery by masking both images in a pairwise comparison in the same way as for clouds and snow cover. We were ultimately able to calculate continuous rates of change and net change of tidal flats across 67.6 % of the study area coastline.

Map accuracy

To assess the accuracies of the two classified tidal flat mosaics, we populated an error matrix for each data set (Congalton and Green 2008). Using stratified sampling, we randomly placed 260 accuracy assessment points across each of the thematic maps. Each point was assigned a class by an independent analyst not involved in the remote sensing classification (Murray et al. 2014). Where possible, sample points were cross-validated against high resolution imagery available from ESRI World Imagery and Google Earth. The map accuracy for the 2000s data set was 89.2 % (Murray et al. 2012) and for the 1980s data set 88.8 % (Table S1). Commission and omission errors indicate that the remote sensing method generally underestimates the true extent of tidal flats but that this does not vary consistently over time. A full discussion of the sources of commission and omission errors is provided in Murray et al. (2012).

Protected areas and important shorebird sites

We constructed a spatial database of protected area boundaries using information from (1) the World Database on Protected Areas (WDPA; http://www.protectedplanet.net; IUCN and UNEP 2014), and (2) a protected area data set developed by non-governmental organisations (NGOs) and academics (J. MacKinnon, personal communication) that accounts for much of the information from East Asia that is missing in the WDPA data set (see Wu et al. 2011). We selected all 238 protected areas that (1) occurred in one or both of the two protected area data sets, (2) exceeded 1 km^2 in area, which is two orders of magnitude greater than the resolution of our tidal flats data set, permitting a robust estimate of habitat change within each protected area, (3) occurred within 5 km of the coastline (as mapped by Wessel and Smith 1996), and (iv) had a delineated boundary (Fig. 1). As a result of the disparate sources of protected area data, it was not possible to include year of designation or class of protection in our analyses.

In addition to protected areas, we also assessed habitat losses within internationally important migratory shorebird sites across the region, namely those that support more than 1 % of the total EAAF population at any time of year (Bamford et al. 2008). We matched the sites listed in Bamford et al. (2008) with a spatial data set of internationally important wetland sites developed by Iwamura et al. (2013), comprising polygon data of wetland boundaries sourced from national wetland maps, Ramsar and other relevant information ($n = 49$ sites; Fig. 1; Table S2).

Spatial analysis

The analysis of change of tidal flat extent over the study area was performed using the two classified tidal flat mosaics. Habitat loss metrics were computed per Landsat tile, so that the rate of change of tidal flats, (r, % year^{-1}), was calculated over the time interval from the mean acquisition time between the first high and low tide pair of satellite images in the 1980s, t_1, and the second image pair from the 2000s, t_2, such that $r = \frac{100}{(t_2 - t_1)} \ln(A_2/A_1)$, where A_1 and A_2 are the total area of tidal flats at time t_1 and t_2, respectively (Murray et al. 2014). In addition to the rate of change, we calculated the net change of tidal flat extent between the two time periods as $A_1 - A_2$. For analyses of tidal flat change within protected areas and important shorebird areas, we excluded areas where A_1 or A_2 was 10 ha or less ($n = 61$ protected areas). Owing to the dynamism of tidal flats (Murray et al. 2014), all analyses were performed at the regional scale rather than on an individual protected area basis, reducing the impact of fine-grained remote sensing error on overall trends. This 'compare-to-everywhere' approach is suitable for describing empirically the pattern of habitat change inside and outside protected areas (Clark et al. 2013), but cannot ascribe any differences to protected area effectiveness as it does not account for any biases in the locations of individual protected areas with respect to habitat loss (Andam et al. 2008). The remote sensing and spatial analyses were performed in ArcGIS 10.2 and the Python programming language (v. 2.7.3). Program R (v. 3.0.2) was used for data processing and analysis (R Core Team 2013).

Results

Extent and pattern of intertidal habitat loss

For the area with sufficient satellite data to map tidal flat extent over the two periods, 248,694 ha of tidal flat appeared in areas not previously tidal flat between the 1980s and the 2000s, but 418,098 ha of the original tidal flat had disappeared, equating to a net loss of 169,484 ha. Thus, we estimate that tidal flats along the coastlines of China, South Korea and North Korea have declined in total extent by 18.9 % in 25 years (Table 1). The rate of change of the tidal flat ecosystem across the full coastline was −0.82 % year^{-1}. Most remaining tidal flats occurred in North Korea, which increased in area by 9 % over the study period (+0.27 year^{-1}). By contrast, tidal flats in South Korea declined by 32.2 % and in China by 19.7 %, with South Korea recording the greatest rate of loss of tidal flats (−1.58 % year^{-1}) followed by China (−0.88 % year^{-1}). While the change statistics are robust, the estimates of absolute areas are considerably lower than the true area of tidal flats, because areas where cloud cover had disrupted the satellite imagery (32.4 % of the coastline) at either time-step were discarded from the analysis (Fig. 1). In addition, the use of SLC-Off Landsat Archive imagery (post-2002) for the change analysis resulted in the loss of approximately 22 % of data from each affected Landsat scene (Goward et al. 2011).

Protected areas cover 11.2 % of the study area coastline, and are somewhat biased toward tidal flats, containing nearly 18.5 % of the mapped tidal flats across the region in the 2000s (Table 2). South Korea's protected area system covers 15.5 % of the country's coastline and contains 12.1 % of the remaining tidal flats, while China's protected areas cover 10.9 % of the coastline, and 22.9 % of the remaining tidal flats. We were unable to confirm the boundaries of coastal protected areas in North Korea, although there is a suggestion that such sites covered about 5 % of tidal flats in that country at least in the 1990s (Barter 2002). The large proportion of tidal flats within protected areas in China is a result of five large areas that hold 20.4 % of China's remaining tidal flats, including Yancheng and Dafeng NR (Jiangsu Province, 12.8 %), Shuangtaihekou NR (Liaoning Province, 3.0 %) and Yalu Jiang NR (Liaoning Province, 2.2 %). Our results are somewhat influenced by the distribution of the remote sensing data and should be interpreted with caution. For example, owing to chronic cloud cover we were unable to map some areas south of the Yellow River delta known to contain large tidal flats (MacKinnon et al. 2012).

The overall rate of change (r) of tidal flats within protected areas was −0.42 % year^{-1}, indicating that rapid losses of tidal flats have occurred within the East Asian coastal protected area system (Table 2). Tidal flats inside China's protected areas declined at a moderately slower rate than outside protected areas (−0.55 % year^{-1} inside, −0.97 % year^{-1} outside). By contrast, in South Korea tidal flats increased within protected areas by 1.13 % per year, but decreased by 1.83 % per year outside (Table 2). Although the trajectory of the tidal flat ecosystem across the region was overwhelmingly negative, there was considerable variation in the patterns of change across individual protected areas. For example, in the protected areas of South Korea, habitat loss ranged from rapid loss (maximum −8.97 % year^{-1}) to rapid gain (maximum 9.87 % year^{-1}). Across all of the areas considered in our analysis, tidal flats were lost at the greatest rate in sites that are internationally important for migratory shorebirds (−1.66 % year^{-1}; Table 2).

Discussion

The designation and management of effective protected areas is a global priority for slowing biodiversity loss along our increasingly crowded coastlines (Pereira et al. 2013). However, our analysis illustrates that there can be substantial differences in the rates of coastal habitat loss among established protected areas. We discovered that losses of tidal flats occurred overwhelmingly outside protected areas in South Korea, but both inside and outside protected areas in China. Moreover, the highest rates of tidal flat loss occurred in internationally important shorebird areas, suggesting that conditions favoured by

Table 1 Extent of tidal flats along the China, North Korea and South Korea coastlines for two time periods in the 1980s and 2000s, and their rate of change over between those periods

Country	Coastline mapped (%)	1980s		2000s		Change		
		Input satellite imagery, t_1 (mean year)	Tidal flat area, A_1 (ha)[a]	Input satellite imagery, t_2 (mean year)	Tidal flat area, A_2 (ha)[a]	Period elapsed between images, $t_2 - t_1$ (years)	Net change (%)	Continuous rate of change, r (% year^{-1})
China	64.8	1980.4	670,647	2005.3	538,564	24.9	−19.7	−0.88
South Korea	72.4	1984.8	140,809	2009.5	95,493	24.6	−32.2	−1.58
North Korea	74.1	1976.7	87,963	2008.4	95,878	31.6	+9.0	+0.27
Overall	67.3	1980.9	899,419	2006.3	729,935	25.4	−18.9	−0.82

[a] These values are subject to data gaps (see "Methods") and should not be considered absolute areas

Table 2 Status of tidal flats inside and outside protected areas in East Asia, and within internationally important shorebird sites

Country	Coastline mapped (%)[a]	Coastline within protected areas (%)[a]	Tidal flats inside protected areas (%)	Net change (%)			Continuous rate of change (r) (% year^{-1})		
			2000s	Outside PA	Inside PA	Shorebird sites	Outside PA	Inside PA	Shorebird sites
China	64.8	10.9[b]	22.9	−21.7	−12.1	−44.0	−0.97	−0.55	−2.06
South Korea	72.4	15.4	12.1	−36.3	+30.1	−18.1	−1.83	+1.13	−0.83
North Korea	74.1	0.0	0.0	+9.0	–	−10.7	+0.27	–	−0.39
Overall	66.0	11.2	18.5	−20.7	−9.6	−35.9	−0.89	−0.42	−1.66

[a] Calculated with coastline data from the global self-consistent, hierarchical, high-resolution shoreline database (Wessel and Smith 1996)

[b] Note that conservation parks listed in the WDPA for China are limited in coverage and, despite our inclusion of an NGO-managed protected area data set, our analysis might not reflect the full extent of protected areas in the region

shorebirds are also those that are associated with vulnerability to habitat loss.

Differences in habitat loss dynamics in relation to protected areas in China and South Korea could be driven either by different protected area effectiveness in the two countries, or a different pattern of bias in the siting of protected areas relative to threatening processes. If protected areas are more likely to be established in places that are less vulnerable to habitat loss, their effectiveness is apparent and not real, as low rates of loss would also have occurred if the protected area had not been designated (Andam et al. 2008; Joppa et al. 2008; Joppa and Pfaff 2011). However, we believe that establishment bias is not a general explanation for our results in this case, because habitat losses outside protected areas were greatest in South Korea, suggesting that baseline levels of threat have been higher in that country. Indeed, that South Korea's protected areas effectively prevented habitat loss suggests a conservation system that is working as intended (Kim 2010; Choi 2014), by diverting threatening processes to areas outside the protected area system. In China, however, our results indicate a coastal protected area system that is permeable to the threat of habitat loss, raising serious doubts about whether coastal ecosystems in China will be preserved regardless of the level of protection. The primary threat to coastal ecosystems in East Asia is development of the coastline for agriculture, aquaculture, urban and industrial land (MacKinnon et al. 2012; Murray et al. 2014). Such developments may be large-scale projects planned at a provincial or national government level (MacKinnon et al. 2012), or illegal reclamations undertaken at local scales. There are documented cases of such developments both inside and outside of China's protected areas (Cho and Olsen 2003; Sato 2006; An et al. 2007; Ma et al. 2009; Bi et al. 2011; Yang et al. 2011) and the rate of reclamation is expected to increase over the next 10 years (Ma et al. 2014). Thus, improving the effectiveness of China's coastal protected area system seems an urgent priority.

Moreover, our results indicate that coastal development is resulting in faster habitat loss in important sites for migratory shorebirds than across the coastline at large, suggesting that the most important sites for biodiversity are also those under the greatest pressure from coastal development. Loss of coastal habitat in East Asia has been suggested as the principal driver of migratory shorebird population declines in the EAAF, but this has not yet been confirmed with quantitative analysis (Amano et al. 2010; Wilson et al. 2011; Iwamura et al. 2013). Major unprotected areas of tidal flat habitat occur throughout the entire region, including in the Bohai Sea, southern Jiangsu province and southern Liazhou Bay in China (Rogers et al. 2010; Yang et al. 2011; MacKinnon et al. 2012), and several areas in North Korea (Barter 2002; MacKinnon et al. 2012). Maintaining these areas of habitat is crucial for conserving the migration of shorebirds in the EAAF (Barter 2002; MacKinnon et al. 2012; Iwamura et al. 2014). Adding these large remaining areas of tidal flat habitat to the protected area system could be an important conservation priority, and a full spatial prioritisation of a cost-effective system of coastal protected areas in the region is urgently required.

Owing to the dynamic nature of tidal flat ecosystems, which change in extent at different tidal elevations and are subject to a multitude of coastal processes that affect their distribution (Healy et al. 2002), our analysis has several limitations. First, the remote sensing data displayed overall accuracies of 89.7 and 88.8 % for the 1980s and 2000s analysis, respectively, and the method is likely providing conservative estimates of the true extent of tidal flats (Murray et al. 2012). Indeed, the remote sensing method was developed for mapping tidal flats at continental scales and uncertainty as a result of resolution issues and changing tide heights are magnified when applied to very small areas (Murray et al. 2012). We addressed the accuracy issue by completing all analyses at regional rather than site-specific scales (see "Methods"). Second, collecting comparable satellite data was not possible over the entire study region and the patterns of tidal flat change in areas that were not mapped will influence the results presented here to an unknown extent. If large, unprotected areas of tidal flat exist in areas that have not been mapped, we would overestimate the proportion of tidal flats occurring within protected areas in the region. Third, our use of a compare-to-everywhere approach might lead to overestimation of the effectiveness of protected areas (Andam et al. 2008). This is particularly the case if protected areas are sited non-randomly across the coastline, where they face inherently different levels of threat (Carranza et al. 2013), and the fact we found poor effectiveness in the Chinese protected area system in spite of the conservative nature of our analysis is thus especially concerning. Lastly, our analysis focused on changes in areal extent of habitat, and thus cannot detect declines in habitat quality for shorebirds. Habitat quality is known to be declining across the region (Choi et al. 2010; He et al. 2014; Murray et al. 2015), and is likely influencing shorebird populations through ongoing direct and indirect effects on individuals of all shorebird species.

Coastal habitats around the world are subject to severe anthropogenic pressure, resulting in widespread loss and degradation of coastal habitats (Lotze et al. 2006; Diaz and Rosenberg 2008). In East Asia, where about 160 million people inhabit the low-elevation coastal zone, a well-managed protected area system that effectively conserves remaining coastal ecosystems is critical to avert imminent extinctions. We have shown that, although the existing protected area system harbours a large proportion of the remaining tidal flats in mainland East Asia, ongoing loss and degradation of coastal ecosystems is occurring both inside and outside these protected areas, particularly in China. The high representation of remaining tidal flats in Chinese protected areas is a huge opportunity to avert ecosystem collapse, providing the sites can be effectively managed.

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