Conserving unprotected important coastal habitats in the Yellow Sea: shorebird occurrence, distribution and food resources at Lianyungang

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Abstract

Coastal wetlands around the world are being destroyed and degraded rapidly. In most developing and recently developed countries, the ecological data required for wetland conservation are scarce, and expertise to collect them are less-established. One of the most rapidly deteriorating coastal regions is the Yellow Sea in East Asia, an important staging area for migratory shorebirds. Conserving the declining shorebird populations that rely on the Yellow Sea requires habitat protection and management based on sound ecological knowledge, especially on the seasonal occurrence of shorebirds, their daily movements and their food resources. Here we gather and assimilate such information for the coastal wetlands at Lianyungang on the Chinese Yellow Sea coast, an understudied and unprotected area where we found 27% of intertidal soft sediment habitats have been destroyed in 2003-2018. In 2008-2018, 43 shorebird species were recorded along this coastline, including 11 globally threatened or 'Near Threatened' species. We recorded 18 shorebird species of numbers exceeded 1% of the Flyway populations, which is the second-highest among the >300 shorebird sites in East Asia. Shorebirds stopping there during migration are probably attracted by the highly-abundant small soft-shelled bivalve species (including 9399 individuals/m^2 of *Potamocorbula laevis*) that dominate the benthic mollusc community of the intertidal flats. Satellite tracked bar-tailed godwits (*Limosa lapponica*) and great knots (*Calidris tenuirostris*) stopped at Lianyungang for 5-28 days during northward and southward migration. The tidal movements of satellite-tagged birds indicated high tide roosts which are inaccessible on-ground. These movements can also be used to evaluate whether high-tide roosts and low-tide foraging areas are close enough to each other, and direct where to create new roost sites. Potential measures to increase the capacity of Lianyungang to support shorebirds include reducing human disturbances, creating roosts at undeveloped parts of the reclaimed land, and the removal of recently-built sea dikes to restore intertidal flats.

Keywords
intertidal mudflats; macrobenthos; reclamation; restoration; satellite telemetry; waders

1. Introduction

The conservation of migratory shorebirds in the East Asian-Australasian Flyway (EAAF) have progressed in the past decades through field research that collected baseline information primarily on bird numbers (Bai et al., 2015; Barter, 2002). This has resulted in the discovery and recognition of major staging sites, many of which are in the Yellow Sea. However, many coastal sites along the EAAF are undergoing extensive habitat loss and degradation (Melville et al., 2016; Murray et al., 2015, 2014; Piersma et al., 2016). This is suggested to be the main driver of declines in adult survival for populations that spend the non-breeding season in Australia and migrate annually along the EAAF (Piersma et al., 2016), resulting in decreasing bird numbers, especially for those populations that rely most on the coastal staging areas along the Yellow Sea (Studds et al., 2017).

In the recent years, the governments in the Yellow Sea region have recognised the ecological value of their coastlines and are committing to protect them (Melville, 2018). In 2017, the Chinese government included 14 coastal sites in the Yellow Sea in a tentative nomination as UNESCO World Heritage (UNESCO, 2017) and released new policies regarding wetland protection and restoration (Melville, 2018; Zhao, 2018). The design of effective protection and restoration measures needs to be based on solid ecological knowledge at the local scale, such as shorebird's habitat use and prey availability. Such knowledge is inadequate in many countries in East and Southeast Asia (Hua et al., 2015), the likely reason being the shorter history of science-based site management (Lee and Khim, 2017) and limited citizen science capacities (e.g. one in about 65000 people in China are birdwatchers in 2010, Ma et al., 2013).

To exemplify how the gathering and assimilation of local ecological knowledge may facilitate ecosystem- and bird-friendly management, and to directly fill a key knowledge gap for conservation of the Yellow Sea region, we present the information needed for managing one of the proposed UNESCO sites in the Yellow Sea that is particularly understudied and unprotected, the Lianyungang Coast (34.4-35.1°N, 119.2-119.8°E) in northern Jiangsu Province, China. We first establish the site's current importance for shorebirds based on counts conducted in 2008-2018. To identify the shorebird habitats along the Lianyungang Coast that require protection and management, we describe how shorebirds use current coastal habitats from our on-the-ground observations and from local movements of satellite-tagged shorebirds. Since land reclamation has reduced the area of intertidal flats in the Yellow Sea substantially (Murray et al., 2015), we describe coastal habitat changes on the Lianyungang coast by measuring rate of intertidal flat loss by reclamation and mapping current status of the reclaimed coastal land from satellite images. We also assess the quality of the intertidal feeding habitat by estimating densities of benthic shellfish in 2015-2017, the staple food of many shorebird species (Choi et al., 2017; Tulp and de Goeij, 1994; Yang et al., 2013).

2. Material and methods

2.1. Study area and background

Our study area comprises the entire 162 km coastline of Lianyungang City, China (34.4-35.1°N, 119.2-119.8°E), in the southern Yellow Sea. The salt ponds along this coastline were listed as an IBA in 2009 (BirdLife International, 2018a) and was proposed as a tentative World Heritage site in 2017 (UNESCO, 2017). The proposal was based on the over 18 000 shorebirds detected in the salt ponds on a single survey in 2004 (Barter and Xu, 2004). Salt production in Lianyungang has a history of over 1100 years, but declined after the discovery of nearby salt mines in the 1980s. The over 500 km^2 of salt ponds were steadily converted to aquaculture and industrial uses and are almost non-existent today (Xie and Gao, 2011, pers obs). Currently, most of the coastline is enclosed by man-made seawalls with aquaculture ponds on the landward side and intertidal flats and rocky coast on the seaward side. During the 2004 survey of the northern portion of these intertidal flats, over 15 000 shorebirds were counted (Barter and Xu, 2004).

2.2. Bird surveys

To describe the number of birds using this coastline, we summarised citizen science count data of the Chinese Coastal Waterbird Census (Bai et al., 2015). These counts were conducted between February 2008 and May 2018 at eight areas along the coast (Fig 1), covering all the main shorebird habitats (for details see Table A.1). For all shorebirds, we present the maximum numbers, whether species met or exceeded the 1% flyway population threshold derived from the world population estimates (Wetlands International, 2018), and conservation status (i.e., Near Threatened, Vulnerable, Endangered, Critically Endangered; IUCN, 2017). We also present the maximum counts of waterbird species of other families that exceeded the 1% flyway population threshold derived from the world population estimates (Wetlands International, 2018) and/or listed as 'Near Threatened' or above in the IUCN Red List (IUCN, 2017). Physical habitat characteristics were noted during some count sessions in spring 2015-2018 (Table A.1).

2.3. Satellite tracking

We characterize bird movements from the tracking data of six great knots and six bar-tailed godwits (maximum counts of these two species at Lianyungang exceed 1% of their flyway population, Table 1) which staged at the Lianyungang coast during 2015–2018. Solar Platform Terminal Transmitters (PTTs, Microwave Telemetry, USA) of 4.5 and 9.5 g were deployed onto great knots and bar-tailed godwits respectively, in September and October 2014, 2015 and 2016, at the northern beaches of Roebuck Bay, Broome, Northwest Australia (18.11°S, 122.27°E). PTTs were programmed to operate on a duty cycle of 8 hours on and 25 hours off. Positions were received from Argos (Collecte Localization Satellites, CLS 2013). The work was carried out under Regulation 17 permits SF 010074, SF010547 and 01-000057-2 issued by The West Australian Department of Biodiversity, Conservation and Attractions.

For migration timing analysis, we filtered the Argos locations to retain all standard locations (i.e. the location classes 3, 2, and 1) and removed implausible auxiliary locations (i.e. classes 0, A, B and Z) by applying the Hybrid Douglas filter (Douglas et al., 2012), with the filtering parameters set at 120 km/h for the maximum sustainable rate of movement and 10 km for

minimum-redundant-distance. Details of the filter application are described in Gill et al. ESM (2009). To calculate arrival and departure times of each bird, the first point with speed <20 km/h within the site boundary was defined as the first point recorded when the individual stopped at Lianyungang, the same for the last point. Arrival and departure times were estimated by extrapolating the average speed of a non-stop flight over the intervening distance between the first stopping point and the previous in-flight point i.e. bird was moving at >20 km/h or was > 50 km away from the shoreline. If the previous point was a stop, we assumed that the flight from the previous site occurred at the mid-point of the time interval between the two. We estimated departure times in the same way. Staging duration is the difference between estimated arrival and departure times.

For the analysis of local distributions and movement, we only used standard locations, as the auxiliary locations have an error radius that is too large for the size of our study area (Douglas et al., 2012). These standard locations are classified as being collected at low or high tide using water level predictions from the Oregon State University Tidal Prediction Software with the China Seas Regional model (http://volkov.oce.orst.edu/tides/otps.html; Egbert and Erofeeva, 2002). Since some tracking data points were on land where there is no water level predictions, for each tracking point, we extracted the predicted water level at its nearest point along a transect at sea, 500 m away from and parallel to the coastline. A point is assigned as 'high tide' if the predicted water level is higher than the 60% quantile of a sample of predicted water level (every 10 min for a month) along this transect (0.5 m), or is assigned as 'low tide' if the water level is lower than the 40% quantile (-0.5 m).

We visualized high- and low-tide locations in heatmap based on Kernel Density Estimation. The radius of each point was two times the published 68% percentile error radius (Douglas et al., 2012) and weighed by the inverse of this radius, and therefore each point is designated as the same 'heat', but is more concentrated (for class 3 locations) or spread out (for the less precise class 2 and 1 locations). We used locations at least one hour apart from one another. If there were more than 1 locations within the hour, we chose the point with highest accuracy, or the earliest point in the case of ties. To examine daily movements, we calculated distances between pairs of points of the same individual within a high-tide, within a low-tide, and between consecutive high- and low-tide, using points that were more than 1 h apart.

2.4. Mapping changes in intertidal area

Reclamations of the intertidal area were mapped from satellite images from January 2003 to June 2018. Landsat TM, TIRS and Sentinel MSI images of 30 m resolution were visualised in Google Earth Engine (GEE) (https://code.earthengine.google.com). Of the 154 satellite images acquired, we analysed 80 (52%) that had more than 10% of the coastline were visible and not covered by clouds. Satellite images were displayed in false colours, and coastal structures were manually mapped on GEE, and later exported to QGIS 2.18.20 as a shape file (.shp). Mudflat area was estimated from an image acquired at low tide in December 2003. An area were defined as 'reclaimed' when completely enclosed by new seawalls visualized at the scale of 1:5000. The rate of reclamation was calculated from 3 separate periods, the break points determined by fitting a piecewise regression onto the area-date relationship with R package 'segmented' (Muggeo, 2008).

Land use of the reclaimed areas were classified into aquaculture ponds, industrial land or undeveloped land (for details see Table A.2).

2.5. Benthic survey

Sampling grids covered the main intertidal mudflats used by foraging shorebirds at Xiuzhenhe, Mutaohe and Xingzhuanghe (Fig. 1). Sampling stations were evenly distributed by 250 or 500 m apart depending on the local situation (Fig. 1; for methodological rationale, see Bijleveld et al., 2012). During the spring migration period of the birds, a total of 41 stations were visited in 5 to 7 May 2015, 70 stations from 28 April to 1 May 2016, and 60 stations from 28 April to 2 May 2017. At each station, a sediment core with a surface area of 0.019 m^2 was taken to a depth of 20 cm and washed over a 0.5 mm sieve. The sieved sample was then stored frozen prior to analysis. In the laboratory, molluscs were counted, identified and measured to the species level using a dissecting microscope, and high density species were subsampled by a Motodo Splitter.

3. Results

Overall, 43 shorebird species were recorded in the surveys, including 11 globally threatened or 'Near Threatened' species (Table 1). For 18 species, their numbers exceeded the 1% of the EAAF population, including the Asian Dowitcher (*Limnodromus semipalmatus*), Black-tailed Godwit (*Limosa limosa*), Eurasian Oystercatcher (*Haematopus ostralegus*) and Eurasian Curlew (*Numenius arquata*) which had counts exceeded 10% of the EAAF population. The highest total number recorded was the over 100 000 shorebirds at the Qingkouhe mudflats (area 4 in Fig. 1) on 5 May 2015. Moreover, 80 species of other waterbird families were recorded in the surveys, in which 13 were globally threatened or 'Near Threatened', and 8 had numbers exceeds the 1% of the EAAF population (Table A.3). Notably, the single count of 63 Dalmatian Pelican (*Pelecanus crispus*) in winter 2012 exceeded the East Asian population estimate of 50 individuals (Wetlands International, 2018)

During northward migration, the Lianyungang coast is used by satellite-tracked great knots and bar-tailed godwits either as a short stop of a few days or for long staging of almost a month before the long flight to the breeding grounds. In spring, one great knot stopped for 8 days and two for 27 and 28 days, respectively. Five bar-tailed godwits staged during spring, three for a long period of 28.6 days (SD=1.5) and two for 5.1 days (SD=0.3). Three tracked great knots stopped in autumn for 18 days (SD=1.4), showing that it is also a main staging site for southward migration. One bar-tailed godwit staged during autumn for 8.0 days.

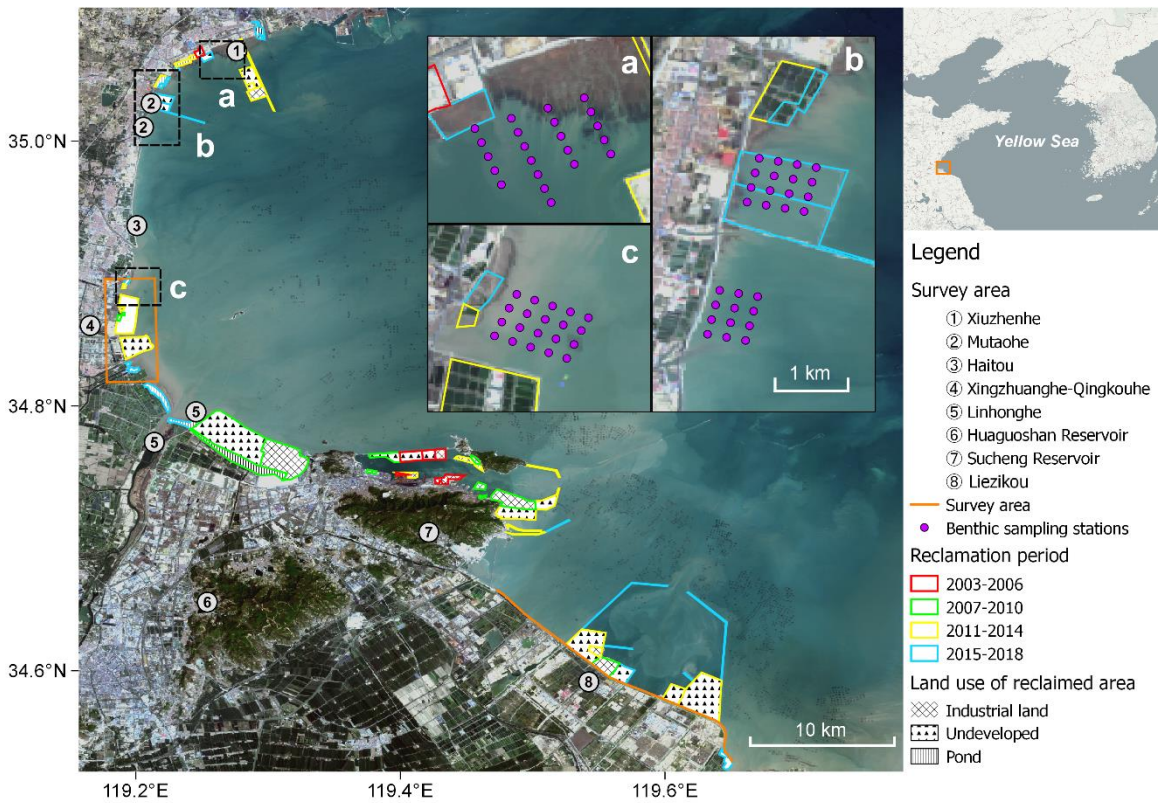

Fig. 1. Map of the Lianyungang coast showing the eight bird survey areas and 70 benthic sampling stations at (a) Xiuzhenhe (b) Mutaohe and (c) Xingzhuanghe. Reclaimed areas are depicted on the map with respective year range (coloured outlines) and the type of land use (shaded).

Table 1. Maximum count of shorebird species along Lianyungang coastline in 2008–2018 sorted by English common name. Species with counts exceeding 1% of the EAAF population are in bold. IUCN Red List status in parentheses (NT=Near Threatened, VU=Vulnerable, EN =Endangered, CR=Critically Endangered). [m] indicates species observed to occur on intertidal mudflats.

Species	1% of EAAF Population	Counts of shorebirds and other species (Maximum number, Date and Site)					
		Northward Migration (March-June)		Southward Migration (July-November)		Wintering Period (December-February)	
Asian Dowitcher (NT) [m] *Limnodromus semipalmatus*	230	**7000**	12 May 2018 Xingzhuanghe-Qingkouhe	**1000**	17 Jul 2017 Xingzhuanghe-Qingkouhe		
Bar-tailed Godwit (NT) [m] *Limosa lapponica*	1700	**4702**	14 Apr 2013 Xingzhuanghe-Qingkouhe	**2700**	25 Jul 2015 Linhonghe	8	19 Feb 2017 Xingzhuanghe-Qingkouhe
Black-tailed Godwit (NT) [m] *Limosa limosa*	1600	**19810**	5 May 2018 Xingzhuanghe-Qingkouhe	**4432**	7 Aug 2012 Linhonghe		
Black-winged Stilt *Himantopus himantopus*	1000	88	Jun 2010 Linhonghe	350	25 Jul 2015 Linhonghe	6	11 Jan 2015 Xingzhuanghe-Qingkouhe
Broad-billed Sandpiper [m] *Limicola falcinellus*	1000	720	5 May 2018 Xingzhuanghe-Qingkouhe	105	12 Sep 2015 Xingzhuanghe-Qingkouhe		
Common Greenshank [m] *Tringa nebularia*	1000	600	May 2008 Linhonghe	694	7 Aug 2012 Linhonghe	8	15 Jan 2011 Liezikou
Common Redshank [m] *Tringa tetanus*	1000	500	May 2008 Linhonghe	241	7 Aug 2012 Linhonghe	130	Dec 2008 Linhonghe
Common Sandpiper *Actitis hypoleucos*	500	3	9 May 2011 Linhonghe	10	Jul 2008 Linhonghe		
Common Snipe *Gallinago gallinago*	10000	5	1 Apr 2014 Xingzhuanghe-Qingkouhe	3	Oct 2010 Liezikou	1	Dec 2008 Linhonghe
Curlew Sandpiper (NT) [m] *Calidris ferruginea*	1800	**2500**	16 May 2014 Xingzhuanghe-Qingkouhe	12	25 Jul 2015 Linhonghe	8	27 Jan 2018 Xingzhuanghe-Qingkouhe

Dunlin [m] *Calidris alpine*	10000	**14000**	May 2008 Linhonghe	8000	22 Oct 2017 Linhonghe	7500	13 Dec 2015 Xingzhuanghe-Qingkouhe
Eastern Curlew (VU) [m] *Numenius madagascariensis*	380	300	16 Apr 2017 Xingzhuanghe-Qingkouhe	543	23 Oct 2016 Xingzhuanghe-Qingkouhe	30	27-Jan 2018 Xingzhuanghe-Qingkouhe
Eurasian Curlew (NT) [m] *Numenius arquata*	350	**1110**	18 Mar 2017 Xingzhuanghe-Qingkouhe	**825**	25 Nov 2017 Xingzhuanghe-Qingkouhe	**2400**	11 Jan 2015 Xingzhuanghe-Qingkouhe
Eurasian Oystercatcher (NT) *Haematopus ostralegus*	100	**406**	16 Mar 2013 Xingzhuanghe-Qingkouhe	70	10 Nov 2013 Xingzhuanghe-Qingkouhe	**3130**	11 Jan 2015 Xingzhuanghe-Qingkouhe
Great Knot (EN) [m] *Calidris tenuirostris*	3800	**4520**	8 May 2018 Xiuzhenhe	2968	8 Aug 2012 Xingzhuanghe-Qingkouhe	350	27 Jan 2018 Xingzhuanghe-Qingkouhe
Greater Sand Plover *Charadrius leschenaultii*	1000	270	1 May 2016 Mutaohe	130	Oct 2010 Liezikou	6	27 Jan 2018 Xingzhuanghe-Qingkouhe
Green Sandpiper *Tringa ochropus*	1000	6	8 May 2018 Mutaohe	4	Oct 2010 Linhonghe	4	12 Feb 2012 Huaguoshan Reservoir
Grey Plover [m] *Pluvialis squatarola*	1300	**8870**	16 Mar 2013 Xingzhuanghe-Qingkouhe	**3500**	19 Aug 2015 Xingzhuanghe-Qingkouhe	**3000**	20 Feb 2018 Xingzhuanghe-Qingkouhe
Grey-headed Lapwing *Vanellus cinereus*	1000	6	12-Mar 2011 Liezikou	8	Oct 2010 Linhonghe		
Grey-tailed Tattler (NT) [m] *Heteroscelus brevipes*	NA	25	9 May 2011 Liezikou	25	Aug 2010 Liezikou		
Kentish Plover *Charadrius alexandrinus*	1000	**2000**	Mar 2010 Linhonghe	**2500**	14 Oct 2012 Linhonghe	100	Feb 2008 Linhonghe
Lesser Sand Plover [m] *Charadrius mongolus*	200	**750**	12 May 2013 Xingzhuanghe-Qingkouhe	**1425**	19 Aug 2016 Linhonghe	60	27 Feb 2018 Xingzhuanghe-Qingkouhe
Little Ringed Plover *Charadrius dubius*	250	10	16 Apr 2017 Xingzhuanghe-Qingkouhe	60	26 Jul 2011 Linhonghe		
Little Stint *Calidris minuta*	NA	1	10 Apr 2014 Linhonghe	1	8 Sep 2012 Liezikou		

Long-billed Dowitcher *Limnodromus scolopaceus*	NA	3	15 Apr 2011 Linhonghe				
Long-toed Stint *Calidris subminuta*	250	4	9 May 2011 Linhonghe	**600**	21 Jul 2012 Liezikou		
Marsh Sandpiper [m] *Tringa stagnatilis*	10000	4150	18 Apr 2015 Xingzhuanghe-Qingkouhe	600	Sep 2010 Linhonghe	145	27 Jan 2018 Xingzhuanghe-Qingkouhe
Nordmann's Greenshank (EN) *Tringa guttifer*	NA	77	12 May 2018 Xingzhuanghe-Qingkouhe	40	11 Oct 2015 Xingzhuanghe-Qingkouhe		
Oriental Pratincole *Glareola maldivarum*	20000	6	9 May 2011 Linhonghe	1	Oct 2010 Liezikou		
Pacific Golden Plover [m] *Pluvialis fulva*	1000	240	22 Apr 2014 Xingzhuanghe-Qingkouhe	4	15 Oct 2011 Linhonghe	1	14 Dec 2011 Linhonghe
Pied Avocet [m] *Recurvirostra avosetta*	1000	**7000**	3 Apr 2016 Xingzhuanghe-Qingkouhe	**11000**	18 Oct 2014 Xingzhuanghe-Qingkouhe	**7000**	13 Jan 2012 Linhonghe
Red Knot [m] *Calidris canutus*	NA	4010	1 and 2 May 2017 Xingzhuanghe-Qingkouhe & Xiuzhenhe	300	12 Aug 2009 Liezikou	35	27 Jan 2018 Xingzhuanghe-Qingkouhe
Red-necked Phalarope *Phalaropus lobatus*	NA			4	10 Sep 2017 Xingzhuanghe-Qingkouhe		
Red-necked Stint [m] *Calidris ruficollis*	3200	**4900**	18 Apr 2015 Xingzhuanghe-Qingkouhe	**6837**	8 Aug 2012 Liezikou	250	27 Jan 2018 Xingzhuanghe-Qingkouhe
Ruddy Turnstone [m] *Arenaria interpres*	1000	85	5 May 2018 Xingzhuanghe-Qingkouhe	90	12 Aug 2009 Liezikou		
Ruff *Philomachus pugnax*	NA	8	16 Apr 2011 Linhonghe	6	10 Sep 2017 Xingzhuanghe-Qingkouhe		
Sanderling *Calidris alba*	220	**232**	May 2010 Liezikou	200	Nov 2010 Liezikou	25	14 Feb 2011 Haitou
Sharp-tailed Sandpiper [m] *Calidris acuminate*	1600	**8000**	May 2008 Linhonghe	**3000**	19 Aug 2015 Xingzhuanghe-Qingkouhe	80	27 Jan 2018 Xingzhuanghe-Qingkouhe

Spoon-billed Sandpiper (CR) *Calidris pygmaea*	NA	1	22 Apr 2014 Xingzhuanghe-Qingkouhe	2	16 Sep 2016 Linhonghe		
Spotted Redshank [m] *Tringa erythropus*	1000	413	16 Apr 2011 Linhonghe	250	26 Jul 2011 Linhonghe	48	17 Dec 2011 Liezikou
Terek Sandpiper [m] *Xenus cinereus*	500	**650**	16 Jun 2012 Linhonghe	180	10 Sep 2017 Xingzhuanghe-Qingkouhe		
Whimbrel [m] *Numenius phaeopus*	550	40	13 Jun 2009 Linhonghe	106	12 Aug 2009 Liezikou	1	27 Jan 2018 Xingzhuanghe-Qingkouhe
Wood Sandpiper *Tringa glareola*	1000	100	May 2008 Linhonghe	12	8 Sep 2012 Liezikou		

We have observed 24 species of shorebirds foraging on the intertidal mudflats from Qingkouhe to Xiuzhenhe (Table 1). During high-tide, shorebirds roosted in mixed-species flocks in aquaculture ponds or undeveloped land with little vegetation and patches of very shallow water (Fig. A.1). Satellite tracking can collect distributional data even at locations that were not accessible during our surveys. During high tide, the tracked great knots mostly roosted at a piece of undeveloped reclaimed land at Xiuzhenhe, while roosts of bar-tailed godwits were scattered along the coastline. At low-tide, tagged individuals of both species occurred on the Mutaohe and Xingzhuanghe mudflats, but on the mudflats of Xiuzhenhe, only great knots occurred. At Linhonghe, only bar-tailed godwits occurred at low tide. One godwit stayed at the southern tip of Liezikou but only for a few days. In general, bar-tailed godwits showed smaller tidal movements than great knots (Table 2).

Table 2. Average distances traveled within and between tidal cycles by individual bar-tailed godwits (n = 6) and great knots (n = 6) at Lianyungang based on satellite-tracked locations.

	Distance travelled (km±SD)	
Tide type	Bar-tailed godwits	Great knots
High	1.52±1.20, n=17	3.84±4.55, n=25
Low	1.94±0.63, n=3	2.76±2.79 n=14
Between consecutive high and low	3.07±2.22, n=29	6.45±4.36 n=33

n = number of pairs of points

The intertidal flats were muddy at most areas, especially at estuaries of Linghouhe, Qingkouhe and Xingzhuanghe, while sandy at Mutaohe (Fig. 1). Invasive Smooth Cord Grass *Spartina alterniflora* occurred at mudflats next to seawalls, and at Linhonghe extended outwards for around 500 m, and at Xiuzhenhe for around 1 km. From 2003 to 2018 a total of 71.4 km^2 of land was claimed along the Lianyungang coastline, in which 44 km^2 was converted from intertidal flats, resulting in 27% of loss in intertidal area. More than half of this new land (40.4 km^2) remains undeveloped as of June 2018. Of the developed areas, 60.3% (18.7 km^2) were used for industrial purposes and the rest (12.3 km^2) for aquaculture ponds (Fig. 1). From January 2003, the rate of land claim was low (0.7 km^2/year), but since October 2007 it increased more than fourfold (8.3 km^2/year), before slowing down from February 2015 to June 2018 (2.5 km^2/year; for details see Fig. A.2).

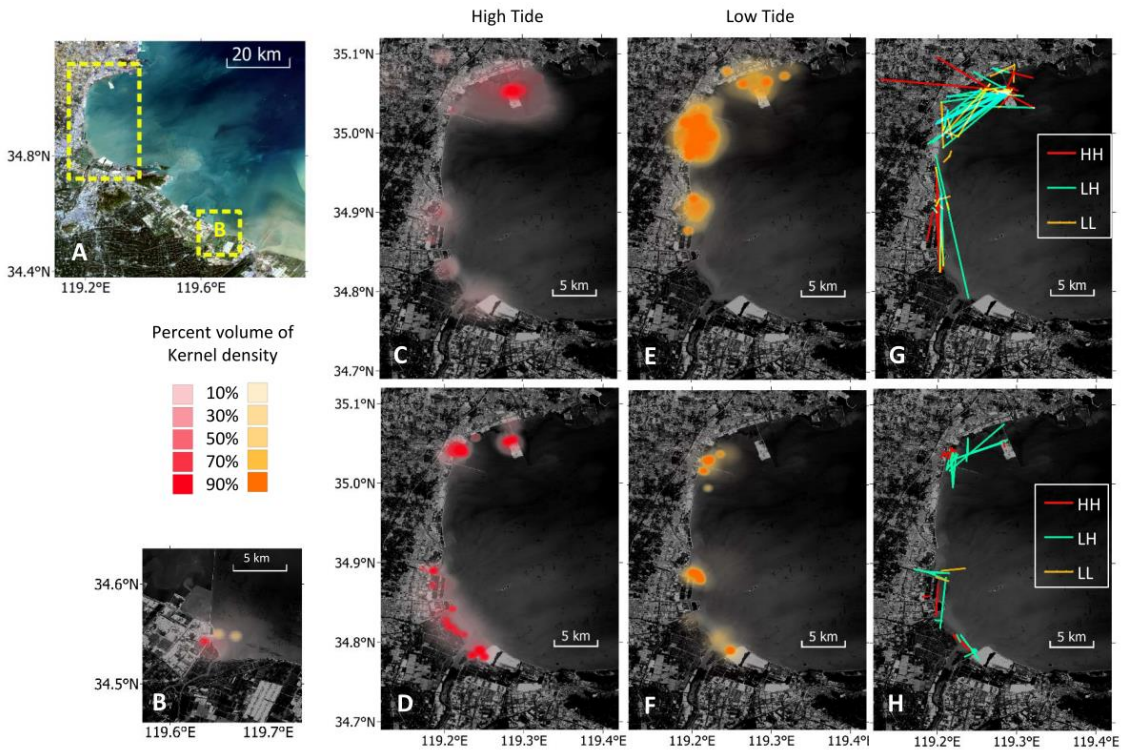

Fig. 2. A. Areas of occurrence (yellow rectangles) of satellite-tracked great knots and bar-tailed godwits along the Lianyungang coastline. B. High tide (red) and low tide (orange) Kernel densities of locations of an individual bar-tailed godwit at Liezikou. Kernel densities of locations during high tide and low tide for great knots (C, E) and bar-tailed godwits (D, F) at Ganyu. Movements within or between tides as depicted by lines connecting pairs of points of the same individual for great knots (G) and bar-tailed godwits (H). HH=points within a high tide; LH=points between consecutive high and low tides; LL=points within a low tide.

A total of 25 species of mollusks were recorded in the benthic surveys. The Xingzhuanghe and Mutaohe mudflats were dominated by *Potamocorbula laevis*, while Xiuzhenhe was dominated by *Musculus senhousei*. Although the community composition was rather different between the three areas, the most abundant species (*P. laevis*, *M. senhousei*, *Ruditapes philippiarum*, *Sinonovacula constricta* and *Retusa cecillii*) were all small (averaged 3.5–9.9 mm), rather soft-shelled, bivalves. These species comprised >98% of the mollusks in each area (Table 3).

Table 3. Mean density (MD), percentage (Perc) and shell length of mollusc species at Xingzhuanghe, Mutaohe and Xiuzhenhe of the Lianyungang Coast.

Species (sorted by most abundant)	**Xingzhuanghe**		**Mutaohe**		**Xiuzhenhe**		**Overall MD**	**Shell Length**		
	MD (ind/m^2)	Perc (%)	MD (ind/m^2)	Perc (%)	MD (ind/m^2)	Perc (%)	**(ind/m^2)**	Mean (mm ± SD)	Range (mm)	Number of individuals measured
Potamocorbula laevis	21724.1	99.56	6471.2	87.52	0	0.00	9398.5	4.8 ± 2.69	1.03-27.77	4831
Musculus senhousei	14.4	0.07	390.8	5.28	1897.5	81.69	767.6	3.52 ± 2.53	1.1-19.71	569
Ruditapes philippiarum	12.8	0.06	462.8	6.26	65.9	2.84	180.5	4.31 ± 4.71	1.4-39.33	409
Sinonovacula constricta	6.3	0.03	14.1	0.19	259.8	11.19	93.4	9.87 ± 2.61	3.5-17.6	230
Retusa cecillii	0.9	0.00	0.7	0.01	60.8	2.62	20.8	4.73 ± 1.83	2.52-15.7	48
Umbonium thomasi	30.5	0.14	7.8	0.11	0.0	0.00	12.8	7.26 ± 3.16	1.67-14.81	54
Mactra veneriformis	2.8	0.01	16.3	0.22	3.9	0.17	7.6	24.24 ± 10.19	1.71-41.86	40
Moerella iridescens	9.9	0.05	4.2	0.06	5.2	0.22	6.4	7.54 ± 3.67	2.3-18.81	21
Nassarius festiva	1.8	0.01	4.9	0.07	5.2	0.22	4.0	9.72 ± 3.57	3.41-13	13
Salinator fragilis	0.0	0.00	0.0	0.00	10.3	0.45	3.4	2.08 ± 0.61	1.27-3.04	8
Cyclina sinensis	0.0	0.00	0.6	0.01	9.0	0.39	3.2	4.34 ± 4.00	2.11-14.55	9
Meretrix pethechialis	0.0	0.00	9.2	0.12	0.0	0.00	3.1	9.01 ± 4.85	3.2-19.6	22
Theora lata	7.2	0.03	0.7	0.01	0.0	0.00	2.6	6.4 ± 3.40	3.36-13.91	9
Bullacta exarata	1.0	0.00	1.4	0.02	3.9	0.17	2.1	6.78 ± 2.30	3.95-10.88	6
Solen gouldi	0.9	0.00	1.4	0.02	1.3	0.06	1.2	17.56 ± 8.20	10.23-28.69	4

Stenothyra glabar	2.7	0.01	-	-	-	-	0.9	2.96 ± 0.26	2.70-3.22	3
Meretrix meretrix	1.8	0.01	0.7	0.01	-	-	0.8	12.9 ± 17.98	1.7-33.64	3
Scapharca subcrenata	0.9	0.00	1.4	0.02	-	-	0.8	4.24 ± 2.85	2.01-7.45	3
Endopleura lubrica	1.8	0.01	-	-	-	-	0.6	8.91 ± 1.63	7.75-10.16	2
Nassarius semiplicatus	-	-	1.4	0.02	-	-	0.5	2.64 ± 0.11	2.56-2.72	2
Nassarius variciferus	-	-	1.4	0.02	-	-	0.5	15.41 ± 2.57	13.59-17.23	2
Cerithidea sinensis	-	-	0.7	0.01	-	-	0.2	14.47	-	1
Mitrella bella	-	-	0.7	0.01	-	-	0.2	11.48	-	1
Neverita didyma	-	-	0.7	0.01	-	-	0.2	5.49	-	1
Punctacteon yamamurae	-	-	0.7	0.01	-	-	0.2	5.84	-	1
Total	21819.8	100	7394.0	100	2322.795	100	10512.2	-	-	6292

4. Discussion

The high bird numbers recorded over the past decade indicate that the coastal wetlands at Lianyungang are important for shorebirds, especially during migration. Particularly, we found that Lianyungang supported over 1% of the flyway populations of 18 shorebird species. This 1% criterion is commonly used by global inventories such as the Important Bird and Biodiversity Areas (IBAs) to assess site importance, and Lianyungang ranked second among the >300 shorebird sites in East Asia with this metric being reported (Bai et al., 2015; Conklin et al., 2014; Zhang et al., 2017). The occurrence of threatened waterbirds of other families boosted the importance of the site. Clearly the intertidal flats and coastal wetlands together fulfilled criteria for inclusion as an IBA and as a Ramsar site (BirdLife International, 2018b; Ramsar Convention Secretariat, 2018). Although reclamation has taken away more than one-fourth of the intertidal habitats along the Lianyungang coastline, the remaining intertidal flats are still productive; particularly, the exceptionally high densities of small soft-shelled bivalves are high-quality food for benthivorous shorebirds to refuel during their migration (Choi et al., 2017; Yang et al., 2013). Compared with two other major shorebird staging sites in the Yellow Sea where benthic surveys have been conducted in spring, the mollusk densities at Lianyungang were much higher than in Yalu Jiang (Zhang et al., 2018), and of similar densities as Nanpu, Bohai Bay (Yang et al., 2016).

The major foraging intertidal flats and roosts delineated from satellite tracking and our ground observations provide direct data for designing boundaries of a protected area. Although sample size of the tracking data is rather small (six individuals per species), satellite tracking was particularly useful in highlighting important shorebird areas that are not accessible by the public, such as the newly reclaimed ‘island’ at Xiuzhenhe, which is intensely used by tracked great knots as a high-tide roosts, and to a lesser degree by bar-tailed godwits (Figs. 1 and 2).

An important consideration for managing the area for shorebirds is the spatial coupling of intertidal foraging areas with suitable supratidal high-tide roosts. Foraging areas may become underused or abandoned if there are no suitable roosts nearby and/or roosts have too much disturbances, likely because the energy costs of commuting and/or alarm flights outweighs the energy gain from foraging (Rogers et al., 2006). The travel distances between and within tides (Table 2) measured in this study can indicate the distance tolerated by that shorebird species to commute daily. A simple exercise will be to assess if suitable roosting sites exist within a 3 km radius (Table 2) of foraging locations of bar-tailed godwits. If necessary, roosts can be created within this radius, either by restricting human disturbances at locations that already have the suitable biophysical features (having little or no vegetation, an open view and wet substrate; Burton et al., 1996; Zharikov and Milton, 2009), or creating such habitats at the many undeveloped land along the coast (Fig. 1).

Although commercial reclamation at intertidal areas has now been halted and being reconsidered in China (Xinhuanet, 2018), active management is still needed to safeguard the shorebird habitats along this coastline. It is necessary to reduce human disturbances to shorebird flocks, especially those caused by the labour-intensive harvesting of seafood such as shellfish, crabs, fishes and worms on the mudflats (causing flocks flying up every few mins, pers obs). Another issue is that invasive cordgrass (*Spartina* sp.) expanded and trapped sediments at some intertidal areas; these areas eventually become supratidal and loss their ecological value (Wan et al., 2009). Even worse, reclamation of supratidal areas can still proceed under the new coastal reclamation policy of China as they are not considered as 'marine' (Zhao, 2018). It is worth to consider restoring intertidal flats by removing areas invaded by *Spartina* (Frid et al., 1999) and removing sea dikes for areas recently being enclosed but remained undeveloped (Fig 1), e.g. where the new seawalls were built around some of our benthic sampling stations at Mutaohe (in blue outline in Fig 1b).

Clearly, the knowledge on the Lianyungang coast presented here is by no means comprehensive; e.g. our surveys along this 162 km coastline were mostly conducted by one person (YXH) on a voluntary basis, and the number of birds using this site is likely to be considerably higher. However, the fast pace of industrial development and the associating destruction and degradation (see Results, Fig. 1 and Fig. A.2) urges immediate conservation actions at this unprotected site. This combined issue of fast degradation and lack of related ecological knowledge is widespread in many sites in the EAAF and developing countries around the world (Lee and Khim, 2017). We hope that our study stimulates the gathering of ecological knowledge and science-based management, and the funding and facilitating of such practices from both the government and non-governmental organisations, at the many shorebird sites that are important but understudied (BirdLife International, 2017).

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Appendix A. Supporting Information

Table A. 1. Number of survey days per month in each of the eight survey areas.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1. Xiuzhenhe (35.06°N, 119.27°E)												
2016				1*	1*					1		
2017					1*							
2018					1*							
2. Mutaohe (35.02°N, 119.21°E)												
2015					1*							
2016				2*	1*							
2017					1*							
2018					1*							
3. Haitou (34.94°N, 119.20°E)												
2011		1										
2016					1				1			
2017										1		
4. Xingzhuanghe-Qingkouhe (34.86°N, 119.19°E)												
2012								1				
2013	1	1		1	1	1	1		1	1	1	1
2014	1		1	2	1		1	1	1	1	1	1
2015	1		1	1	1*		1		1	1	1	1
2016		1	1	4#	1	1		1	1	1	1	1
2017	1	1	1	2	1*	1	1	1	1	1	1	1
2018	1	1	1	1	3*							
5. Linhonghe (34.79°N, 119.25°E)												
2008	1	1	1		1		1	1	1	1	1	1
2009	1	1	1	1		1	1	1		1	1	
2010	1		1	1	1	1		1	1	1	1	1
2011	1	1	1	1	1	1	1	1		1	1	1
2012	1	1	1		1	1	1	1	1	1	1	1
2013			1	1								
2014				2						1	1	1
2015	1					1	1	1	1	1	2	1
2016		1	1			1		1	1	1		
2017								1		1		1
6. Huaguoshan Reservoir (34.65°N, 119.25°E)												
2011		1										
2012		1	1									
7. Sucheng Reservoir (34.70°N, 119.42°E)												
2009				1								
8. Liezikou (34.59°N, 119.55°E)												
2009	1		1	1			1	1	1			
2010	1	1		1	1	1		1	1	1	1	1
2011	1	1	1	1	1	1	1	1		1	1	1
2012	1	1	1	1	1	1	1	1	1			1
2013	1	1		1								
2014				2			1					

*Surveys with habitat characteristics noted.

#Habitat characteristics were noted only during surveys on 28 and 29 Apr 2016.

Table A.2. Characteristics for classifying land use of reclaimed areas

	Type of land use		
	Industrial	Ponds	Undeveloped
Sediment deposits	Present	Absent	Present or Absent
Water	Absent	Present	Present
Infrastructures	Present	Absent	Absent
Colour under false colour band arrangements	Brown or pink (vegetation cover)	Cyan Blue in chequered pattern	Mixture of brown and cyan blue
Example			

Table A.3. Maximum count of waterbirds species along Lianyungang coastline in 2008–2018, that have an IUCN Red List status of 'Near Threatened' (NT), 'Vulnerable' (VU) or 'Endangered' (EN) or the count exceeded 1% of the EAAF population (in bold), sorted by English common name.

Species	1% of EAAF Population#	Maximum Count recorded in 2008-2018	Count date and location
Baikal Teal (VU) *Anas Formosa*	5000	200	19 Feb 2011 Liezikou
Black-faced Spoonbill (EN) *Platalea minor*	15	3	17 Jul 2017 Xingzhuanghe-Qingkouhe
Caspian Tern *Hydroprogne caspia*	250	**300**	14 Nov 2015 Linhonghe
Chinese Egret (VU) *Egretta eulophotes*	30	**31**	8 Aug 2012 Liezikou
Common Pochard (VU) *Aythya farina*	3000	96	16 Feb 2016 Xingzhuanghe-Qingkouhe
Common Shelduck *Tadorna tadorna*	1300	**1920**	24 Dec 2017 Xingzhuanghe-Qingkouhe
Dalmatian Pelican (NT) *Pelecanus crispus*	1	**63**	11 Nov 2012 Linhonghe
Falcated Duck (NT) *Anas falcate*	350	**6000**	15 Jan 2011 Liezikou
Ferruginous Pochard (NT) *Aythya nyroca*	1000	4	1 Jan 2015 Linhonghe
Long-billed Murrelet *Brachyramphus perdix*	NA	2	12 Mar 2011 Linhonghe
Oriental Stork (EN) *Ciconia boyciana*	30	9	12 May 2013 Xingzhuanghe-Qingkouhe
Red-crowned Crane (EN) *Grus japonensis*	10	**25**	9 Mar 2012 Linhonghe
Relict Gull (VU) *Larus relictus*	120	**250**	16 Feb 2016 Linhonghe
Saunders's Gull (VU) *Larus saundersi*	85	**310**	7 Dec 2016 Xingzhuanghe-Qingkouhe
Streaked Shearwater (NT) *Calonectris leucomelas*	NA	2	1 Oct 2010 Liezikou
Swan Goose (VU) *Anser cygnoides*	800	29	14 Oct 2012 Linhonghe

Estimates from Wetlands International (2018). NA=The EAAF Population is not estimated.

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Fig. A.1. High-tide roosts of shorebirds at Lianyungang coast.

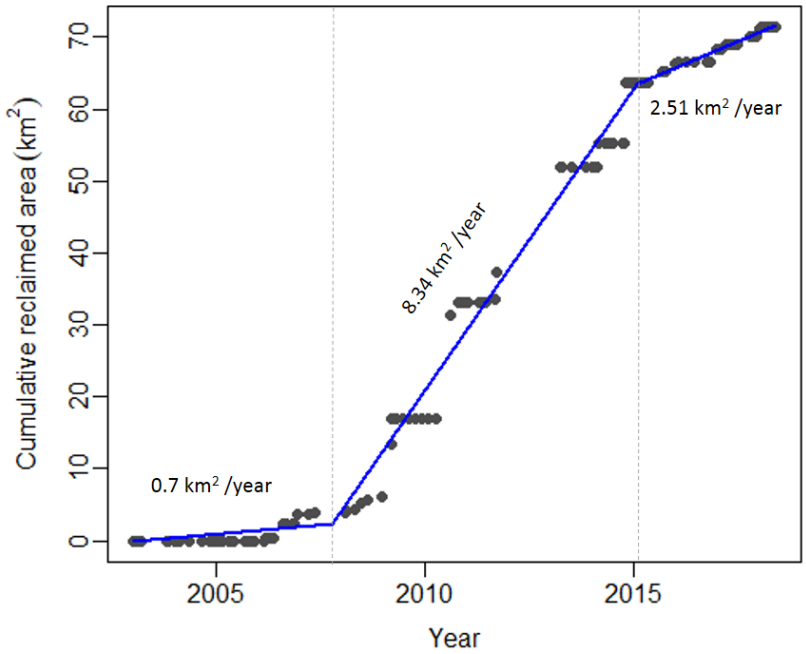

Fig. A2. The trend of reclamation of intertidal flats at Lianyungang coast in 2003-2018. Reclamation rates are calculated in three periods, separated on 18 Oct 2007 and 10 Feb 2015.