Waterbird habitat loss fringing the Yellow and Bohai seas along the East Asian–Australasian migratory flyway

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Abstract:

Natural wetland along the coasts of Yellow and Bohai seas provided key stopover sites for migratory waterbirds. However, these wetlands are facing land loss. Understanding how natural wetlands loss influence habitat is an important step for habitat management. Using species distribution model to report changes in area of suitable habitat, and the effects of natural wetland loss on habitat for 80 waterbird species attributed to four functional categories (shorebird, duck, heron, gull), between 2000 and 2015 in the Yellow and Bohai seas. Of 1794.8 km^2 of coastal wetland lost to development between 2000 and 2015, most represented tidal flats converted into aquaculture and salt pan habitat, or for construction. Consequently, habitat for 73 of these 80 species has decreased in area over this time period. Generally, the proportional decline in habitat suitable for species of duck was less than it was shorebirds, herons and gulls. The proportional loss of tidal flat habitat that formerly represented suitable habitat for shorebirds, herons and gulls was also significantly higher than it was for ducks. Because more species of duck exploit aquaculture and salt pan habitat converted from tidal flats than do shorebird, heron and gull species, such conversion of tidal flats pose a greater threat to shorebirds, herons and gulls than they do to ducks. Preventing further reclamation of tidal flats and managing artificial wetlands are priorities for waterbirds conservation, especially for the species ducks.

Keywords: land reclamation; artificial wetlands; waterbirds; suitable habitat; conservation

1. Introduction

Coastal wetlands in China provide key stopover sites for waterbird species along the East Asian–Australasian Flyway (EAAF)—a region supporting more than 50 million waterbirds from more than 250 populations during their breeding, wintering and stopover periods (Barter, 2002; Bai et al., 2015; Xia et al., 2016). These species are sensitive to environmental change, with suitable habitat and migration routes potentially affected by both climate change (Hu et al., 2020; Steen et al., 2018) and human activities (Xu et al., 2019; Yang et al., 2011). A decrease in habitat quantity and quality at stopover sites poses a serious threat to waterbird populations (Studds et al., 2017).

Depending on waterbird species' habits and their habitat preferences, changes in coastal wetland habitat might affect different species in different ways (Duan et al., 2020a; Wang et al, 2013). For example, species that prefer foraging in artificial wetlands will be less affected by coastal wetland loss than those that forage in natural coastal wetland habitat (Jackson et al., 2020). Changes in suitable bird habitat have attracted considerable international attention (Názaro et al., 2020; Kalle et al., 2018; Howes et al., 2019).

Defining suitable habitat is a key step in the assessment of change. Waterbird distribution ranges and identification of suitable habitats are usually determined by experts (Zheng, 2005; MacKinnon, 2000). For example, the worldwide distribution ranges of waterbird species are delineated by BirdLife International (BLI; BirdLife International and NatureServe, 2016), and these BLI data only report the distributions of species at a relatively coarse level, potentially overestimating habitat boundaries and underestimating actual threats (Ramesh et al., 2017; Marsh et al., 2019).

Citizen science data are routinely collected over large spatial and temporal scales. Such data can include the likes of, but not be limited to species records (names), location data (longitude, latitude, place name), and survey dates (Duan et al., 2019; Ma et al., 2012). Species distribution models (SDMs) can identify relationships between distribution records of species and corresponding environmental variables, enabling information on the potential habitat of species to be generated (Andrew and Fox, 2020; Austin et al., 2017). Combining SDMs and citizen science data can contribute towards accurate prediction of species habitat ranges (Tanner et al., 2019; Panda et al., 2018; Hu et al., 2020).

Change in suitable habitat for waterbird species in China is reported to 2007 (Li et al., 2013). However, the number of birdwatchers and bird reports has grown rapidly since this time (Ma et al., 2012; Dai et al., 2019), enabling us to provide an update on changes in waterbird habitat, which we herein do to 2015. In addition, the extent to which natural wetland change is reducing waterbird habitat throughout coastal mainland China, and its difference for different waterbird categories, has not been quantified. We collate 4000+ occurrence records of 80 waterbird species primarily sourced from freely accessible websites, and using SDMs, combine these citizen science data from Yellow and Bohai seas, China, to 1) identify changes in suitable habitat for waterbirds between 2000 and 2015; 2) identify how changes in coastal wetland use have affected the habitat available to waterbirds; and 3) determine how this might have affected different categories of waterbird.

2. Materials and methods

2.1. Study area

Off mainland China, the Yellow and Bohai seas are spread over the provinces, autonomous regions and municipalities of Liaoning, Hebei, Tianjin, Shandong, and Jiangsu. Coastal wetland within this range mainly comprises natural wetland tidal flat, estuarine delta, and estuarine waters. Inland artificial wetlands include salt pan, aquaculture pond, and paddy field habitats (Duan et al., 2020b). Both natural coastal and artificial inland wetland types provide important foraging and resting sites for waterbirds (Fig.1; Xia et al., 2016). Coastal wetland in this region has been lost or degraded between 2000 and 2015 (Duan et al., 2019), contributing to a rapid decline in waterbird populations.

2.2. Change in coastal wetlands

Land use raster data for the Yellow and Bohai seas in the years 2000 and 2015(with a spatial resolution 100m) were acquired from the Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences (Li et al., 2019). Land types were divided into 15 categories of paddy, dryland, forest, grassland, construction land, canal, lake, reservoir, bottomland, coastal wetlands (tidal flat, estuarine water, estuarine delta), salt pan, aquaculture, and unused.

We used ArcGIS 10.5 to examine change in coastal wetlands from 2000 to 2015, and calculated the area of tidal flat, estuarine water, and estuarine delta wetland habitat that has been lost over this 15 year period. Typical regions with notable coastal wetland loss and typical wetland categories were chosen to present coastal wetland conversion.

2.3. Waterbird survey data

Waterbird occurrence records were collected from multiple sources, including citizen science data from the publicly accessible eBird website (https://ebird.org/home), Global Biodiversity Information Facility (GBIF; http://www.gbifchina.org/), the BirdReport website (http://www.birdreport.cn/), the China Coastal Waterbird Census Group (CCWC), a regional waterbird monitoring program established in 2005 and mostly carried out by trained volunteers (Bai et al., 2015), and Status of Waterbirds in Asia 1987–2007. Each record included the species name, place name, longitude, latitude, survey date, and data source. The occurrence of species might fluctuate between years due to weather conditions or spontaneous disturbance. Perhaps, we divided these records into the two time periods of 2000–2005 and 2010–2015 to give a better picture of the 'real' distribution of a species in 2000 and 2015 respectively (Liu et al., 2017).

Citizen science data can contain sampling biases (Robinson et al., 2017) and inconsistencies in site names and boundaries. For this reason, coordinates that deviated significantly from a place name were verified manually using Google Maps 6.5 (https://www.google.com/maps) (Hu et al., 2017), with the central point of a named area taken to represent its geographical coordinates. To estimate the likelihood of errors, collection data for 30% of sites reporting latitude and longitude were randomly selected and input into Google Earth 6.0; site accuracy exceeded 90%.

For each species, duplicate records from sites with the same longitude and latitude were removed. Our model of species distribution, MaXent, also required us to exclude any species with fewer than 5 occurrence records (Hu et al., 2017). These procedures reduced our data set from 128 to 80 species, comprising 44 shorebirds, 17 ducks, 9 herons, and 10 gulls. Of these species, 1is Critically Endangered (CR), 4 are Endangered (EN), 4 are Vulnerable (VU), 10 are Near Threatened (NT) and 61 are of Least Concern (LC) (IUCN, 2019) (Table A1).

2.4. Environmental variables

Our environmental variables included land use, bioclimate (precipitation and temperature), and topography (DEM (digital elevation model), slope and aspect). Land use data for the years 2000 and 2015 were acquired from the Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences (Li et al., 2019) to match the two time ranges (2000–2005 (2000) and 2010–2015 (2015)) of waterbird occurrence records (Duan et al., 2019). We downloaded 19 average bioclimatic variables from WorldClim2.0 (http://worldclim.org/version2) for the years 1970–2000 (ESRI grids, bio 10 m) (see Appendix Table A2). DEM was acquired from the Data Center for Resources and Environmental Sciences at the Chinese Academy of Sciences (RESDC) (http://www.resdc.cn).

All environmental variables were resampled to 100 m resolution and transformed to ASCII format, then masked by the study area scale.

2.5. Identification of suitable habitat

We combine environmental variables and occurrence records using MaXent 3.1 (http://www.cs.princeton.edu/*schapire/maxent/) to simulate the distribution range of the 80 species for the years 2000 and 2015. This procedure calculated the constraints of a target species' distribution from the environmental characteristics of species occurrence sites, and explored the possible distribution of maximum entropy under these constraints (Harte and Newman, 2014). One advantage of MaxEnt is that it can define species distributions from few occurrence records (Hu et al., 2017).

For all SDMs, we randomly selected 75% of presence data for model training purposes, and used 25% as test data. Average outputs of five bootstrap replicates were used in analysis. The Area Under the Curve (AUC) was used to assess model effect, with a value of 0.7 considered acceptable (Li et al., 2017). We used average predicted probability as a threshold to transform the model result of probability distribution to presences/absences; the areas of probability distribution above the threshold are defined as the suitable habitat of each species (Zeng et al., 2015).

2.6. Impact of coastal wetland change on suitable habitat for waterbirds

We used ArcGIS 10.5 to calculate the change ratio of areas of habitat suitable for waterbirds in 2000 and 2015. We used ArcGIS 10.5 to calculate the area of coastal wetland that was lost between 2000 and 2015 as a proportion of the total area of suitable habitat lost in this same time period to quantify the impact of coastal wetland change on suitable habitat. SPSS 22.0 was used to examine for differences in this proportion between the four bird categories (shorebirds, ducks, herons, gulls).

To explain the difference of impact of coastal wetland change on suitable habitat between different functional categories. We calculated the land area converted from natural coastal wetland to aquaculture and salt pan habitat between 2000 and 2015 among the suitable habitats for waterbirds in 2015 for different categories of shorebirds, herons, gulls and ducks. We did so because (1) between 2000 and 2015, in this region, natural coastal wetland habitat was converted mainly into aquaculture and salt pan habitat (Duan et al., 2019); (2) aquaculture and salt pan habitat is frequently used by waterbirds (Lei et al., 2018, Duan et al., 2019); and (3) the four bird categories (shorebirds, herons, gulls, ducks) have different preferences for aquaculture and salt pan habitat (Ma et al., 2019).

3. Results

3.1. Loss of coastal wetlands

Changes in coastal wetland habitat between 2000 and 2015 are illustrated in

Figure 2. Bohai Bay, Laizhou Bay, Yancheng National Nature Reserve (Yancheng NNR), and the coasts of Rudong and Dongtai were the main areas with coastal wetlands, and all experienced serious natural wetland loss. The total coastal wetland area in 2000, 6123.0 km^2, was reduced to 4331.04 km^2 in 2015. Of this, tidal flat habitat in 2000 (4262.3 km^2) was reduced to 3125.5 km^2 in 2015, representing the largest loss of all coastal wetland types. Estuarine delta habitat reduced from 1838.0 km^2 in 2000 to 1183.8 km^2 in 2015. Estuarine water reduced from 22.7 km^2 in 2000 to 21.74 km^2 in 2015 (Table 1).

Three types of artificial wetland—that land used for aquaculture, salt pan and construction—accounted for the highest area of converted coastal wetlands. Of the 1136.8 km^2 of tidal flat habitat lost between 2000 and 2015, 430.47 km^2 of this was converted for aquaculture use, 242.52 km^2 into salt pans, and 240.61 km^2 into construction land. Of the 654.2 km^2 of estuarine delta habitat lost between 2000 and 2015, 211.08 km^2 of this was converted for aquaculture use, 157.16 km^2 into salt pans, and 94.45 km^2 into construction land. A relatively minor 0.96 km^2 of estuarine water was converted into grassland and canals (Figure 3).

3.2. Model results

The AUCs of model results for the same 80 species in the years 2000 and 2015 exceeded 0.9, which indicates that the 'Maxent' model was highly accurate in modeling species distributions.

For each species, the contribution of the three top environmental factors most affecting the Maxent model for the years 2000 and 2015 are presented in Table A3. Land use generally contributed most to model results, as did the first three habitat types (Table A4). Waterbird species preferred natural tidal flat and estuarine delta habitat, followed by artificial salt pan and aquaculture habitats.

3.3. Change in suitable habitat between 2000 and 2015

Based on modeled species distributions, suitable habitat was identified for all 80 species in 2000 and 2015 (Fig. A.1). Most suitable habitat occurred close to the coast, particularly in Yalujiang Estuary, Liaohe Estuary, and Yellow River Delta and Jiang su

Yancheng National Nature Reserves. Bohai and Laizhou bays, the coast of Lianyungang in Jiangsu province, and Dongtai Jianggang (Tiaozini) and Rudong coasts were also important areas of suitable habitat.

Areas of suitable habitat declined for 73 of 80 species between 2000 and 2015. Areas that changed were highly consistent with areas of intense coastal wetland development (Fig. A.1). Areas of suitable habitat for 41 of 44 shorebird species, 16 of 17 ducks, 8 of 9 herons, and 8 of 10 gulls all declined (Fig.4). Suitable habitat decreased by between 3.20% and 58.16% for shorebirds, 0.91% and 56.91% for ducks, 4.23% and 54.41% for herons, and 6.26% and 71.74% for gulls. Generally, the proportional decline in suitable habitat for ducks was less than it was for the other three categories (χ^2=2.34, df=3, p=0.51) (Fig.5).

3.4. The effect of coastal wetland change on suitable habitat for waterbird species

Coastal wetland tidal flats were both the most suitable habitat type for waterbirds, and the habitat category most susceptible to wetland loss. For each of 73 waterbird species, the proportion of tidal flat area that represented suitable waterbird habitat in 2000 that was lost by 2015 ranged 12.48% to 95.75%. The proportional loss of tidal flat habitat suitable for shorebirds, herons and gulls was also significantly higher than it was for ducks (χ^2=35.43, df=3, p=0.000) (Fig. 6).

The area of new artificial wetland in 2015 (formerly tidal flats in 2000) that also represents suitable habitat for ducks was significantly higher than it was for shorebirds, herons and gulls (χ2=34.55, df=3, p=0.000) (Fig. 7). This suggests that species of duck can exploit more artificial wetlands than other categories of waterbird.

4. Discussion

4.1. Change in coastal wetlands

Tidal flat and estuarine delta coastal wetlands have reduced in area considerably from 2000 (Chen et al., 2019). These habitats have been converted mainly into artificial wetlands (aquaculture and salt pan), and land for construction (Ma et al., 2014; Murray et al., 2014). Wetlands in China have decreased markedly in area between 1990 and 2010 because of urban development (Mao et al., 2018). We report considerable land degradation in the Beijing–Tianjin Metropolitan Region and the Yangtze River Delta covering the Bohai Bay and the coasts of Yancheng NNR and Rudong–Dongtai. In these areas significant conflict exists between the interests of developers and conservation (Paulson Institute, 2016).

Natural wetland tidal flats and the estuarine delta have experienced the greatest losses in area along the coasts of Bohai Bay, Laizhou Bay, Yancheng NNR and Rudong–Dongtai, where important stopover sites for migratory waterbirds along the EAAF exist (Duan et al., 2020). Land reclamation and economic development had converted coastal wetlands into different artificial categories (Ma et al., 2014). Our results also reveal that tidal flat and estuarine delta habitat has been transformed primarily into lands for aquaculture and salt pans, and construction.

4.2. Loss of suitable waterbird habitat because of coastal wetland change

According to our model, tidal flat habitat is the most important habitat for most waterbird species, and that this habitat has decreased in area from 2000 to 2015 for more than 90% (73) of our 80 shorebird, duck, heron and gull species. These results are consistent with those of Ma et al. (2019), Duan et al. (2020) and Jackson et al. (in press). The loss of tidal flat habitat has affected species in different ways. The proportions of tidal flat area lost between 2000 and 2015 that represented suitable habitats for shorebirds, herons and gulls was significantly higher than it was for ducks. More artificial wetland habitat in 2015 (tidal flat habitat in 2000) now represents suitable habitat for ducks than it does for shorebirds, herons and gulls (Fig.6). This indicates that tidal flat habitat loss poses a greater threat to shorebirds, herons and gulls than it does to species of duck. Most shorebird populations along the EAAF prefer to forage in natural tidal flat with rich invertebrate communities (Jackson, 2020). Conversely, most ducks are generalists and occur inland, with their wider ecological niche enabling them to exploit more diverse habitats (Ma et al., 2010).

4.3. Habitat management and conservation

Many natural wetlands along China's coast have been lost or have degraded since the 1960s, with waterbird (especially shorebird) populations and their habitats markedly declining in number and area (Wu et al., 2020; Melville et al., 2016). For example, populations of the Red Knot, a species that prefers intertidal habitat in Tianjin and Tangshan along western and northern Bohai Bay, have become increasingly concentrated along the coast of Tangshan (Beipu, Nanpu and Zuidong) during their northward migration from 2000–2010. This has been attributed to persistent loss of tidal flat habitat in Bohai Bay (Yang et al., 2011). Although natural reserves along China's coasts have been created to both manage and protect habitat, large conservation gaps exist because some important artificial wetlands are afforded no protection (Choi et al., 2019; Li et al., 2020).

Different waterbird species have various habitat requirements, the same management measures might affect different groups in different ways (Craig and Beal 1992; Mitchell et al. 2006). This suggests that appropriate management needs to target specific groups (Stralberg et al. 2009). We report new aquaculture and salt pan habitat (converted from natural wetlands) as providing important waterbird habitat, especially for species of duck. While management and protection of artificial wetlands must be balanced with that of production (Ma et al., 2010), this may be challenging because many artificial wetlands are working sites not specifically managed for waterbirds, and they could be highly susceptible to land use changes that cause habitat loss or degradation. Producers must be compensated, because conservation of waterbirds reduces the economic benefit of artificial wetlands (Jensen et al. 2008).

4.4. Data limitation

All models contain uncertainty. While our model does not predict all suitable habitats for each species, we endeavored to exclude large areas of unsuitable habitat. We also tried to resolve sampling bias inconsistencies in site names and boundaries, and used 5 year blocks of occurrence data to relieve the temporal bias. Further data limitations warrant consideration. For example, typically, the sampling of background observations needs to be proportional to the sampling effort in space (i.e. more background observations from areas where lots of sampling took place, and less from where little sampling took place) (Hu et al., 2017); this was caused mainly by uneven distribution of birdwatchers throughout the survey region (Ma et al., 2013; Li et al., 2013). This suggests that more targeted modeling methods should be applied to deal with species with such distribution patterns. We believe that comprehensive various correction methods can maximize the use of citizen science data for identification of species habitats in the future.

5. Conclusions

The loss of coastal wetlands has resulted in a decrease in suitable habitat for 73 of 80 waterbird species between 2000 and 2015. Tidal flat habitat loss poses a greater threat to shorebirds, herons and gulls than it does to species of duck. This is because wetlands now used for aquaculture or salt extraction (converted from tidal flats sometime between 2000 and 2015) are more frequently used by species of duck than they are by shorebirds, herons and gulls. Our results suggest that conservation should focus on management of habitat according to the different requirements of various categories of species. For shorebirds, herons and gulls, it is essential to prevent further tidal flat reclamation. However, for species of ducks, conservation of artificial wetlands (converted from coastal wetlands) should occur concurrently with conservation of natural wetland habitat.

Data accessibility statement

Records of species supporting this study can be acquired from the USA eBird (https://ebird.org/home), Global Biodiversity Information Network (GBIF) (http://www.gbifchina.org/) and BirdReport in China (http://www.birdreport.cn/) websites.

Conflicts of interest

None declared

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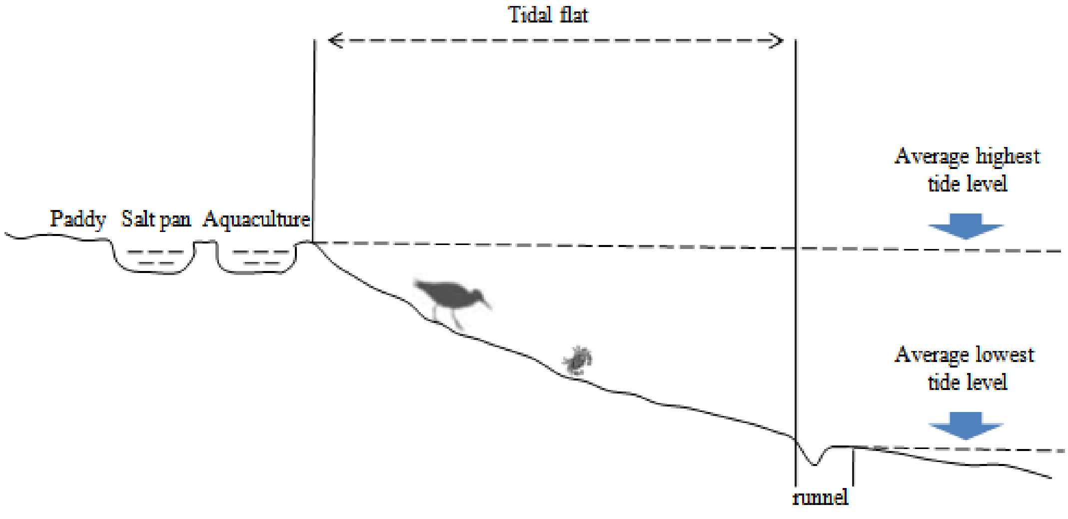
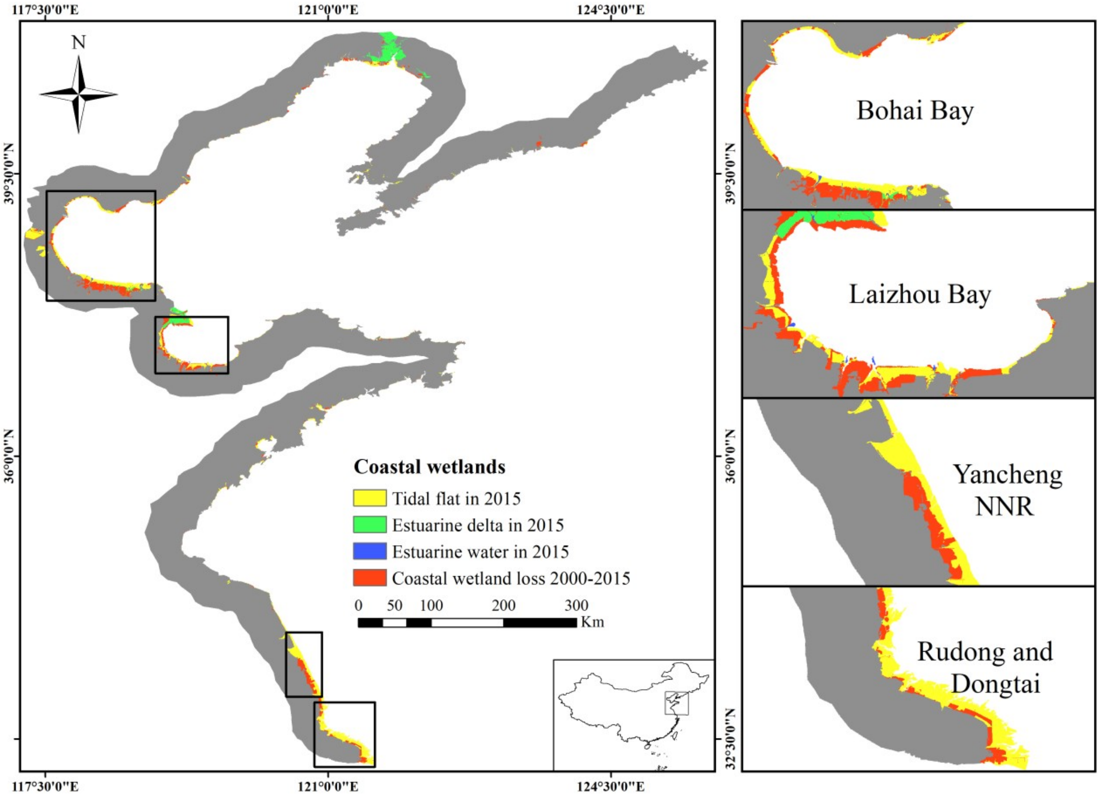
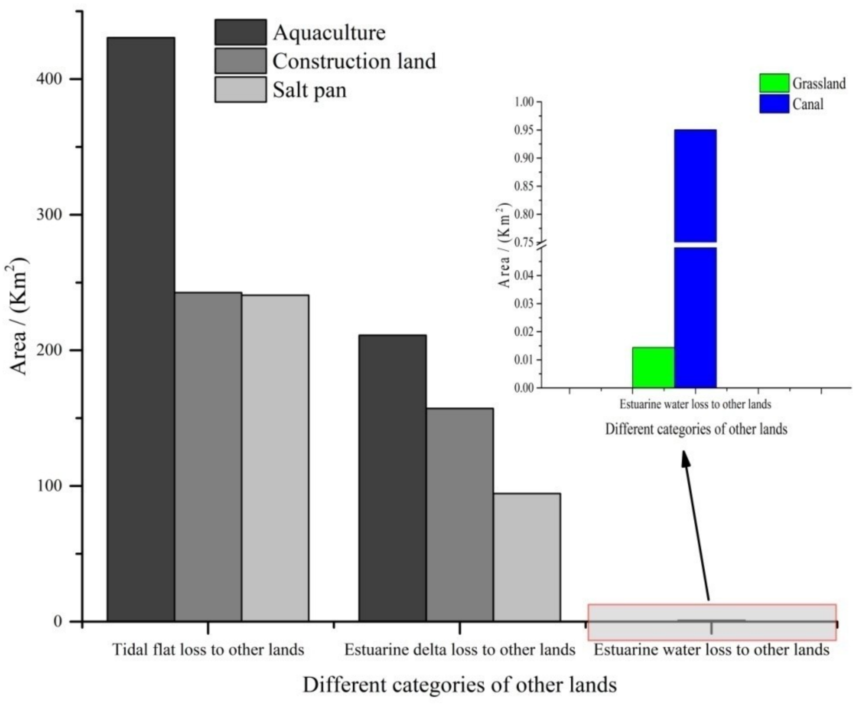
Table 1 Change in coastal wetland area between the years 2000 and 2015.

Coastal wetland categories	2000 (km^2)	2015 (km^2)	Change (km^2)
Tidal flat	4262.3	3125.5	-1136.8
Estuarine delta	1838.0	1183.8	-654.2
Estuarine water	22.7	21.74	-0.96
Total	6123.0	4331.04	-1791.96

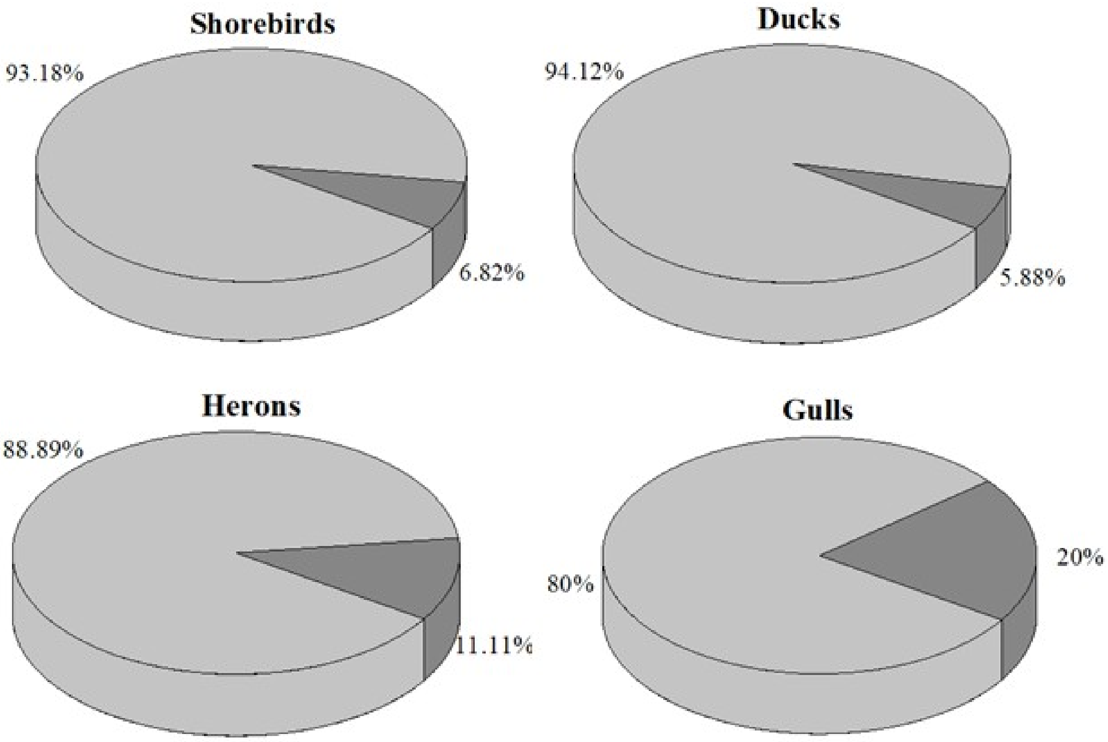

Tidal flat
Average highest
tide level
Paddy
Salt pan
Aquaculture
Average lowest
tide level
runnel

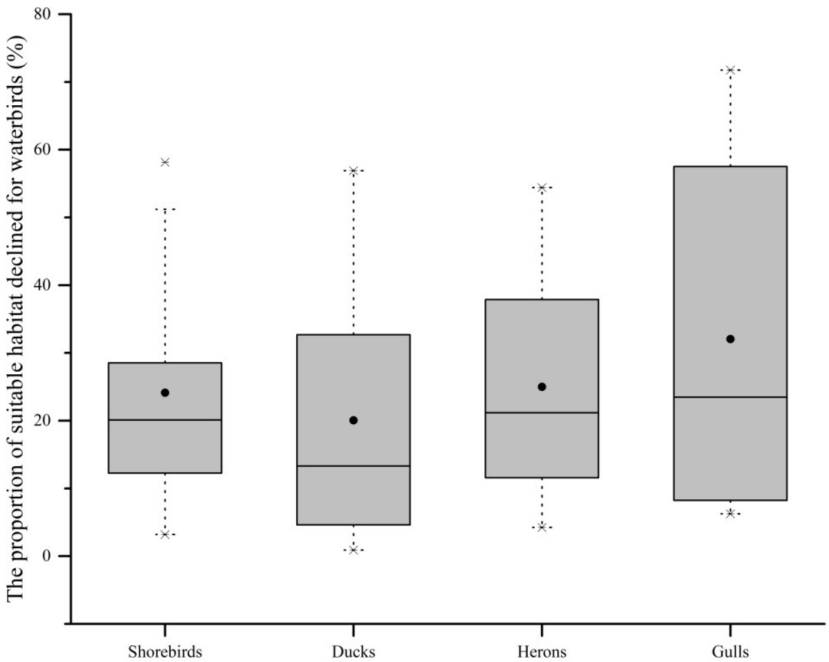


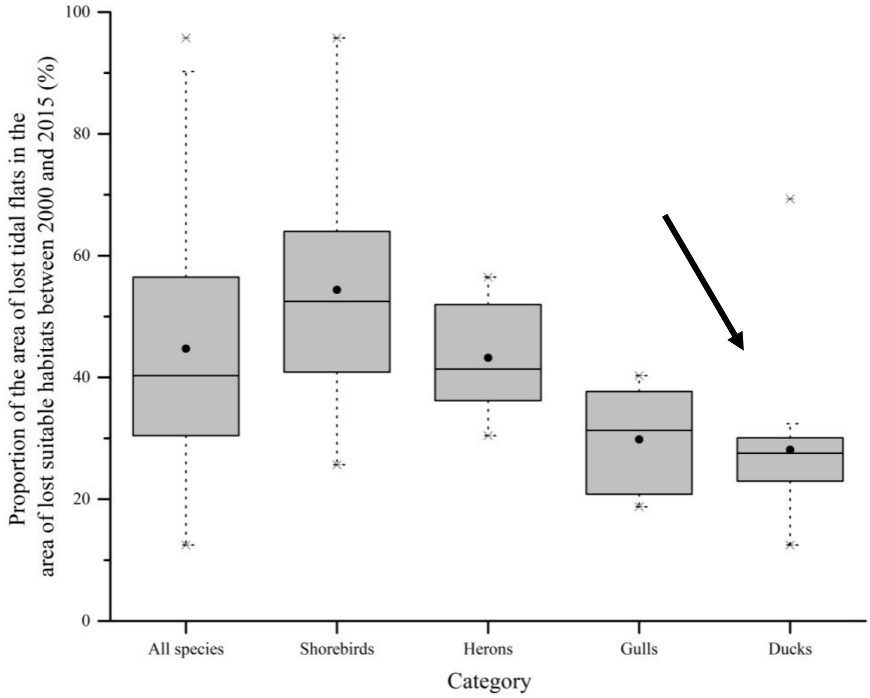
117°30'0"E
121°0'0"E
124°30'0"E
39°30'0"N
36°0'0"N
32°30'0"N
N
Coastal wetlands
Tidal flat in 2015
Estuarine delta in 2015
Estuarine water in 2015
Coastal wetland loss 2000-2015
0 50 100 200 300
Km
Bohai Bay
Laizhou Bay
Yancheng NNR
Rudong and Dongtai

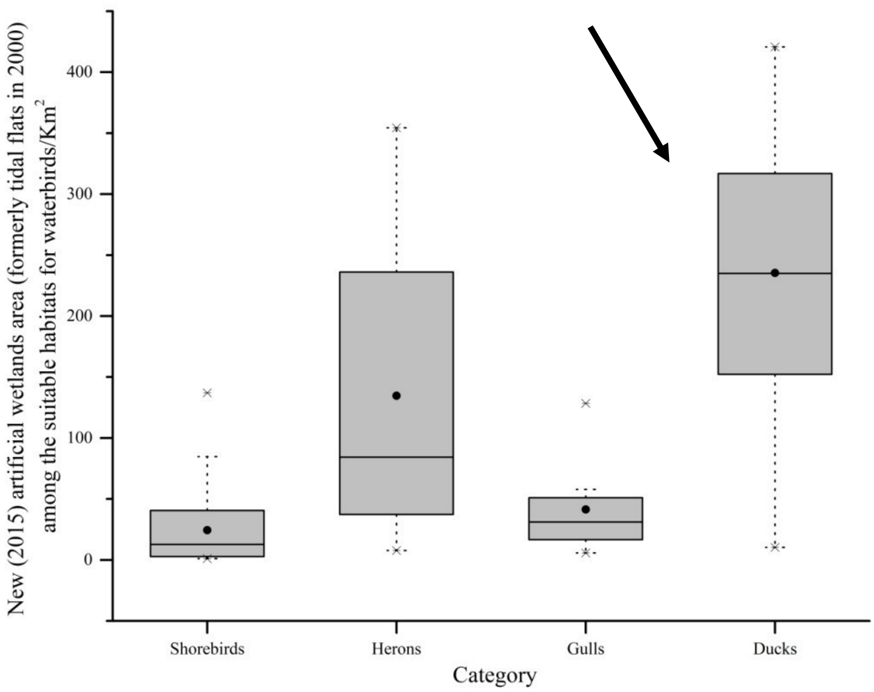


Aquaculture
Construction land
Salt pan
Area / (Km^2)
400
300
200
100
0
Tidal flat loss to other lands
Estuarine delta loss to other lands
Estuarine water loss to other lands
Different categories of other lands
Grassland
Canal
1.00
0.95
0.90
0.85
0.80
0.75
0.04
0.03
0.02
0.01
0.00
Estuarine water loss to other lands
Different categories of other lands


Shorebirds
93.18%
6.82%
Ducks
94.12%
5.88%
Herons
88.89%
11.11%
Gulls
80%
20%


80
60
40
20
0
The proportion of suitable habitat declined for waterbirds (%)
Shorebirds
Ducks
Herons
Gulls


100
80
60
40
20
0
Proportion of the area of lost tidal flats in the area of lost suitable habitats between 2000 and 2015 (%)
All species
Shorebirds
Herons
Gulls
Ducks
Category


400
300
200
100
0
New (2015) artificial wetlands area (formerly tidal flats in 2000) among the suitable habitats for waterbirds/Km^2
Shorebirds
Herons
Gulls
Ducks
Category

Figures

Figure 1. Schematic diagram of natural habitats and artificial habitats on coastal wetland in the Yellow and Bohai seas, China. Shorebirds forage on the tidal flat of the natural habitats and stopover in paddy, salt pan and aquaculture components of the artificial habitats.

Figure 2. Change in coastal wetland use between 2000 and 2015, Yellow and Bohai seas, China.

Figure 3. Coastal wetland conversion categories.

Figure 4. Proportions of species in each waterbird category for which the area of suitable habitat changed between 2000 and 2015 (light gray, habitat decrease; dark gray, habitat increase).

Figure 5. Proportional decrease suitable habitat area for each bird category between 2000 and 2015. Black circles represent mean values, horizontal bars within boxes represent median values; upper and lower limits of boxes represent maxima and minima, and whiskers represent 1% and 99%.

Figure 6. Proportional loss in area of suitable waterbird habitat between 2000 and 2015 as a percentage of lost tidal flat area. Black circles represent mean values, horizontal bars within boxes represent median values; upper and lower limits of boxes represent maxima and minima, and whiskers represent 1% and 99%.

Figure 7. Box plots of tidal flat habitat in 2000 converted to artificial wetlands by 2015 (km^2) that represent ‘suitable habitat’ for waterbird species. Black circles represent mean values, horizontal bars within boxes represent median values; upper and lower limits of boxes represent maxima and minima, and whiskers represent 1% and 99%.