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RESEARCH ARTICLE

Population Changes of Migratory Shorebirds at Yalu Jiang Estuary Wetland, a Critical Refuelling Sites along the East Asian-Australasian Flyway

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Abstract

Migratory birds require one or more stopover sites to refuel during their migration journeys between breeding and wintering sites. Many migratory birds have suffered population decline due to habitat loss and degradation at key stopover sites. This issue is particularly pronounced for migratory shorebirds in the East Asian-Australasian Flyway (EAAF). Loss of intertidal wetlands, the critical foraging habitats for shorebirds, in the Yellow Sea region has threatened population maintenance of many species along the EAAF. Detecting population dynamics at key stopover sites is the basis for making conservation and management actions. In this study, we conducted shorebird surveys and compared population changes over the past 20 years at Yalu Jiang estuarine wetland, a critical refueling sites in the Yellow Sea. While the number of species remained relatively constant throughout the years, peak count of shorebirds in late April declined by about 30-50%. Bar-tailed Godwits (*Limosa lapponica*), Great Knots (*Calidris tenuirostris*) and Dunlins (*Calidris alpina*) were the three most abundant species in the survey, comprising 88-95% of total birds recorded. The peak count of Bar-tailed Godwits declined by 44% since 2010, whereas Great Knots declined by 17%. Seven shorebird species attained 1% Ramsar criterion for wetlands of international importance in all the three years from 2022 to 2024, among which three were listed as threatened species in the IUCN Red List. This study confirmed that Yalu Jiang estuarine wetland is a critical staging site for migratory shorebirds. It is urgent to protect the coastal and estuarine wetlands of the Yellow Sea from further land reclamation and maintain a healthy habitat to stop or slow down the decline of shorebird populations.

Introduction

More than one fifth of bird species in the world are migratory birds [1]. Some species can fly over ten thousand kilometers for one-way flight between breeding and wintering sites. During their long-distance migratory journeys, birds generally make one or several stopovers along the flyway to refuel [2,3]. At refuelling sites, birds consume a large amount of food and deposit a lot of energy for the next leg of migratory flight. These refuelling sites are important for maintaining the migration connection of the flyway [3,4]. Detecting population changes of migratory birds at

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refuelling sites is critical for making conservation measures.

Spanning more than 20 countries, the East Asian-Australasian Flyway (EAAF) is one of the world's largest and most important flyways. At least 54 migratory shorebird species have been identified in the EAAF, including 15 species are restricted to the EAAF [5,6], with an estimate of over five million shorebird individuals total [7]. Many shorebirds are tideland specialists, they highly depend on tideland habitat during migration stopover and wintering periods.

At midpoint along the EAAF, the coastal and estuarine wetlands of the Yellow Sea are the most critical stopping areas for migratory shorebirds, supporting approximately three million shorebirds annually during northward and southward migration [8,9]. Coastal area of Yellow Sea is also one of the most populated areas along the flyway, where intertidal habitats are frequently reclaimed for human development [10-12]. The loss of habitats suitable for migratory shorebirds has caused a rapid decline in shorebird populations that rely on Yellow Sea tidal mudflats as refuelling sites [13-15]. The shortage of optimal food resources is another challenge for some migratory shorebirds [16,17].

The Yalu Jiang Estuarine Wetland National Nature Reserve (hereafter the "reserve") is located in the northern Yellow Sea (Figure 1). Though it has many anthropogenic activities common to other coastal areas of the Yellow Sea, the area has relatively less development pressure and undergoes very little loss of intertidal habitats [18]. The reserve supports more than 250,000 shorebirds, including 100,000 Bar-tailed Godwits (*Limosa lapponica*) and 55,000 Great Knots (*Calidris tenuirostris*) during northward migration [8]. It is a critical staging site for many shorebird species to replenish fuel before their destination at breeding grounds [3,16,19,20]. It is estimated that Yalu Jiang estuarine wetland supports on average at least 42% of the flyway's northward-migrating *baueri* subspecies of Bar-tailed Godwits [21,22], 19% of *L. l. menzbieri* godwits [22], and 22% of the Great Knots [22]. A total of 17 shorebird species has met the 1% Ramsar criterion for wetlands of international importance at least once at Yalu Jiang estuarine wetland [23], with 8 species regularly meeting the criterion [19].

Though the reserve was established in 1987 and was designated as a national nature reserve in 1997 to protect shorebirds and their important habitats, it was not until May 1999 when the first shorebird survey was conducted in the area and a total of 152,000 birds were recorded [24]. Since then, shorebird surveys were carried out in several years between April and May [19]. Compared with historical peak counts during northward migration, the study in Yalu Jiang estuarine wetland from 2010 to 2012 indicates a 13% decline in Bar-tailed Godwits since 2004 and an 18% decline in Great Knots since 1999 [22]. Number of Bar-tailed Godwits further declined in the following years, with peak numbers declined from more than 60,000 individuals in 2011–2013 to fewer than 30,000 in 2016 [16], probably caused by habitat loss and degradation due to land reclamation, as well as shortage of food resources.

In 2024, the Yalu Jiang estuarine wetland was inscribed as a component of world heritage site, the "Migratory Bird Sanctuaries along the Coast of the Yellow Sea-Bohai Gulf of China" [25]. However, the population dynamics of shorebirds in the Yalu Jiang estuarine wetland is still unknown. This makes a knowledge gap for shorebird conservation and habitat management. Here we conducted shorebird surveys during northward migration in 2022-2024 and compare the results with bird surveys in 1999 and 2010. We focused on the population changes of total number of shorebirds, dominant species, threatened species, and the species that attained the 1% Ramsar criterion for wetlands of international importance.

Methods

Study area

The study was carried out in the Dandong Yalu Jiang estuarine wetland National Nature Reserve (39°40′04″-39°57′58″N, 123°33′38″-124°07′23″E) and its surrounding area, located in Northeast part of China (Figure 1). The reserve covers a total area of 101,000 hectares of intertidal mudflats, aquaculture ponds, reedbeds and rice paddies, extending for about 60km along the coast westwards from the Yalu River [19]. Rice paddies extend from the northern boundary of the reserve southward to within 1-3km of the coast. The next 1-3km is mainly consists of aquaculture ponds, covering a total area of approximately 9,000 hectares. Apart from the naturally rocky coast at the western end of the reserve, the entire length of the reserve has an artificial seawall, and several kilometers of mudflats stretching southward from the seawalls.

The intertidal area is characterized by semi-diurnal tides. At most sites the tide reaches the seawall

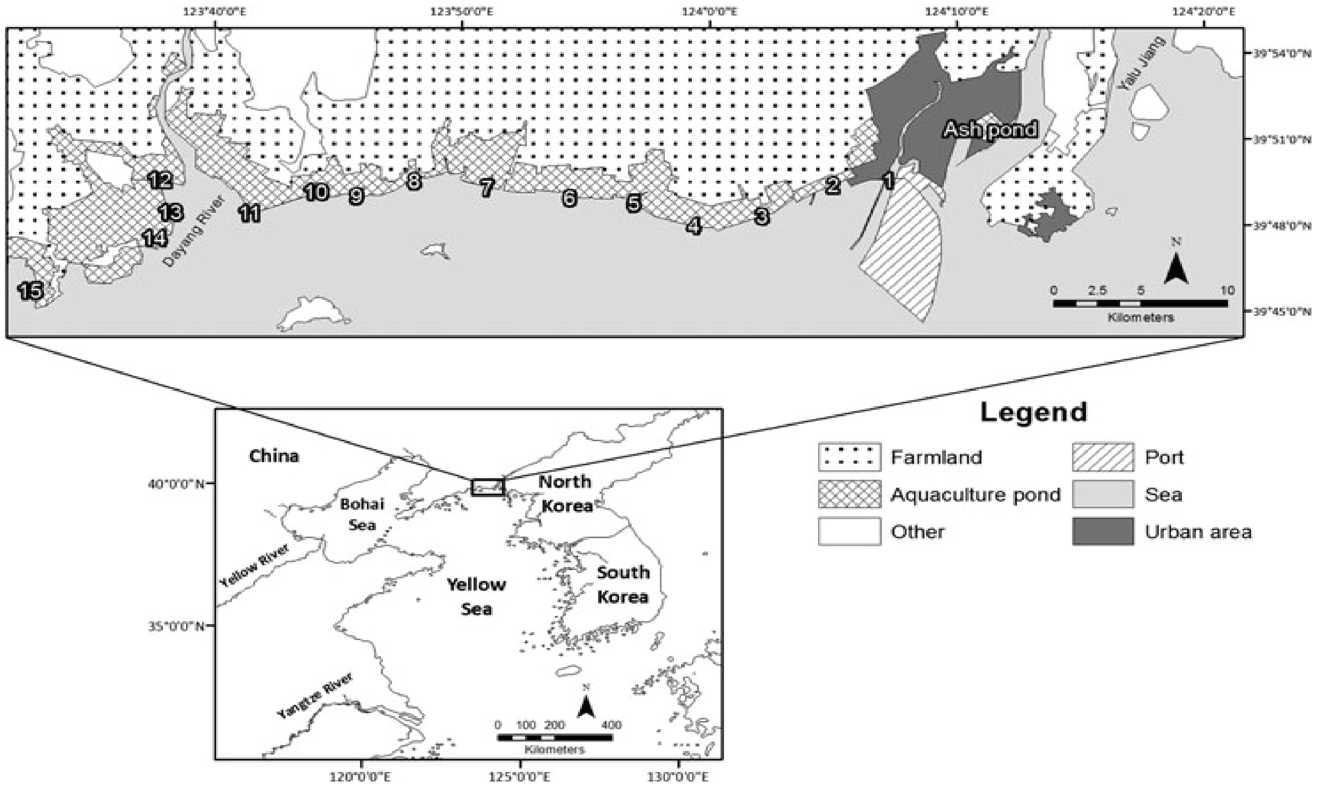

Figure 1 Map of the survey area at Yalu Jiang estuarine wetland, showing the 16 pre-roosts counted during the surveys. The inset shows the location of Yalu Jiang estuarine wetland within the Yellow Sea region. The channel east of the Ashpond is the western branch of Yalu Jiang, which marks the boundary between China and North Korea. The map is adopted from Choi, et al. [22].

at about 6.0-6.3m. High tides over 6.0m inundate most mudflats, forcing shorebirds to roost inland, or move to areas where mudflat is still available up to tide of 6.8m. In the early 2000s, it is estimated that at least 200,000 shorebirds stayed in the reserve to refuel during the northward migration between March and May each year [24].

Bird surveys

The shorebird surveys were carried out during northward migration in three consecutive years from 2022 to 2024 (April 16-18 of 2022, April 23-25 of 2023, and April 24-28 of 2024). We chose to conduct surveys in late April because previous studies show that highest shorebird counts occur in late April [21], and most Bar-tailed Godwits and Great Knots, the dominant species, leave the area by mid-May [16].

We adopted Barter and Riegen's approach [21] and conducted bird counts among 15 identified fixed pre-roosts in the reserve and an additional roost (Ashpond) 7 km further east of the reserve's eastern boundary. The detailed description of the survey sites was described in Riegen, et al. [19]report. The surveys were conducted during high-tide period when the birds are forced to roost on intertidal flats near the seawall or the near-coastal ponds at each survey site. Survey teams of 2-3 person arrived at survey sites two hours before high tide, conducting bird counts from east to west along the seawall.

Data Analysis

The survey data in 2022-2024 were compared with the data collected in 1999 and 2010 shorebird survey in the reserve. The survey in 1999, carried out by Mark Barter and the reserve staff in early May, was the first full shorebird survey in the reserve [24]. Since then, several shorebird surveys were carried out between April and May. The 2010 survey was chosen as a comparison because it was at midpoint between the first survey in 1999 and our current surveys in 2022-2024, and it was also conducted in similar time frame (April 15-24) as our study.

Results

The number of shorebird species recorded in the recent surveys ranged from 19 species in 2023 to 24 species in 2024, with total counts ranging from

89,709 in 2022 to 112,687 in 2023 (Table 1). Bar-tailed Godwits, Great Knots and Dunlins (*Calidris alpina*) were the three most abundant species in the survey, comprising 88%-95% of total birds recorded. Other common species were Far Eastern Curlews (*Numenius madagascariensis*), Eurasian Curlews (*Numenius arquata*) and Grey Plovers (*Pluvialis squatarola*), all exceeding 1000 individuals every year, and Eurasian Oystercatchers (*Haematopus ostralegus*), ranging from 400 to 600 individuals (Table 1). These seven species attained the 1% Ramsar criterion for wetlands of international importance in all three years. The 1% of the flyway population mark has been used as it matches Criterion 6 of the Ramsar convention which states that "A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird". The number of species that reached 1% Ramsar criterion was slightly lower when compared to 8 species in 1999 and 9 species in 2010.

Table 1: Shorebird counts in the Dandong Yalu Jiang Estuarine Wetland National Nature Reserve during northward migration in late April of 2022 to 2024, compared with shorebird survey data from 1999 and 2010 [19]. The number marked with * indicates the count has attained the 1% population criteria which is used to designate "Wetlands of International Importance". The 1% criteria is based on the report published by Wetland International [38].

Species	IUCN Status	1999	2010	2022	2023	2024
Black-tailed Godwit *Limosa limosa*	NT		2		20	
Bar-tailed Godwit *Limosa lapponica*	NT	51918*	84680*	28246*	47000*	26662*
Little curlew *Numenius minutus*	LC					14
Whimbrel *Numenius phaeopus*	LC	286	135	87	174	502
Far Eastern Curlew *Numenius madagascariensis*	EN	3744*	3282*	1802*	1382*	1456*
Eurasian Curlew *Numenius arquata*	NT	234	3039*	3802*	1858*	1546*
Spotted Redshank *Tringa erythropus*	LC	162*	3	75		
Common Redshank *Tringa totanus*	LC	49	17	6	3	7
Marsh Sandpiper *Tringa stagnatilis*	LC			11		
Common Greenshank *Tringa nebularia*	LC	351	50	19	59	186
Spotted Greenshank *Tringa guttifer*	EN		15*	3		9
Green Sandpiper *Tringa ochropus*	LC				1	
Wood Sandpiper *Tringa glareola*	LC	490				
Grey-tailed Tattler *Tringa brevipes*	LC	6				
Terek Sandpiper *Xenus cinereus*	LC	153	18	32	34	72
Common Sandpiper *Actitis hypoleucos*	LC	5	3	2		
Ruddy Turnstone *Arenaria interpres*	NT	44	5	3	34	76
Great Knot *Calidris tenuirostris*	EN	54178*	53467*	31070*	30396*	44780*
Red Knot *Calidris canutus*	NT	1499*	5			250
Sanderling *Calidris alba*	LC		2	7	25	121
Red-necked Stint *Calidris ruficollis*	NT	299		5	57	247
Long-toed Stint *Calidris subminuta*	LC	24				
Sharp-tailed Sandpiper *Calidris acuminata*	VU	61				3
Dunlin *Calidris alpina*	NT	25181*	25301*	20300*	29351*	28100*
Broad-billed Sandpiper *Calidris falcinellus*	VU	729*				60
Eurasian Oystercatcher *Haematopus ostralegus*	NT	70	177*	394*	590*	481*
Black-winged Stilt *Himantopus himantopus*	LC	38	4	170		30
Pied Avocet *Recurvirostra avosetta*	LC			235		30
Pacific Golden Plover *Pluvialis fulva*	LC	147				
Grey Plover *Pluvialis squatarola*	VU	3995*	3001*	2760*	1051*	1940*
Little Ringed Plover *Charadrius dubius*	LC					1
Kentish Plover *Charadrius alexandrinus*	LC	12	1251*	680	649	116
Siberian Sandplover *Charadrius mongolus*	EN	306	1		2	86
Oriental Pratincole *Glareola maldivarum*	LC				1	
Snipe spp.		5				
Curlew spp.		20	1258			
Unidentified		7702	819			
Total number		151708	176535	89709	112687	106775
Total species		25	21	21	19	24
Number of species attained 1% threshold		8	9	7	7	7
Number of IUCN threatened species		6	5	4	4	7

During our study period from 2022 to 2024, the number of shorebird species and total counts remained stable (Table 1). In comparison with the survey results in 1999 and 2010, the number of shorebird species was similar, ranging from 19 to 24 species, compared to 25 species in 1999 and 21 species in 2010. However, the total individual counts declined by about 30-40% compared to the 1999 survey, and declined by about 40-50% compared to the 2010 survey.

The decline of shorebird populations can be shown from the decline of Bar-tailed Godwits and Great Knots (Figure 2), which were both dominant species. The number of Bar-tailed Godwits declined from 50,000-80,000 individuals in 1999 and 2010, to 26,000-47,000 individuals in 2022-2024. The number of Great Knots declined slightly from above 50,000 individuals to 30,000-45,000 individuals. The other dominant species, Dunlins, remained stable throughout the years, ranging from 20,000 to 30,000 individuals (Figure 2). Far Eastern Curlews also showed decline since 2010. The number declined

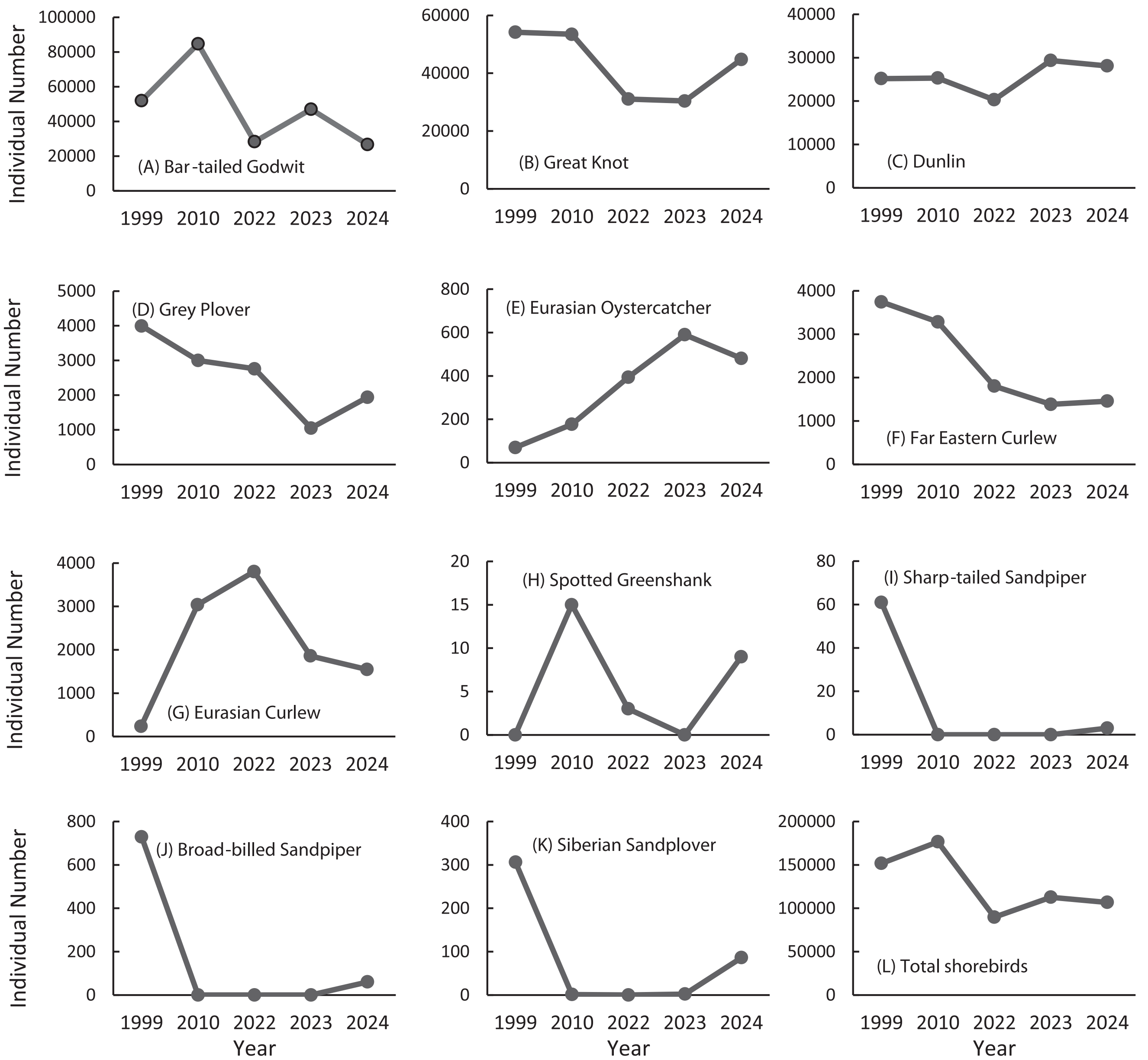

Figure 2 Population trend of selected shorebird species, (A) Bar-tailed godwit (B) Great knot (C) Dunlin (D) Grey plover (E) Eurasian oystercatcher (F) Far eastern curlew (G) Eurasian curlew (H) Spotted greenshank (I) Sharp-tailed sandpiper (J) Broad-billed sandpiper (K) Siberian sandplover, and (L) Total shorebirds in the Dandong yalu Jiang estuarine wetland National Nature Reserve. These 11 species were selected because they either attained 1% ramar criterion or listed as threatened species by IUCN.

from 3000-4000 in 1999 and 2010, to 1000-2000 individuals in 2022-2023. It is listed as Endangered in The IUCN Red List of Threatened Species (2024) because of its rapid population decline in the past 25 years. Another similar curlew species, Eurasian Curlews, did not show decline in 2022. However, the number of individuals declined by about 50% in 2023 and 2024 compared to that of 2022, and the historical data in 2010. Grey Plovers also showed a slight decline in their population in late April. However, their peak count in the reserve is usually in May [19]. The number of Grey Plovers in our survey may not represent their actual population in the Yalu Jiang estuarine wetland. Among the seven common species that met the 1% Ramsar criterion, Eurasian Oystercatchers were the only species that showed a slight increase since 1999 (Figure 2).

Seven shorebird species in our study are listed as threatened by IUCN (2024), among which four species are endangered. Apart from the three threatened species that attained 1% Ramsar criterion, Great Knots (endangered, EN), Far Eastern Curlews (EN) and Grey Plovers (vulnerable, VU). The other four threatened species recorded in our study were Spotted Greenshanks (*Tringa guttifer*, EN), Siberian Sandplovers (*Charadrius mongolus*, EN), Sharp-tailed Sandpipers (*Calidris acuminata*, VU) and Broad-billed Sandpipers (*Calidris falcinellus*, VU). We spotted 9 individuals of Spotted Greenshanks in 2024, which almost attained the 1% population threshold (10 individuals). The number of Siberian Sandplovers, Sharp-tailed Sandpipers and Broad-billed Sandpipers were all lower than that of the 1999 survey which was conducted in early May. The three species are late arrivals in Yalu Jiang estuarine wetland, which explained their low population in late April. Future surveys in May should find their actual population trend in the area.

Discussion

We found that the number of shorebird species, threatened species, and the species that attained 1% Ramsar criterion kept similar, while the total counts of shorebirds, showed 30-50% decline over the past two decades. Among the shorebird species that are common in the Yalu Jiang estuarine wetland, most species showed population decline, including the dominant species Bar-tailed Godwits and Great Knots, and many other threatened species. The population of Dunlin, a dominant species, remained stable throughout the period. The peak count of Bar-tailed Godwits in 2022-2024 declined by 44% compared with 2010 survey, while the peak count of Great Knot declined by 17%. Far Eastern Curlew, which is listed as an endangered species, declined by 51% since 1999.

Zhang SD, et al. [16] found peak number of Bar-tailed Godwit declined by about 50% between 2011-2013 and 2016, mainly due to a decline in *L. l. menzbieri* by 91% in their study period. We found 26,000-47,000 Bar-tailed Godwits in late April from 2022 to 2024, which is similar to, if not more than, the peak number in 2016. This could indicate that population decline may have occurred in recent years. Both godwit subspecies, *L. l. menzbieri* and *L. l. baueri*, use Yalu Jiang estuarine wetland as staging sites during northward migration, with *L. l. baueri* arriving approximately two weeks earlier than *L. l. menzbieri* [22]. The two subspecies overlap in late April during our study period. Further study should include longer survey period between March and May to understand the population trend of each subspecies in Yalu Jiang estuarine wetland.

The 1999 surveys were carried out in May 2-9, when many Bar-tailed Godwits and Eurasian Curlews had departed to breeding grounds [22]. Thus, the shorebird counts in late April of 1999 could be higher. Therefore, the estimate of 30-40% decline of total shorebird population compared to 1999 survey was conservative, and the actual decline since 1999 could be higher.

The loss and degradation of estuarine and coastal wetland of Yellow Sea due to intertidal reclamation, spread of invasive *Spartina*, pollution, and overharvesting of marine resources [9-11] may explain the recent declines in population sizes of some shorebird species. Even though there has been little loss of intertidal habitat at Yalu Jiang estuarine wetland, the bivalve *Potamocorbula laevis*, which is the dominant macrobenthic species of intermediate and lower tidal flat and the major food for Bar-tailed Godwits and Great Knots [22,26], has dramatically declined in abundance since 2013 [16]. The shortages of food resources have greater impacts on later arriving *L. l. menzbieri*, which may seek other high-quality habitats in Yellow Sea region [16]. However, because of the rapid loss and degradation of coastal mudflats in the Yellow Sea area [11,13,27], including the Saemangeum reclamation in South Korea [12], there is a lack of alternative habitats as refuelling sites for migratory shorebirds. Even though some birds can switch to a different diet with morphological and digestive adjustments [17], the reduction in food quality and quantity can lead to downstream effects on survival and breeding success [13,28], which cause their long-term population decline.

Environmental pollutants, such as mercury [29], lead [30,31], persistent organochlorines [32,33] and oil contamination [34,35], could also pose a great threat to the health of birds throughout their dynamic life cycle, leading to their population declines [36]. However, the impacts of pollutants on shorebird health have not been fully investigated, especially for the migratory shorebirds along the EAAF [36]. The coastal area of Yellow Sea is contaminated in various degrees with pollutants from domestic, agricultural and industrial sources, with the Bohai Bay among the most contaminated area on China's coast [37]. How pollutants have impacted the health of migratory shorebirds and whether it is associated with their population decline needs to be investigated in the future.

We found 7 shorebird species meeting the 1% Ramsar criterion in all three survey years. Their populations in the reserve during northward migration exceed the 1% threshold derived from waterbird population size estimates compiled by Wetlands International (2022) [38]. In fact, Yalu Jiang estuarine wetland supports almost half of the flyway's northward-migrating *L. l. baueri* godwits [21,22], and more than 20% of the Great Knots [22]. Among the 7 species that attained the 1% population threshold, Great Knots and Far Eastern Curlews are listed as endangered by IUCN as their populations decline rapidly in recent decades mainly due to widespread land reclamation at their staging grounds [12,15,39]. Grey Plover was recently uplisted to vulnerable species by IUCN as their population has declined by more than 30% in the past 23 years [40,41]. The other four species are all listed as near threatened, which is likely to become threatened in the near future if their population keeps declining. The reserve also supports a considerable number of endangered Spotted Greenshanks which are restricted to EAAF with a global population of only 1500-2000 individuals [42].

A total of 1499 Red Knots (Calidris canutus) was recorded in the historical 1999 survey (Table 1), which attained the 1% population threshold; however, only a few individuals were spotted at the reserve in the following years [19] and the highest count from 2022 to 2024 was 250 individuals (Table 1). It seems that the large flock of Red Knots in 1999 was an exception at the reserve. In contrast, a 20-km stretch of coastline at northern Bohai Bay, which is about 600 kilometers to the west of our study site, supports over 45% of the EAAF population of Red Knots during northward migration [43]. It is possible that the flock appeared at the reserve in 1999 may have faced unfavorable weather conditions. Favorable winds can confer considerable time and energy in long-distance migrating shorebirds [44]; on the other hand, when facing adverse wind conditions, birds may make additional stops or take diverted courses [45,46]. By incorporating various meteorological, tidal or oceanographic factors, Lagrangian agent-based model has been used to track the migration route of birds [47], and predict the spatiotemporal distribution of seabirds [48]. Future studies in Yalu Jiang estuarine wetland could use Lagrangian models to analyze how wind and other atmospheric factors affect the migration and distribution of shorebirds.

Compared to other coastal or estuarine wetlands in Yellow Sea region, Yalu Jiang estuarine wetland is among the sites with most shorebirds during northward migration [8]. The highest seasonal count at Yalu Jiang wetland was over 150,000 shorebirds, compared to 110,000 shorebirds at Yancheng NNR, and 130,000 shorebirds at Huang He NNR [8]. Even though the total number of shorebirds may not be too much different at various sites in Yellow Sea region, the composition of shorebirds and the species that attained 1% Ramsar criterion was different at each site [8]. For example, Rogers DI, et al. [43] found that a small area in northern Bohai Bay supports over 45% of the EAAF population of Red Knots (Calidris canutus) during northward migration, while no other sites of comparable importance to Red Knots have been found in the Yellow Sea area [8]. Huang He National Nature Reserve is an important staging site for Kentish Plovers (Charadrius alexandrinus), supporting over 24,000 plovers (more than 25% of the flyway population) during northward migration [8]. Same species may also use different staging areas during northward migration and southward migration. Bar-tailed Godwits L. l. baueri usually fly non-stop from wintering grounds in New Zealand to coastal staging grounds in Yellow Sea region, before heading to Alaskan breeding grounds; however, baueri use a different route during southward migration, staging in southwest Alaska before flying non-stop across the Pacific Ocean from Alaska to Nea Zealand [45]. Future studies could involve more sites at Yellow Sea region to understand the importance of each site to different groups of shorebirds.

Although many shorebird species exhibited population decline at the Yalu Jiang estuarine wetland, our study indicated that Yalu Jiang estuarine wetland is still an important staging site for migratory shorebirds, including many threatened species, during their northward migration. Millions of shorebirds along the EAAF depend on the coastal mudflats of the Yellow Sea, including Yalu Jiang estuarine wetland, to replenish with sufficient fuel reserve for their final leg towards northern breeding ground [8,9]. Those species with the greatest reliance on the Yellow Sea as stopover site show the most serious declines [15], indicating an urgent conservation measure to be taken in the Yellow Sea area. Protecting the area from further land reclamation and maintaining a healthy habitat with high-quality and abundant food resources is essential in the conservation of migratory shorebirds. Furthermore, we should continue to monitor the shorebird populations in the Yalu Jiang estuarine wetland and other areas of the Yellow Sea region annually, preferably during the entire period of northward migration from March to May, as well as during southward migration. Bird surveys help detect the population status of all migratory shorebird species in the area.

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