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Effects of Vegetative Cover Changes on the Carrying Capacity of Migratory Shorebirds in a Newly Formed Wetland, Yangtze River Estuary, China

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Zhen-Ming Ge, Xiao Zhou, Tian-Hou Wang, Kai-Yun Wang, Enle Pei, and Xiao Yuan (2009) Effects of vegetative cover changes on the carrying capacity of migratory shorebirds in a newly formed wetland, Yangtze River estuary, China. *Zoological Studies* **48**(6): 769-779. The Jiuduansha wetland is a shoal which formed in the Yangtze River estuary during the 1940s. Shorebird surveys were conducted at Jiuduansha wetland in 2004-2005 during the spring (northerly) and autumn (southerly) migration seasons. Over 6000 individuals of 25 shorebird species were recorded at the wetland during spring and 3000 birds during autumn. Their preferred roosting habitat was the bare mudflat and bulrush (*Scirpus* × *mariqueter* and *S. triqueter*) zones. The carrying capacity of the wetland for shorebirds based on the available foraging resources of medium-sized macrobenthos was estimated during the spring and autumn of 2006. Thirty species of macrobenthos were identified and defined as potentially appropriate food for shorebirds at Jiuduansha, comprised mostly of mollusks, crustaceans, and annelids (polychaetes). The total standing benthic invertebrate crop was 1973.64 kg ash free dry weight (AFDW) in spring and 1557.28 kg AFDW in autumn. We calculated that this could theoretically support about 1.51×10^6 bird-days (the number of birds present) in spring and 1.20×10^6 bird-days in autumn. However, field surveys in 2006 indicated that only 10% of the standing crop of biomass was available to shorebirds, and that the actual carrying capacities were about (0.15 and 0.12) × 10^6 bird-days in spring and autumn, respectively. Actual shorebird abundances at Jiuduansha were significantly lower than the theoretical carrying capacity. Furthermore, satellite imagery from 1998-2006 indicated that an introduced species of smooth cordgrass *Spartina alterniflora* has rapidly spread, invading the bare mudflat and bulrush zones. This has reduced the availability of suitable high-tide roosting habitat, and may be the key factor, rather than food availability, limiting use of the area by shorebirds. We provide recommendations for the management of Jiuduansha wetland to benefit shorebirds and other waterbird species. http://zoolstud.sinica.edu.tw/Journals/48.6/769.pdf

Key words: Recently formed wetland, Shorebirds, Macrobenthos, Change in vegetative cover, *Spartina alterniflora*.

The migration of animals results in seasonal fluctuations in population densities in a particular area. These population changes are governed by internal factors, which determine the reproductive success of the population, and external factors, which include food supply, predation, and climate change (Sun 2001). Changes in animal population numbers during migration are mainly driven by external factors, of which the quality of stopover habitats is one of the most important.

The utilization value of a habitat for a population can be assessed by the amount of

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potential food it contains, roost-site availability, climate conditions, predation pressure, human disturbance, etc., which combine to determine the carrying capacity of the habitat. The carrying capacity refers to the potential maximum number of individuals a specific habitat can accommodate. This “capacity” was recently applied to evaluate habitats for migratory birds and is defined as the maximum number of birds the habitat can support during an entire season or throughout the year (Goss-Custard et al. 2002 2003). Assessing the carrying capacity for wildlife is a valuable tool to guide the management of nature reserves, thereby maintaining and increasing the value of protected areas (Sutherland and Allport 1994).

The mudflats along the Yangtze River estuary shoreline are important areas which migratory shorebirds use as stopover sites along the East Asian-Australasian flyway (Minton 1982, Tulp et al. 1994). The Yangtze River has deposited billions of tons of sediments in the eastern estuary, resulting in the appearance of Jiuduansha wetland as an island about 50 yrs ago (Yang 1999, Yang et al. 2006). Jiuduansha lies in the East Asian monsoon belt with a stable climate in spring and autumn, and there are no human inhabitants and little anthropogenic disturbance (Chen et al. 2001, Ma et al. 2007); moreover, with the continuing sedimentation of silt and sand, Jiuduansha wetland continues to grow and should provide potentially valuable stopover sites for shorebirds. Consequently, the island is considered a potentially high quality habitat for migratory shorebird species and was designated a National Nature Reserve in Aug. 2005. However, this shorebird habitat in the nature reserve has been invaded by the invasive, non-native smooth cordgrass *Spartina alterniflora* (Chen 2003, Qing et al. 2004, Huang and Zhang 2007).

Although a preliminary estimate of this area’s carrying capacity for shorebirds was conducted, it was based on the total macrobenthos biomass (Ge et al. 2007b). In this study, we used preferred prey sizes to estimate the biomass available, given that this method can provide a better estimate of the carrying capacity (Guy and Fischer 1984, Piersma et al. 1993, González 1996). Moreover, the current shorebird community size and potential effects of such factors as vegetation cover changes on shorebirds need to be examined.

The study aimed to (1) survey shorebird abundance and diversity, (2) investigate the macrobenthos to determine the carrying capacity, and (3) evaluate the effects of vegetation changes.

MATERIALS AND METHODS

Study site

Jiuduansha wetland is the 3rd generation of recently developed shoal islands at the Yangtze River estuary (31°03'-31°17'N, 121°46'-122°15'E) with an east-west length of 50 km and a north-south width of 15 km. The area includes Shangsha shoal (SS), Zhongsha shoal (ZS), and Xiasha shoal (XS) (Fig. 1). The intertidal area exposed at low tide ranges from 145 (Wusong tide station at 0 m) to > 200 km^2 (Wusong tide station at -2 m) (Wang 2003). The annual mean air temperature is 15.5°C, and the annual mean water temperature is 17.5°C. The tide model of Jiuduansha wetland follows an irregular half-day tidal pattern with a mean tidal range of 2-3 m.

The plant community is dominated by the reed *Phragmites australis* and bulrush species *Scirpus* × *mariqueter* and *S. triqueter*. Since 1997, the introduced species smooth cordgrass has been planted in Jiuduansha wetland to stabilize sediments and promote wetland growth (Chen et al. 2001, Chen 2003, Tang and Lu 2003).

Bird surveys

Shorebirds in the Yangtze River estuary are present from Mar. to May in spring and Aug. to Oct. in autumn (Wang and Qian 1988, Huang et al. 1993). Monthly bird surveys of the Jiuduansha wetland were conducted in Aug.-Oct. 2004 and Mar.-May 2005, for a total of 6 surveys.

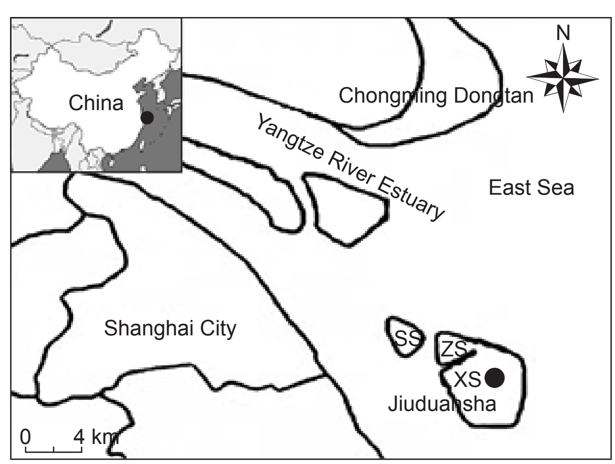

Fig. 1. Location of the Jiuduansha wetland comprised of the Shangsha (SS), Zhongsha (ZS), and Xiasha shoals (XS) in the Yangtze River estuary, China.

The Jiuduansha wetland was divided into 4 zones according to habitat type: bare mudflat zone, bulrush zone, creek zone, and reed/smooth cordgrass zone. Four teams simultaneously surveyed the 4 zones during low tide in daytime (observations generally lasted 3-4 h). Due to the open aspect, scanning surveys of the mudflat and bulrush zones were completed on foot during neap tide periods. A wooden boat was used to carry the others to the target landing sites (zones of creek and reed/ smooth cordgrass) in the Shangsha, Zhongsha, and Xiasha shoals. Analysis of the survey sites using maps and satellite images showed that 20 creeks up to 500 m in length were surveyed by boat. The adjacent reed and smooth cordgrass zones were surveyed by teams on foot. Using binoculars and 20-60x telescopes, investigators counted all shorebirds present at the survey sites, and also recorded other species of waterbirds (Laridae, Sternidae, Ardeidae, and Anatidae). Birds flying over the sites were excluded.

In order to investigate shorebird presence at Jiuduansha during the migratory seasons, we recorded the maximum count for each bird species during each seasonal census and their distribution across the different habitat types. Analysis of variance (ANOVA) was performed to test discrepancies in habitat use by shorebirds with the statistical package SPSS 12.0 (SPSS, Chicago, IL, USA. 1990).

Macrobenthos collection and estimation of the potential food biomass

Surveys of the macrobenthic community of the Jiuduansha wetland have been carried out on an annual basis since 2004-2005 (Ge et al. 2007b). There were 61 fixed sampling sites, each surveyed in both the autumn and spring seasons, distributed across the different habitats in the 3 parts of Jiuduansha: 18 in bare mudflat zones, 22 in bulrush zones, 12 in reed zones, and 9 in smooth cordgrass zones (Fig. 2).

In spring (Mar.-May) and autumn (Sept.-Nov.) 2006, topsoil samples were collected with a 10 cm diameter hand-held PVC pipe to a depth of 20 cm. At each site, 4 samples were collected before sieving and sorting, giving a total area sampled of 0.0314 m^2. As soon as was possible, each sample was sieved on site (with a mesh size of 0.5 mm), and the retained sediment was packed in polyethylene bags, preserved with 5% formalin, and stained with rose bengal. Subsequent sorting and identification were done in the laboratory according to the methods described in “Survey methods of coastal zone biological resources” in the normative operation instructions (Compiling Group of Concise Regulation of National Coastal Zone and Coastal Resources Comprehensive Survey 1986).

Our pilot study revealed that mollusks and crustaceans were the most abundant invertebrates in the macrobenthos community of the Jiuduansha wetland. The biomass of macrobenthos was determined as the ash-free dry weight (AFDW) (Howes and Bakewell 1989, Bessie and Sekaran 1995).

The size of macrobenthos is one of the most important factors for prey item selection by shorebirds (Guy and Fischer 1984, Piersma et al. 1993, González 1996). Typically, most species of shorebirds select mollusks with a shell length of < 10 mm and crustaceans with a carapace width of < 15 mm for feeding (Guy and Fischer 1984, Piersma et al. 1993, González 1996). Therefore, only macrobenthic items meeting these criteria were included in the quantification of ‘potential food’ from each soil sample. These were oven-dried separately at 60°C to a constant weight, and then ashed at 600°C for 6 h (Howes and Bakewell 1989, Bessie and Sekaran 1995).

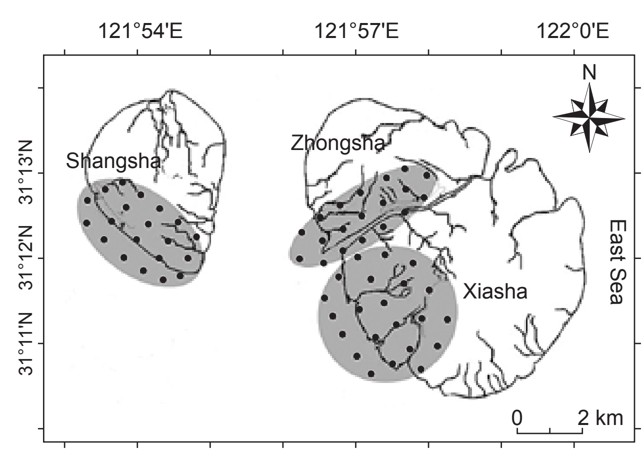

Fig. 2. Locations of the main study areas (shaded) within the Shangsha, Zhongsha, and Xiasha shoals at Jiuduansha wetland. The dots represent the approximate locations of macrobenthos sampling sites. The peripheral lines around Jiuduansha show the approximate boundaries of bare mudflats and vegetation zones at about sea level (Wusong tide station). The 0 m level refers to figure 3.

Carrying capacity calculation

We calculated the total standing crop biomass for the entire island including the main habitats of bare mudflats, bulrush, reed, and smooth cordgrass during the autumn and spring migratory seasons. We then estimated the macrobenthos biomass consumed by shorebirds in Jiuduansha wetland, according to the methods of Meire et al. (1994), using the following transformed formulae:

$$C = C_1 \text{ (bare mudflat zone)} + C_2 \text{ (bulrush zone)} + C_3 \text{ (reed zone)} + C_4 \text{ (smooth cordgrass zone)}, \quad \text{(F. 1)}$$

$$C_i = \frac{AFDW_i \times A_i}{\pi r^2} \times 10^8 \text{ , and} \quad \text{(F. 2)}$$

$$C = \frac{D \times N \times 3 \times BMR}{Q \times F \times 10^3} \leftrightarrow N = \frac{C \times Q \times F}{D \times 3 \times BMR} \times 10^3 \text{ ;} \quad \text{(F. 3)}$$

where C is the total macrobenthos biomass available to shorebirds in the entire wetland (g AFDW), C_i is the total AFDW of each habitat (g), $AFDW_i$ is the biomass of each sampling site (g/hm^2), A_i is the total area of sampling sites of each habitat (hm^2), r is the radius of the PVC collection pipe (5 cm), D is the length of the migration season (90 d in each season for which shorebirds are present at the wetland) (Wang and Qian 1988, Huang et al. 1993), BMR is the gross basal metabolic rate of shorebirds in the Yangtze River estuary (kJ/d), N is the number of birds present (bird-days, as defined by Meire et al. 1994), Q is the assimilation efficiency of the food (0.85) (Kersten and Piersma 1987, Zwarts and Blomert 1990), and F is the caloric value (22 kJ/g) (Howes and Bakewell 1989, Zwarts and Blomert 1990).

Based on the bodily form indices of the fat-free lean weight, *BMR*, and body length (Meire et al. 1994), we classified the shorebird community into 3 somatotypes, of large-, medium-, and small-sized species, and the *BMR* of the 3 types of bird groups were separately estimated (Ge et al. 2007b). Detailed data on the classification of the shorebird community and gross *BMR* estimations were taken from Meire et al. (1994) and Battley et al. (2001a b). In order to obtain an estimate of the gross *BMR* for shorebirds, we determined the shorebird community composition using long-term shorebird survey data for the Yangtze River estuary, which includes Jiuduansha and contiguous wetlands, such as the Chongming Dongtan wetland and those on the outskirts of Shanghai (Wang and Qian 1988, Ma et al. 2002a b, Ge et al. 2006, Ma et al. 2007, Pei et al. 2007).

These data indicate that around the Yangtze River estuary, small shorebirds typically dominate the shorebird community, but there is variation in community compositions between seasons. In spring, the shorebird community comprises approximately 70% small birds, with medium birds accounting for 20% and large birds 10% of the total. In autumn, the proportion of medium birds rises to 35%, with the relative proportions of small (60%) and large (5%) birds correspondingly decreasing. The *BMR* value for each size-class of shorebirds was worked out as the product of the community proportion and average *BMR*. The sum of the 3 shorebird size classes (called the gross *BMR*) was calculated to be 90.50 kJ/d in spring and about 90.25 kJ/d in autumn (Ge et al. 2007b).

Habitat area and vegetative cover changes

A Landsat-TM satellite image taken at around 0 m (Wusong tide station) in 2006 was used to characterize the vegetation cover and define the habitats. Comparisons of images taken in 1998, 2002, and 2006 were used to measure physical changes in the wetland. Images were analyzed using Arcinfo 9.0 (a geographic information system tool of ESRI, USA), and ground truthing was carried out before creating habitat vectorgraphs using replicate vegetation plots.

Our pilot study revealed that no shorebirds accessed the area around the -2-0 m tide level which was rarely exposed and thus unavailable to shorebirds. We identified only those areas of the wetland exposed at a tide level of > 1 m (as recorded at the Wusong tide station) and calculated the area of each habitat using Arcinfo tools, taking the navigation chart of South Yangtze River estuary in 2006 as the geographical reference.

RESULTS

Community composition of shorebirds and habitat selection

In 2004 and 2005, our surveys at Jiuduansha revealed 3696 shorebirds of 25 species during autumn and 6442 shorebirds of 25 species during spring. There were clear differences in shorebird abundances among the habitats (autumn: $F_{2,81}$ = 8.907, $p < 0.001$; spring: $F_{2,81}$ = 9.420, $p < 0.001$) with most shorebirds showing a marked preference for the bare mudflats. Of the shorebirds recorded, 98.70% (autumn) and 98.62% (spring) were observed in the bare mudflat and bulrush habitats, few in the creek habitats, and none in the reed and smooth cordgrass zones (Table 1).

Macrobenthos biomass (potential food for shorebirds)

Referring to table 2, 30 macrobenthic species of moderate size suitable for shorebirds to feed upon in 5 phyla, 7 classes, 10 orders, 21 families, 25 genera were collected and identified. The macrobenthos community was dominated by mollusks, crustaceans, and annelids (mostly polychaetes).

At low tide, the dominant habitat type at Jiuduansha is intertidal mudflat, followed by significant areas of bulrush and reed habitats, and a comparatively small area of smooth cordgrass. The total area covered by each type of habitat is presented in table 3. The total macrobenthos

Table 1. Total numbers of waterbird species in each vegetation zone at Jiuduansha wetland during the autumn (2004) and spring (2005) surveys

Species	Bare mudflat		Bulrush		Creek		Reed		Smooth cordgrass	
	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring
Eurasian Curlew *Numenius arquata*	45	12	-	-	-	-	-	-	-	-
Whimbrel *Numenius phaeopus*	145	235	14	36	-	-	-	-	-	-
Far Eastern Curlew *Numenius madagascariensis*	2	6	-	-	-	-	-	-	-	-
Bar-tailed Godwit *Limosa lapponica*	24	31	8	5	-	-	-	-	-	-
Black-tailed Godwit *Limosa limosa*	21	25	-	-	-	-	-	-	-	-
Great Knot *Calidris tenuirostris*	620	1204	-	-	-	-	-	-	-	-
Dunlin *Calidris alpina*	255	575	35	430	-	-	-	-	-	-
Red Knot *Calidris canutus*	77	152	-	-	-	-	-	-	-	-
Red-necked Stint *Calidris ruficollis*	618	875	18	62	12	15	-	-	-	-
Sharp-tailed Sandpiper *Calidris acuminata*	169	118	6	15	-	-	-	-	-	-
Curlew Sandpiper *Calidris melanotos*	22	68	-	-	-	-	-	-	-	-
Sanderling *Calidris alba*	-	51	-	-	-	-	-	-	-	-
Broad-billed Sandpiper *Limicola falcinellus*	9	22	-	-	-	11	-	-	-	-
Terek Sandpiper *Xenus cinerea*	140	245	21	54	-	12	-	-	-	-
Common Greenshank *Tringa nebularia*	137	336	3	6	-	26	-	-	-	-
Common Redshank *Tringa totanus*	86	150	-	-	-	-	-	-	-	-
Spotted Redshank *Tringa erythropus*	54	124	-	-	-	-	-	-	-	-
Wood Sandpiper *Tringa glareola*	3	-	111	-	-	-	-	-	-	-
Marsh Sandpiper *Tringa stagnatilis*	2	-	-	-	-	-	-	-	-	-
Common Sandpiper *Tringa hypoleucos*	27	53	-	-	12	13	-	-	-	-
Green Sandpiper *Tringa ochropus*	5	-	-	-	-	12	-	-	-	-
Grey-tailed Tattler *Tringa brevipes*	-	-	5	71	10	-	-	-	-	-
Ruddy Turnstone *Arenaria interpres*	12	20	-	-	-	-	-	-	-	-
Lesser Sand Plover *Charadrius mongolus*	36	139	-	-	-	-	-	-	-	-
Greater Sand Plover *Charadrius leschenaultii*	64	105	22	27	-	-	-	-	-	-
Kentish Plover *Charadrius alexandrinus*	832	1049	-	-	14	-	-	-	-	-
Grey Plover *Pluvialis squatarola*	-	-	-	52	-	-	-	-	-	-
Others*	416	260	263	40	25	28	-	-	-	-

*Other waterbirds observed included species from the Laridae, Sternidae, Ardeidae, Anatidae families. -: No birds observed.

biomass for the entire Jiuduansha wetland was calculated to be 1973.64 kg AFDW in spring and 1557.28 kg AFDW in autumn (Table 3).

The theoretical maximum carrying capacity of Jiuduansha wetland

Using formula 3, the maximum carrying capacity of shorebirds supported by the total macrobenthos in all habitats in Jiuduansha wetland was about 1,510,416 bird-days in spring and 1,195,082 bird-days in autumn:

$$\text{Spring: } N = \frac{1973637.92 \times 0.85 \times 22}{90 \times 3 \times 90.50} \times 1000 = 1510416.58$$

Table 2. Species composition and distribution of macrobenthos at Jiuduansha

Species	Abundance	Potential predators*
Annelids (polychaete)		Red-necked Stint, Sharp-tailed Sandpiper, Sanderling, Kentish Plover, and other small-sized species
Limnodrilus hoffmeisteri	a	
Tubifex sinicus	a	
Tylorrhynchus heterochaetus	a	
Glycera chirori	a	
Capitella capitata	a	
Mollusks	a	Great Knot, Terek Sandpiper, Common Greenshank, Common Redshank, Wood Sandpiper, Ruddy Turnstone, and other medium-sized species
Corbicula fluminea	a	
Mactra veneriformis	a	
Glaucomya chinensis	b	
Sinonovacula constricta	a	
Potamocorbula ustulata	c	
Stenothyra glabra	d	
Assiminea violacea	c	
A. latericea	b	
Cerithidea sinensis	b	
Bullacta exarata	a	
Crustaceans		Eurasian Curlew, Whimbrel, Far Eastern Curlew, Bar-tailed Godwit, Black-tailed Godwit, and other large-sized species
Philyra pisum	a	
Macrophthalmus japonicus	a	
M. dilatatus	a	
Sesarma plicata	a	
Uca dussumieri	a	
U. arcuata	a	
Ilyrplax deschampsi	c	
I. dentimerosa	a	
Helicetridens tientsinensis	a	
Metopograpsus quadridentatus	a	
Orithyia sinica	a	
Porcellio sp.	a	
Insects		Some small-sized and medium-sized shorebirds
Insect larva sp.	b	
Insect sp.	b	
Fish		Some large-sized shorebirds
Boleophthalmus pectinirostris	a	

Species abundance classes: [a]: < 1% of total individuals; [b]: 1% < x < 10%; [c]: 10 < x < 20%; [d]: > 20%. *The potential shorebird predators are listed alongside each group of macrobenthic species, using information taken from Brooks (1967), Baker (1977), Piersma et al. (1993), Weber and Haig (1997), Ribeiro et al. (2003), Stillman (2003) Zhu et al. (2007), and Chongming Dongtan Birds Nature Reserve long-term records.

and

$$\text{Autumn: } N = \frac{1557281.51 \times 0.85 \times 22}{90 \times 3 \times 90.50} \times 1000 = 1195082.15$$

Habitat changes at Jiuduansha wetland during 1998-2006

As shown in the satellite images (Fig. 3) and their interpretation of vegetation cover by plant type (Table 4), areas of the bare intertidal mudflats and the vegetation cover of bulrush, reed, and smooth cordgrass all increased during the period 1998-2006, but the smooth cordgrass cover expanded at a faster rate than the other habitat types (5.87% to 16.78%). The expansion of smooth cordgrass was greatest on the Zhongsha and Xiasha shoals, where its extent grew by about 8 fold, and it began to invade the mudflat and bulrush areas. In contrast, reeds spread only at Shangsha (Fig. 3), where smooth cordgrass planting was not carried out.

DISCUSSION

Factors affecting shorebird distributions

The value of a habitat for wildlife can be evaluated based on the available food resources. The Yangtze River estuary including Jiuduansha wetland is a significant stopover site in terms of shorebird life history strategies (Minton 1982, Tulp et al. 1994), as it is of international importance for Kentish Plover *Charadrius alexandrinus*, Whimbrel *Numenius phaeopus*, Spotted Redshank *Tringa erythropus*, and Little Ringed Plover *C. dubius* (Barter 2002), and over 5 × 10^6 shorebirds pass through the flyway every year (Wilson and Barter 1998, Barter 2002).

At Jiuduansha wetland, the resources available for foraging shorebirds during the migration seasons potentially can support approximately 1.51 × 10^6 shorebird-days in spring and 1.20 × 10^6 shorebird-days in autumn. The actual amount of food consumed by shorebirds was estimated to be about a 13%-23% intake rate of the standing crop biomass on breeding grounds and about a 12% intake rate in the overwintering region (Meire et al. 1994, Goss-Custard et al. 2003). It is hypothesized that the feeding intensity at stopover sites for refueling equals that in breeding or overwintering areas; thus, the intake rate of shorebirds at Jiuduansha wetland can be hypothesized to be about 10% of the standing crop biomass, in which case, the expected bird-days would be about 0.15 × 10^6 in spring and 0.12 × 10^6 in autumn.

There are, however, many other factors affecting estimates of the carrying capacity for shorebirds, such as climate conditions, interspecific and intraspecific competition, and human disturbance (Caldow et al. 2004, Goss-Custard et al. 2003). Jiuduansha, which is situated in the East Asian monsoon moderate climate zone, is especially valuable as there are no human inhabitants and little anthropogenic disturbance, except for small-scale fishing and catching of eel-fry during winter (Chen et al. 2001, Ma et al. 2007).

Some studies showed that the predation risk from raptors has significant effects on habitat use by shorebirds (Cresswell 1994, Lawler 1996, Hotker 2000, Ydenberg et al. 2002). At Jiuduansha, 4 species of raptor were recorded including Northern Goshawk *Accipiter gentilis*, Common Buzzard *Buteo buteo*, Western Marsh

Table 3. Area of each habitat and estimated biomass standing crop (C_i) at Jiuduansha wetland during spring and autumn

Habitat type	Area (hm^2)	Spring		Autumn	
		$AFDW_i$ (g/hm^2)	C_i (kg)	$AFDW_i$ (g/hm^2)	C_i (kg)
Bare mudflat	3878.01	241.45 ± 156.42	936.35	169.37 ± 73.01	656.82
Bulrush	2619.36	204.57 ± 128.30	535.84	198.52 ± 90.26	520.00
Reed	1345.71	179.64 ± 86.63	241.74	152.17 ± 68.54	204.78
Smooth cordgrass	799.54	324.82 ± 161.78	259.70	219.74 ± 143.23	175.69
Total	8642.42	-	1973.64	-	1557.28

$AFDW_i$: The food mass in the samples; C_i: The food mass in each habitat, calculated by formula 2 Mean (± SD) $AFDW_i$ in four categories of zones were presented ($n_{\text{Bare mudflat}}$ = 18, n_{Bulrush} = 22, n_{Reed} = 12, and $n_{\text{Smooth cordgrass}}$ = 9 AFDW, ash-free dry weight. hm^2 = ha.

Harrier *Circus aeruginosus*, and Common Kestrel *Falco tinnunculus*. However, these species are not wetland specialists and were observed with low frequency, with most recorded flying over the shoals as opposed to actually hunting (Ma et al. 2007); therefore, we do not consider raptors to be a limiting factor for the shorebird community at Jiuduansha.

In this context, Jiuduansha should support a large number of shorebirds. However, our survey revealed the actual abundance was much lower than the predicted carrying capacity, even much lower than that of Chongming Dongtan, a nearby wetland (see Fig. 1; Barter et al. 2006). With the vegetation succession of the wetlands progressing from intertidal bare mudflats to bulrushes and then to reed/smooth cordgrass communities, our study showed that shorebirds avoided dense estuarine vegetation in the upper zones (reed/smooth cordgrass) (Ge et al. 2007a). They favored the primary stage of succession, which included the bare mudflat and bulrush vegetation zones. These kinds of mudflat habitats are generally most suitable for shorebirds because that is where the best feeding opportunities are, but they are only available to them for a restricted period during low tide periods. It is therefore reasonable to find lower abundances of shorebirds at Jiuduansha.

Negative influence of introduced species

Food availability seems to be the main factor

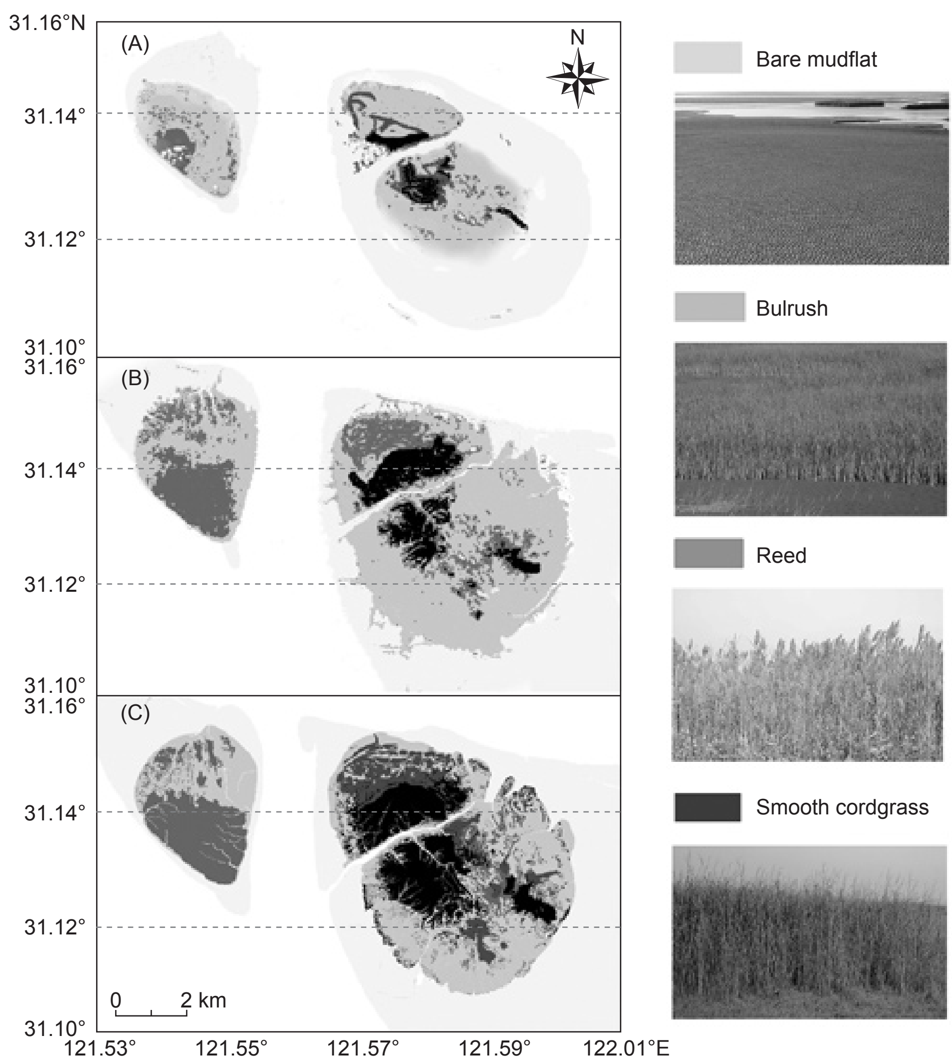

Fig. 3. Variations in vegetation distributions (A, 1998; B, 2002; C, 2006). The local government began planting smooth cordgrass at Jiuduansha wetland to stabilize sediments and promote land growth in 1997 (Chen et al. 2001). The outermost lines indicate the 0 m level.

determining habitat suitability for shorebirds (Sutherland 2000, Holmes and Sherry 2001). There are abundant macrobenthos resources in the Jiuduansha wetland which could theoretically support about (0.12-0.15) × 10^6 shorebird-days during migration seasons. If shorebird numbers were to increase to this level, Jiuduansha wetland could meet the criteria for designation as a wetland of international importance. However, the actual shorebird numbers at Jiuduansha wetland were lower than those theoretically possible based on the macrobenthos biomass, as was similarly found in other research (Ma et al. 2006, Zheng et al. 2006), providing further evidence that food resources might not be the limiting factor for shorebirds using the wetland.

In 1997, reeds and smooth cordgrass were planted in the wetland to stabilize the sediments and promote land growth, while bulrushes naturally colonized the area (Chen et al. 2001 2004). Since that time, the vegetation cover has greatly increased (9.20% to 28.24% for reeds and 5.87% to 16.78% for smooth cordgrass, Table 4), and areas of intertidal bare mudflats and bulrushes are being invaded (see Fig. 3). Shorebirds do not generally feed or roost in areas with deep water or with dense vegetation, but favor habitats of bare mudflats and bulrushes (Hervey 1970, Goss-Custard and Moser 1988, Liang et al. 2002, Wang et al. 2003, Ge et al. 2007a). Consequently, the loss of available habitats caused by the rapid spread of the invasive smooth cordgrass is a serious threat to shorebirds through habitat loss.

On the other hand, we consider that the low elevation of Jiuduansha is also one of the negative causes. The highest elevation of Jiuduansha wetland is about 3-3.5 m (Wang 2003), and a large portion of Jiuduansha (most of the bare flats and some of the vegetated zones) are inundated by tidewater during medium- or high-tide periods, while the area above the tide level is covered by reeds and smooth cordgrass (Chen 2003, Zheng et al. 2006). Some observations of shorebird distributions during high tide showed that the birds will leave and temporarily roost on the neighboring Shanghai shoreline (information from a routine survey by the Shanghai local management department of the Jiuduansha Wetland Nature Reserve) (Tang and Lu 2003).

Shorebirds choose roost sites to avoid inundation and minimize the distance from feeding grounds, thereby maximizing feeding opportunities and minimizing energy expenditure (Dias et al. 2006, Rosa et al. 2006, Rogers et al. 2006). Currently the numbers of shorebirds feeding on the intertidal flats at Jiuduansha are considerably less than what might be expected from the potential macrobenthos prey stocks, making it clear that shorebirds might not be using this site to maximum carrying capacity because of a lack of suitable roosting habitats.

Implications for management

Unfortunately, it is known that a large area of mudflats of northern Chongming Dongtan will be reclaimed for development according to the current decisions of the local government. Once this development goes ahead, Jiuduansha wetland will become an even more important habitat for waterbirds. However, it is likely that Jiuduansha wetland will not be a stable energy-replenishing site for shorebird refueling for a long period but only a stopover site. Therefore the future management of Jiuduansha should consider vegetation management for migratory shorebirds. Our detailed recommendations are to (i) open up areas at higher elevations as roosting habitats by removing smooth cordgrass; (ii) maintain peripheral reed beds at a width of about 50-100 m to protect the wetland from tidal erosion; (iii) leave reed belts of about 20 m width

Table 4. Changes in vegetation cover area at Jiuduansha

Vegetation community	Year					
	1998		2002		2006	
	Area (hm^2)	Percent (%)	Area (hm^2)	Percent (%)	Area (hm^2)	Percent (%)
Reed	156.5	9.20	910.22	24.40	1345.71	28.24
Smooth cordgrass	100	5.87	227.37	6.10	799.54	16.78
Bulrush	1445.3	84.93	2591.47	69.5	2619.36	54.98
Total	1701.8	-	3729.06	-	4764.61	-

hm^2 = ha.

to form buffer zones and segregate sections for passerine birds (*Acrocephalus*, Passeriformes, Emberizidae etc., see Huang et al. 1993, Chen 2003) when harvesting the reeds; (iv) release and maintain populations of native fish macrobenthos which can provide food for a range of waterbird species, in addition to sustaining adult fish stocks; and (v) regulate the waterline to a low level during spring and autumn to maximize habitat availability for visiting shorebirds and to a high level outside this period to benefit overwintering waterbirds (the Anatidae comprises the dominant species in winter, see Chen 2003, Ma et al. 2007). These strategies would increase utilization of the nature reserve by waterbirds and shorebirds by providing optimum roosting habitats and foraging resources.

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REFERENCES

Baker MC. 1977. Shorebird food habits in the eastern Canadian Arctic. Condor **79:** 56-62.

Barter MA. 2002. Shorebirds of the Yellow Sea: importance, threats and conservation status. Canberra, Australia: Wetlands International Global Series 9, International Wader Studies 12.

Barter MA, G Lei, L Cao. 2006. Waterbird survey of the middle and lower Yangtze River floodplain (Feb. 2005). Beijing: China Forestry Publishing House.

Battley PF, A Dekinga, MW Dietz, S Tang, K Hulsman. 2001a. Basal metabolic rate declines during long-distance migratory flight in Great Knots. Condor **103:** 838-845.

Battley PF, MW Dietz, T Piersma, A Dekinga, S Tang, K Hulsman. 2001b. Is long-distance bird flight equivalent to a high-energy fast? Body composition changes in freely migrating and captive fasting Great Knots. Physiol. Biochem. Zool. **74:** 435-449.

Bessie O, K Sekaran. 1995. Changes in the macrobenthos community of a sand flat after erosion. Coast. Shelf Sci. Estuar. **40:** 21-33.

Brooks WS. 1967. Food and feeding habits of fall migrant shorebirds at a small midwestern pond. Wilson Bull. **79:** 307-315.

Caldow RWG, HA Beadman, S McGrorty, RA Stillman, JD Goss-Custard, SEA Durrell, AD West, MJ Kaiser, K Mould, A Wilson. 2004. A behavior-based modeling approach to reducing shorebird-shellfish conflicts. Ecol. Appl. **14:** 1411-1427.

Chen JK. 2003. Reports of Shanghai Jiuduansha Wetland Nature Reserve. Beijing: Science Press. (in Chinese)

Chen JY, DJ Li, WH Jin. 2001. Eco-engineering of Jiuduansha Island caused by Pudong International Airport construction. Engin. Sci. **3:** 1-8.

Chen ZY, B Li, Y Zhong, JK Chen. 2004. Local competitive effects of introduced *Spartina alterniflora* on *Scirpus mariqueter* at Dongtan of Chongming Island, the Yangtze River estuary and their potential ecological consequences. Hydrobiologia **528:** 99-106.

Compiling Group of Concise Regulation of National Coastal Zone and Coastal Resources Comprehensive Survey. 1986. Concise regulation of national coastal zone and coastal resources comprehensive survey. Beijing: Ocean Press.

Cresswell W. 1994. Age-dependent choice of redshank (*Tringa totanus*) feeding location: profitability or risk? J. Anim. Ecol. **63:** 589-600.

Dias MP, JP Granadeiro, M Lecoq, CD Santos, JM Palmeirim. 2006. Distance to high-tide roosts constrains the use of foraging areas by Dunlins: implications for the management of estuarine wetlands. Biol. Conserv. **131:** 446-452.

Ge ZM, TH Wang, X Yuan, X Zhou, WY Shi. 2006. Use of wetlands at the mouth of the Yangtze River by shorebirds during spring and fall migration. J. Field Ornithol. **77:** 347-356.

Ge ZM, TH Wang, X Zhou, KY Wang, WY Shi. 2007a. Changes in the spatial distribution of migratory shorebirds along the Shanghai shoreline, China, between 1984 and 2004. Emu **107:** 19-27.

Ge ZM, X Zhou, WY Shi, TH Wang. 2007b. Carrying capacity of shorebirds at Jiuduansha wetland during the migratory seasons. Acta Ecol. Sin. **27:** 90-96.

González PM. 1996. Food, feeding, and refueling of Red Knots during northward migration at San Antonio Oeste, Rio Negro, Argentina. J. Field Ornithol. **67:** 575-591.

Goss-Custard JD, ME Moser. 1988. Rates of change in the numbers of Dunlin *Calidris alpina*, wintering in British estuaries in relation to the spread of *Spartina anglica*. J. Appl. Ecol. **25:** 95-109.

Goss-Custard JD, RA Stillman, RWG Caldow, AD West, M Guillemain. 2003. Carrying capacity in overwintering bird: When are spatial models needed? J. Appl. Ecol. **40:** 176-187.

Goss-Custard JD, RA Stillman, AD West, RWG Caldow, S McGrorty. 2002. Carrying capacity in overwintering migratory birds. Biol. Conserv. **105:** 27-41.

Guy A, DH Fischer. 1984. Food habitats of fall migrant shorebirds on the Texas high plains. J. Field Ornithol. **55:** 220-229.

Hervey B. 1970. Shorebirds leaving the water to defecate. Auk **87:** 160-161.

Holmes RT, TW Sherry. 2001. Thirty-year bird population trends in an unfragmented temperate deciduous forest: importance of habitat change. Auk **118:** 589-609.

Hotker H. 2000. When do Dunlins spend high tide in flight? Waterbirds **23:** 482-485.

Howes J, D Bakewell. 1989. Shorebird studies manual. Kuala Lumpur: Asian Wetland Bureau Publication **no. 55:** pp. 143-147.

Huang HM, LQ Zhang. 2007. Remote sensing analysis of range expansion of *Spartina alterniflora* at Jiuduansha shoals in Shanghai, China. J. Plant Ecol. **31:** 75-82. (in Chinese with English abstract)

Huang ZY, ZH Shun, K Yu. 1993. Bird resources and habitat in Shanghai. Shanghai, China: Publishing House of Fudan Univ.

Kersten M, T Piersma. 1987. High levels of energy expenditure in shorebirds; metabolic adaptations to an expensive way of life. Ardea **75:** 175-187.

Lawler W. 1996. Wader roost construction in Moreton Bay: a feasibility study into the construction of migratory wader (shorebird) high tide roosts in Moreton Bay, Qld, using Raby Bay as a case study. Mount Glorious, Australia: Queensland Wader Study Group.

Liang SH, BS Shieh, YS Fu. 2002. A structural equation model for physiochemical variables of water, benthic invertebrates, and feeding activity of waterbirds in the Sitsao wetlands of southern Taiwan. Zool. Stud. **41:** 441-451.

Ma ZJ, CY Choi, XJ Gan, S Zheng, JK Chen. 2006. The importance of Jiuduansha wetlands for shorebirds during northward migration: energy-replenishing sites or temporary stages? Stilt **50:** 54-57.

Ma ZJ, XJ Gan, CY Choi, K Jing, SM Tang, B Li, JK Chen. 2007. Wintering bird communities in newly-formed wetland in the Yangtze River estuary. Ecol. Res. **22:** 115-124.

Ma ZJ, K Jing, SM Tang, JK Chen. 2002a. Shorebirds in the eastern intertidal areas of Chongming Island during the 2001 northward migration. Stilt **41:** 6-10.

Ma ZJ, SM Tang, F Lu, JK Chen. 2002b. Chongming Island: a less important shorebird stopover site during southward migration? Stilt **41:** 35-37.

Meire PM, H Schekkerman, PL Meininger. 1994. Consumption of benthic invertebrates by waterbirds in the Oosterschelde estuary, SW Netherland. Hydrobiologia **282-283:** 525-546.

Minton RS. 1982. Report on wader expedition to north west Australia in Aug./ Sept.1981. Stilt **2:** 14-26.

Pei EL, X Yuan, CD Tang, Q Ma, XZ Chen, YY Liu. 2007. Study on the waterbird communities during southward migration in Shanghai. J. Fudan Univ. (Nat. Sci.) **46:** 906-912. (in Chinese with English abstract)

Piersma T, A Koolhaas, A Dekinga. 1993. Interactions between stomach structure and diet choice in shorebirds. Auk **110:** 552-564.

Qing WH, Z Wang, MK Jiang. 2004. Invasion of *Spartina alterniflora* Loisel to two wetland nature reserve in Changjiang estuary. Weed Sci. **4:** 15-16.

Ribeiro PD, OO Iribarne, L Jaureguy, D Navarro, E Bogazzi. 2003. Variable sex-specific mortality due to shorebird predation on a fiddler crab. Can. J. Zool. **81:** 1209-1221.

Rogers DI, T Piersma, CJ Hassell. 2006. Roost availability may constrain shorebird distribution: exploring the energetic costs of roosting and disturbance around a tropical bay. Biol. Conserv. **133:** 225-235.

Rosa S, AL Encarnacao, JP Granadeiro, JM Palmeirim. 2006. High water roost selection by waders: maximizing feeding opportunities or avoiding predation? Ibis **148:** 88-97.

Stillman RA. 2003. Predicting wader mortality and body condition from optimal foraging behaviour. Wader Study Group Bull. **100:** 192-196.

Sun RY. 2001. Animal ecology theory. Beijing: Beijing Normal Univ. Press. (in Chinese)

Sutherland WJ. 2000. The conversation handbook: research, management and policy. Oxford, UK: Blackwell Science Ltd. Edition Offices.

Sutherland WJ, GA Allport. 1994. A spatial depletion model of the interaction between Bean Geese and Wigeon with the consequences for habitat management. J. Appl. Ecol. **63:** 51-59.

Tang CJ, JJ Lu. 2003. Studies on plant community on the Jiuduansha shoals at the Yangtze estuary. Acta Ecol. Sin. **23:** 399-403. (in Chinese with English abstract)

Tulp I, S McChesney, P De Goeij. 1994. Migratory departures of waders from north-western Australia: behaviour, timing and possible migration routes. Ardea **82:** 211-221.

Wang SN. 2003. Wetland utilization and protection. Shanghai, China: Science and Technology Press. (in Chinese)

Wang TH, GZ Qian. 1988. The waders in the Changjiang estuary and the Hangzhou Bay. Shanghai, China: East China Normal Univ. Publishing House. (in Chinese)

Wang TH, XJ Wen, JY Shi, YX Su, LN Yang. 2003. HSBC wetland management training manual. Hong Kong: copyrighted by the World Wide Fund for Nature Reserve.

Weber LM, SM Haig. 1997. Shorebird diet and size selection of nereid polychaetes in South Carolina coastal diked wetlands. J. Field Ornithol. **68:** 358-366.

Wilson JR, MA Barter. 1998. Identification of potentially important staging area for “long jump” migrant waders in the East Asian-Australian flyway during northward migration. Stilt **32:** 16-26.

Yang SL. 1999. Sedimentation on a growing intertidal island in the Yangtze River mouth. Estuar. Coastal Shelf Sci. **49:** 401-410.

Yang SL, M Li, SB Dai, Z Liu, J Zhang, PX Ding. 2006. Drastic decrease in sediment supply from the Yangtze River and its challenge to coastal wetland management. Geophys. Res. Lett. doi: 10.1029/2005GL025507.

Ydenberg RC, RW Butler, DB Lank, CG Guglielmo, M Lemon, N Wolf. 2002. Trade-offs, condition dependence and stopover site selection by migrating sandpipers. J. Avian Biol. **33:** 47-55.

Zheng S, CY Choi, XJ Gan, ZJ Ma, SM Tang, J Zhu. 2006. Shorebirds numbers at the Jiuduansha wetlands during the 2005 southward migration. Stilt **50:** 58-61.

Zhu J, K Jing, X Gan, Z Ma. 2007. Food supply in intertidal area for shorebirds during stopover at Chongming Dontan, China. Acta Ecol. Sin. **27:** 2149-2159. (in Chinese with English abstract)

Zwarts L, AM Blomert. 1990. Selectivity of Whimbrels feeding on fiddler crabs explained by component specific digestibilities. Ardea **78:** 193-208.