

Carrying capacity for shorebirds during migratory seasons at the Jiuduansha Wetland, Yangtze River Estuary, China

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Abstract The carrying capacity of food resources for migrating shorebirds was estimated at a stopover site in the Yangtze River Estuary during the two migratory seasons (spring and autumn). From March to May and September to November 2005, the macrobenthos resources of the Jiuduansha Wetland were investigated, and most of the macrobenthos species in the newly-formed shoal were found to be appropriate food for shorebirds. Biomass measurements showed that the total food resource was about 4541.20 kg AFDW (Ash-Free Dry Weight) in spring and about 2279.64 kg AFDW in autumn. Calculations were also done in the available habitats (intertidal bare mudflat and *Scirpus × mariqueter*/*Scirpus triqueter* zones) for the shorebirds. The food resources in the available areas were about 3429.03 kg AFDW in spring and about 1700.92 kg AFDW in autumn. Based on the classification (by lean weight, basic metabolic rate and body length) of the shorebird community, and using the energy depletion model, it was theorized that all of the food resources in the Jiuduansha Wetland could support about 3.5 million shorebirds during spring season and 1.75 million shorebirds during autumn season. The shorebird carrying capacities in terms of the available food were about 2.6 million and 1.3 million birds during the two respective migration seasons. Considering the effect of intake rate, the potential carrying capacity was about 0.13–0.26 million shorebirds in the study area. The main factor restricting use of the area by shorebirds was the scarcity of available habitats for roosting at high tide rather than availability of food supply. We recommend restoring some wading pools in the dense *Phragmites australis* and *Spartina alterniflora* zones for shorebirds to roost in, to improve shorebirds' utilization efficiency of the resources in the Jiuduansha Wetland.

Keywords Jiuduansha, shorebirds, migratory seasons, carrying capacity

1 Introduction

The potential utilization of a habitat by wildlife can be assessed by determining the carrying capacity of the available resources. The carrying capacity refers to the potential maximum number of wildlife stocks a specific habitat can accommodate. Here, “capacity” implies providing population resources such as food, space and other conditions for survival. This term has recently been widely applied in the evaluation of 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). Assessment of the carrying capacity for wildlife is a valuable tool to guide the management of nature reserves, which play an important role in the maintenance and improvement of protective measures for wildlife (Sutherland and Allport, 1994).

However, there have been few such studies in China. Over 5 million shorebirds pass through the East Asian – Australasian Flyway, and the Yangtze River Estuary is an important stopover site (Barter 2002; Wilson and Barter, 1998; Minton, 1982). The Jiuduansha Wetland (National Nature Reserve) is an important part of the Yangtze River Estuary Wetland, and of global importance for Kentish Plover *Charadrius alexandrinus*, Whimbrel *Numenius phaeopus*, Spotted Redshank *Tringa erythropus*, and Little Ringed Plover *Charadrius dubius* (Barter 2002). It is a typical estuarine shoal island with no human habitation. No shorebirds breed on the island, therefore it provides a suitable study site for the assessment of the carrying capacity during the main migratory seasons (spring and autumn) (Wang and Qian, 1988; Zhou et al., 2005).

2 Methods

The Jiuduansha Wetland belongs to the third generation of recently developed shoal islands in the Yangtze River Estuary (N 31°03′–31°17′, E 121°46′–122°15′) with an east–west width of 50 km and north–south width of 15 km. The area includes the Shangsha shoal (SS), Zhongsha shoal (ZS) and Xiasha shoal (XS) (Fig. 1). The total area exposed is about 145 km² when the tide line is at zero meters at the Wusong Tide Station, and over 200 km² at the –2 m tide line (Wang, 2003). The Jiuduansha Wetland lies in the East Asia monsoon climate belt and has four distinct seasons. The annual mean air temperature is 15°C–16°C, and the annual mean water temperature is 17°C–18°C. The Jiuduansha Wetland is classified as having an irregular half-day tide, and the mean tidal range is 2–3 m. The dominant plant community is composed of *Phragmites australis*, *Spartina alterniflora*, *Scirpus × mariqueter* and *Scirpus triqueter* (Chen, 2003; Tang and Lu, 2003).

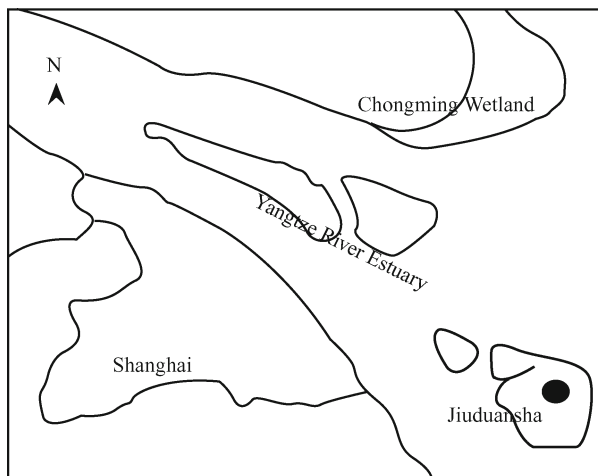


Fig. 1 Location of the Jiuduansha Wetland

2.1 Habitat area calculation

The Landsat-TM satellite image taken at low tide (around zero meters at Wusong Tide Station) in May 2004 was used to characterize the vegetation cover and define the habitats. The image was read using ArcView 3.2, and ground truthing was done before creating habitat vector-graphs. Taking the navigation chart of the South Yangtze River Estuary of 2004 as the geographical reference, we identified the wetland at over 1 m (Wusong Tide Station) and calculated the area of every habitat using ArcView 3.2.

2.2 Macrobenthos collection and biomass estimation

In spring (March–May) and autumn (September–November) 2005, we marked 54 sampling sites distributed among the different habitats; 21 in mudflat zones, 14 in

Scirpus × mariqueter/*Scirpus triqueter* zones, 11 in *Phragmites australis* zones and 8 in *Spartina alterniflora* zones. The topsoil samples were collected with a hand-held PVC pipe which had a diameter of 10 cm, submerged to a depth of 20 cm. Four samples were collected at each site, giving a total area sampled of 0.0314 m². Immediately on site, each sample was sieved (mesh size of 0.5 mm) and the sediment retained was packed in polyethylene bags, preserved with 5% formalin and stained with Rose Bengal. Subsequent sorting and identification were performed in the laboratory according to the methods described in the 7th chapter of the “Survey methods for coastal and seabeach zone biological resources” in the “Technical regulations on comprehensive survey of national coastal and seabeach zone resources.” Our pilot study revealed that the macrobenthos community of the Jiuduansha Wetland is mostly composed of molluscs and crustaceans, based on the number of individuals. The biomass of the macrobenthos was measured as Ash-Free Dry Weight (AFDW) (Howes and Bakewell, 1989; Bessie and Sekaran, 1995). The macrobenthos collected from every soil sample was oven-dried separately at 60°C to constant weight, and then ashed at 600°C for 6 hours.

2.3 Carrying capacity calculation

According to the methods of Meire et al. (1994) for the calculation of macrobenthos biomass consumed by shorebirds in inter-tidal zones, we calculated the total standing crop biomass for (a) the whole island and (b) for those habitats used by shorebirds (mudflat zones and *Scirpus × mariqueter*/*Scirpus triqueter* zones) during the migratory seasons at the Jiuduansha Wetland (spring: March–May; autumn: September – November) (Wang and Qian, 1988; Ge et al., 2006). We then calculated the macrobenthos biomass consumed by shorebirds in the intertidal zone using the following formulae:

$$C = C_1 (\text{mudflat zones}) + C_2 (\text{Scirpus} \\ \times \text{mariqueter/Scirpus triqueter zones}) \\ + C_3 (\text{Phragmites australis zones}) \\ + C_4 (\text{Spartina alterniflora zones}) \quad (\text{F.1})$$

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

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

Based on the bodily form indices – fat-free lean weight (*LW*), basal metabolic rate (*BMR*) and body length (*BL*) – we classified the shorebirds community into three

somatotypes, viz. large-, medium- and small-sized species, and the *BMRs* of the three types of bird groups were estimated. According to data from shorebird surveys in the contiguous wetlands such as the Chongming Dongtan Wetland and wetlands along Shanghai suburbs (Wang and Qian, 1988; Ma et al., 2002a, 2002b; Ge et al., 2006), we determined the shorebird community composition and estimated the gross BMR using the following formulae:

$$\begin{aligned}
 BMR &= BMR_1 \times P \text{ (large - sized species)} \\
 &+ BMR_2 \times P \text{ (medium - sized species)} \\
 &+ BMR_3 \times P \text{ (small - sized species)} \quad (F.4)
 \end{aligned}$$

$$\begin{aligned}
 &P \text{ (large - sized species)} \\
 &+ P \text{ (medium - sized species)} \\
 &+ P \text{ (small - sized species)} = 1 \quad (F.5)
 \end{aligned}$$

Where: *C* – total consumption of macrobenthos by shorebirds (g AFDW); *C_i* – total AFDW of each habitat (g); *AFDW_i* – biomass of each sampling site (g); *A_i* – total area of sampling sites at each habitat (hm²); *r* – radius of PVC collection pipe (5 cm); *D* – number of migrating days (90 d for each season) (Wang and Qian, 1988); *BMR* – basal metabolic rate (kJ/d) (Kersten and Piersma, 1987); *BMR_i* – average basal metabolic rate of each size-type of shorebird group (kJ/d); *P* – percentage of each size-type of

shorebird group (%); *N* – maximum carrying capacity for shorebirds (bird-days); *Q* – assimilation efficiency of the food (0.85) (Kersten and Piersma, 1987; Zwarts and Blomert, 1990); *F* – heat values (22 kJ/g) (Howes and Bakewell, 1989; Zwarts and Blomert, 1990).

3 Results

3.1 Resource status of the macrobenthos at the Jiuduansha Wetland

Based on the classification and calculations using ArcView tools, the areas of different habitat types at the Jiuduansha Wetland above 1 m (at Wusong Tide Station) were: intertidal bare mudflat 3878.01 hm², *Scirpus × mariqueter* / *Scirpus triqueter* zones about 2619.36 hm², *Phragmites australis* zones about 1345.71 hm², and *Spartina alterniflora* zones about 799.54 hm² (Fig. 2 and Table 1).

The total number of organisms recorded was expressed as a % of the total, and the macrobenthos community was dominated by molluscs, crustaceans and annelids (more than 96%, Fig. 3) (Weber L M and Haig S M, 1997; Baker M C, 1977), all of which are potential food for shorebirds (Piersma et al., 1993).

The total macrobenthos biomass of the whole Jiuduansha Wetland was about 4541.20 kg AFDW in

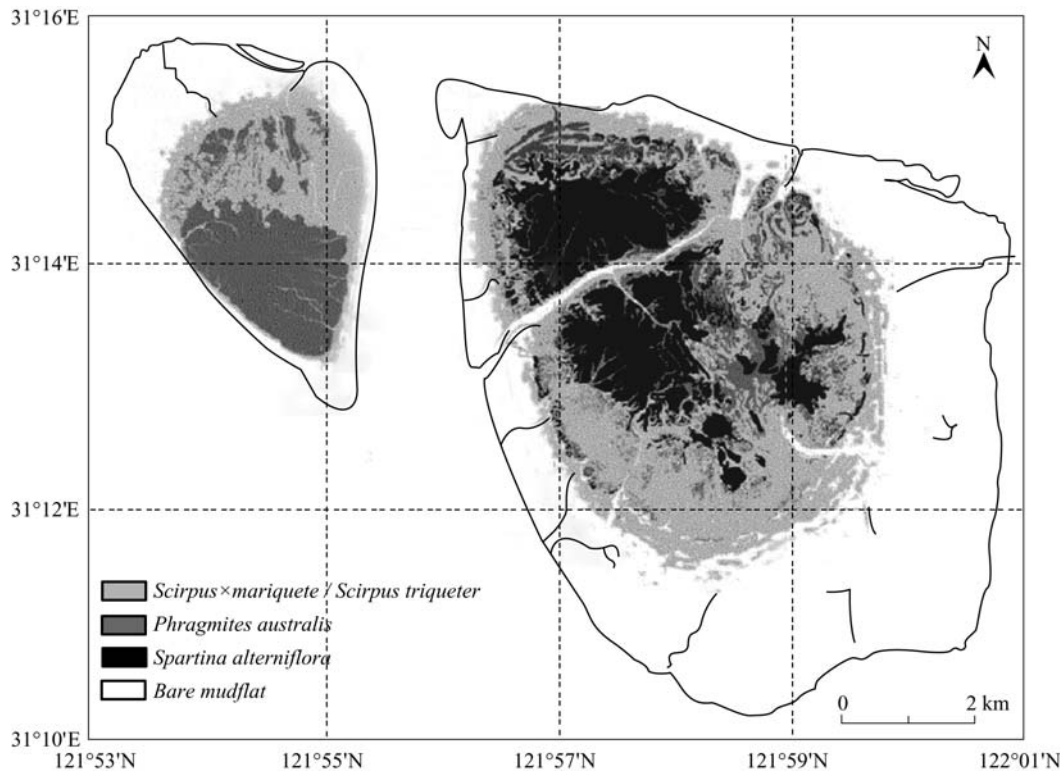


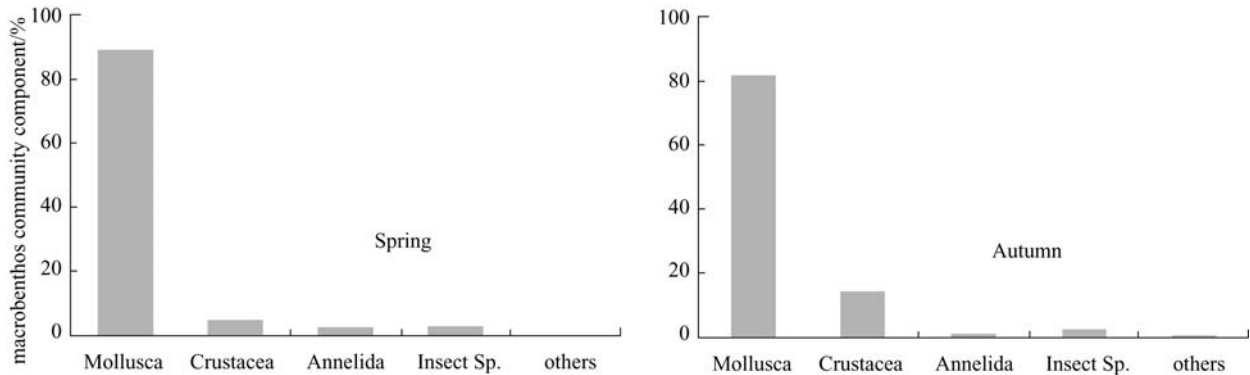
Fig. 2 Habitat classification in the Jiuduansha Wetland (at over 1 m tide line)

Table 1 Area and food mass of each habitat in the Jiuduansha Wetland during spring and autumn

| habitat type | area/hm ² | spring | | autumn | |
|---------------------|----------------------|--------------------------------------|-------------------|--------------------------------------|-------------------|
| | | AFDW _i /g·m ⁻² | C _i /g | AFDW _i /g·m ⁻² | C _i /g |
| bare mudflat | 3878.01 | 64.37 ± 60.86 | 2496275.04 | 20.72 ± 13.10 | 803523.67 |
| bulrush | 2619.36 | 35.61 ± 26.15 | 932754.10 | 34.26 ± 20.52 | 897392.74 |
| reed | 1345.71 | 23.13 ± 22.26 | 311262.72 | 14.73 ± 8.87 | 198223.08 |
| <i>Spartina</i> sp. | 799.54 | 100.17 ± 55.49 | 800899.22 | 47.59 ± 34.81 | 380501.09 |
| available habitats* | 6497.37 | – | 3429029.14 | – | 1700916.41 |
| sum | 8642.42 | – | 4541191.08 | – | 2279640.58 |

* Available habitats for shorebirds: Bare mudflat and Bulrush zones.

AFDW_i: The food mass in the samples; C_i: The food mass in each habitat.

**Fig. 3** Macrobenthos community components in the Jiuduansha Wetland during spring and autumn (density percentage)

spring and about 2279.64 kg AFDW in autumn. Considering only the habitats suitable for shorebird foraging (mudflat and *Scirpus × mariqueter*/*Scirpus triquetra* zones), the biomass of the macrobenthos was about 3429.03 kg AFDW in spring and 1700.92 kg AFDW in autumn (Table 1).

3.2 Classification of shorebird community and gross basic metabolic rate estimation

As shown in Table 2, based on the bodily form indices *LW*, *BMR* and *BL*, we classified the shorebird community into three somatotypes, viz. large (*LW* > 0.4 kg, *BL* > 40 cm), medium (0.4 kg > *LW* > 0.1 kg, 40 cm > *BL* > 24 cm) and small-sized species (*LW* < 0.1 kg, *BL* < 24 cm).

In the Yangtze River Estuary area, published results have reported that the shorebird community is composed of large (10%), medium (20%), and small-sized (70%) birds in spring; in autumn it is composed of large (5%), medium (35%), and small-sized (60%) birds (Table 3). Using formula 4, the average BMR of shorebirds at the Jiuduansha Wetland was estimated to be 90.50 kJ/d in spring and 90.25 kJ/d in autumn.

3.3 Carrying capacity for shorebirds

Using formula 3, at areas over the 1 m line (Wusong Tide Station), the maximum carrying capacity for shorebirds supported by the total macrobenthos in all habitats at the

Table 2 Classification of the shorebirds by bodily form

| species | lean weight/kg | BMR/kJ·d ⁻¹ | body length/cm | somatotype |
|----------------------------------|----------------|------------------------|----------------|----------------------|
| <i>Charadrius alexandrinus</i> | 0.05 | 49 | 15 | small-sized species |
| <i>Calidris alpina</i> | 0.05 | 49 | 19 | |
| <i>Charadrius hiaticula</i> | 0.05 | 49 | 19 | |
| <i>Calidris alba</i> | 0.05 | 49 | 20 | |
| <i>Arenaria interpres</i> | 0.08 | 69 | 23 | |
| <i>Calidris canutus</i> | 0.14 | 104 | 24 | medium-sized species |
| <i>Tringa nebularia</i> | 0.18 | 125 | 32 | |
| <i>Tringa totanus</i> | 0.14 | 104 | 28 | |
| <i>Tringa erythropus</i> | 0.14 | 104 | 30 | |
| <i>Limosa lapponica</i> | 0.27 | 168 | 40 | |
| <i>Phuivialis squatarola</i> | 0.19 | 130 | 28 | |
| <i>Recurvirostra avosetta</i> | 0.24 | 154 | 43 | |
| <i>Numenius madagascariensis</i> | 0.70 | 337 | 63 | large-sized species |
| <i>Haematopus ostralegus</i> | 0.53 | 275 | 44 | |
| <i>Numenius phaeopus</i> | 0.41 | 228 | 43 | |

This data is from Meire et al. (1994); the species listed above do not represent the whole species group surveyed in the Jiuduansha Wetland, but only the species with published available data on lean weight and BMR.

Jiuduansha Wetland was 3475353.93 individuals in spring and 1749431.78 individuals in autumn. However, taking into account only the biomass in those habitats suitable for foraging waders, the carrying capacity was 2624221.20 individuals in spring and 1305309.81 individuals in autumn.

Table 3 Community component and BMR of the shorebirds in the Jiuduansha Wetland

| somatotype community | BMR _i /kJ·d ⁻¹ | proportion in spring (%) | proportion in autumn (%) |
|----------------------|--------------------------------------|--------------------------|--------------------------|
| large-sized species | 280 | 10 | 5 |
| medium-sized species | 127 | 20 | 35 |
| small-sized species | 53 | 70 | 60 |

Consumption of the total macrobenthos:

$$\text{Spring : } N = \frac{4541191.08 \times 0.85 \times 22}{90 \times 3 \times 90.50} \times 1000$$

$$= 3475353.93$$

$$\text{Autumn : } N = \frac{2279640.58 \times 0.85 \times 22}{90 \times 3 \times 90.25} \times 1000$$

$$= 1749431.78$$

Consumption of the macrobenthos in available habitats:

$$\text{Spring : } N = \frac{3429029.14 \times 0.85 \times 22}{90 \times 3 \times 90.50} \times 1000$$

$$= 2624221.20$$

$$\text{Autumn : } N = \frac{1700916.41 \times 0.85 \times 22}{90 \times 3 \times 90.25} \times 1000$$

$$= 1305309.81$$

4 Discussion

4.1 Factors affecting the carrying capacity

Assessment of the value of habitats for wildlife with respect to the available food resource is direct and objective. One important measure is to estimate the carrying capacity for wildlife supported by the resources. We found that during the migration seasons, the total food resource could maintain 1.75–3.50 million shorebirds at the Jiuduansha Wetland, while the capacity was 1.30–2.60 million when taking into account the resources only in the available habitats.

According to previous research, the feeding mass of small-sized shorebirds was about 8.60 g AFDW/d (González et al., 1996), that of *Calidris canutus* was 0.433 mg AFDW/s (González et al., 1996), that of *Haematopus ostralegus* was 0.67–0.87 mg AFDW/s (Caldow et al., 2004), that of *Numenius madagascariensis*, one of the largest-sized shorebirds, was 2.5–3.6 mg AFDW/s (Zharikov and Skilleter, 2004), and that of some medium-sized shorebirds was in the range of 20.57 to 45.00 g AFDW/d (Meire et al., 1994).

Based on long-term surveys on shorebirds at the Yangtze River Estuary, it is evident that the distribution of shorebirds along the estuary area was uneven. The total density of shorebirds was low. There were great differences in feeding and inhabiting niches between shorebirds and other waterbirds (such as *Ardeidae*, *Anatidae*) (Wang and Qian, 1988; Zhou et al., 2005). Therefore, the effect of intake rate was considered preferentially in determining the carrying capacity for shorebirds at the Jiuduansha Wetland, which has had minimal man-made disturbance.

According to previous reports, the amount of food consumption by shorebirds is about 13%–23% in the breeding regions, and about 12% in the over-wintering regions (Meire et al., 1994; Goss-Custard et al., 2003). The feeding intensity is usually higher in breeding / over-wintering areas than in stopover sites. The Jiuduansha Wetland and other contiguous wetlands at the Yangtze River Estuary are the stopover sites for shorebirds during the migration process. Therefore, the intake rate of shorebirds at the Jiuduansha Wetland could be assumed to be about 10%, by which the shorebird carrying capacity that could be supported by the available habitats is 0.13–0.26 million.

4.2 Implications for nature reserve management

The foremost task of conservation biology is to identify the biological richness and assess the value of different regions in order to determine the priority protection areas and undertake various protection measures for wildlife (Sutherland, 2000). There are abundant macrobenthos resources at the Jiuduansha Wetland, which could support theoretically about 0.13–0.26 million shorebirds during the migration seasons. With such a huge number, the Jiuduansha Wetland may meet the criteria of wetlands of international importance (An area that holds over 20000 waterbirds or more than 1% of the individuals in the population of a species of waterbirds – “The Ramsar Convention”). Therefore, how to make the Jiuduansha Wetland hold this number of shorebirds is a key problem that needs to be solved urgently for this nature reserve.

The Yangtze River has been carrying billions of tonnes of sediment which have been deposited at the east estuary, resulting in the appearance of the Jiuduansha Wetland as an island for already about 50 years. In 1997, a large amount of *Phragmites australis* and *Spartina alterniflora* were planted in the wetland (Chen et al., 2001), and the habitat classification map of the Jiuduansha Wetland in 2004 showed that there were large areas of *Phragmites australis* and *Spartina alterniflora* covering the up-tide land (Fig. 2).

Morphological and behavioral research have suggested that shorebirds cannot feed and roost in an area with dense and high vegetation (such as *Phragmites australis*

and *Spartina alterniflora*), but rather favor the habitats of mudflats and *Scirpus × mariquete* / *Scirpus triqueter* zones (Hervey, 1970; Wang et al., 2003; Ge et al., 2006). The *Spartina alterniflora* was an introduced species useful in sedimentation and wave-damping, however, its overspreading could invade the mudflat area and other areas of native plants. Already, the available habitats for shorebirds have shrunk severely (Chen et al., 2004). In addition, the highest elevation of the Jiuduansha Wetland is about 3.5 m. Most of the areas of mudflat and *Scirpus × mariquete* / *Scirpus triqueter* zones at the low tide line would be inundated during high tide periods. Relevant research showed that the shorebirds would fly to the up-tide land of the wetlands when tides rose up (Wang et al., 2003). However, the dense *Phragmites australis* and *Spartina alterniflora* clusters have reduced the available habitats for shorebirds, and the available useful habitats for shorebirds at the Jiuduansha Wetland has decreased. Consequently, the actual number of shorebirds did not reach the carrying capacity estimated above despite the rich macrobenthos resources.

In accordance with the behavioral characteristics of shorebirds, plants in the up-tide land could be adjusted and managed under the prerequisite of not effecting sedimentation and wave-damping by the peripheral *Phragmites australis* and *Spartina alterniflora* clusters. Measurements should be taken to develop a certain area of mudflats and wading pools (2–5 cm water level) in the up-tide land to increase the area of available habitats for shorebirds and to improve the utilization efficiency of the resources by the shorebirds in the Jiuduansha Wetland.

Acknowledgements This study was sponsored by the National Technology Support Program (No. 2006BAC01A14), Shanghai Technology & Science Administration Key Project (No. 06DZ12303), and Shanghai Educational Development Foundation. We thank the reviewers of *Acta Ecologica Sinica* for assisting with editing and for providing helpful comments on this paper.

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