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Are artificial wetlands good alternatives to natural wetlands for waterbirds? – A case study on Chongming Island, China

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Abstract. Loss of natural wetlands is a global phenomenon that has been a serious threat to the wildlife. A common practice is to construct artificial wetlands to compensate for the loss of natural wetlands. To test whether artificial wetlands as habitats for waterbirds are good alternatives to natural wetlands, we compared species richness, abundance, and seasonal dynamics of waterbird communities of natural (here tidelands) and artificial wetlands (here aquacultural ponds) on Chongming Island, China. Our results indicate that habitat preference of waterbirds showed seasonal difference: most of the shorebirds were found on tidelands in spring, whereas most of the natatorial birds were recorded in aquacultural ponds in winter. Waterbirds preferred the tidelands rather than aquacultural ponds in both spring and autumn, whereas they showed no preference for either the tidelands or the ponds in summer and winter. It is concluded that natural wetlands are better habitats for waterbirds than artificial wetlands on Chongming Island, while the artificial ones are also suitable habitats for waterbirds in winter. The waterbirds might use artificial wetlands only when natural wetlands are unavailable or of poor quality. An over-emphasis that artificial wetlands are suitable habitats for waterbirds might encourage land managers to convert natural wetlands into the artificial ones, resulting in considerable loss of bird diversity. Therefore, for the purpose of bird conservation, it would be a better practice to conserve natural wetlands rather than to construct artificial ones after destruction of natural wetlands.

Introduction

Globally, natural wetlands are under heavy pressure with the intensification of human activities and environmental changes (Turner et al. 2000; Froneman et al. 2001). Over recent decades, a large area of natural wetlands has been lost, degraded or transformed, thus artificial wetlands are being created for the purpose of biodiversity conservation worldwide (Lu 1990; Kennish 2001; Tourenq et al. 2001). Many studies (e.g. Ogden 1991; Streever et al. 1996; Duncan et al. 1999; West et al. 2000) have compared the properties of natural and artificial wetlands that are used as the habitats for waterbirds. While most of these studies (e.g. Ogden 1991; Elphick and Oring 1998; Guillemain et al. 2000) have drawn the conclusion that artificial wetlands can provide suitable habitats for waterbirds during wintering, migrating, and even breeding periods, another possibility may also exist that natural wetlands have special functions for waterbirds, and hence may not be replaced by artificial types. Compared with artificial wetlands, natural wetlands may support greater numbers of birds (species and abundance) (e.g. Ma et al. 1999; Tourenq et al. 2001). Nevertheless, the debate continues.

Here, we report a case study that was conducted at the estuary of Yangtze River in Eastern China. This region used to host a spectacular array of natural wetlands, including lakes, marshes (including seasonally flooded marshes), and tidelands (Lu 1990). However, rapid urbanization has transformed most of the natural wetlands in this region (Scott 1989). Some natural wetlands disappeared completely due to reclamation of wetlands for agriculture and expansion of towns; some were degraded in quality due to environmental pollution; and some were changed to artificial wetlands such as paddy fields, aquacultural ponds, reservoirs and irrigation canals (Lu et al. 1998). For economic reasons, aquaculture expanded rapidly in the past decades, and has become the most important industry of the region (Yang 1998). According to the 2000 data, the area of aquacultural ponds on Chongming Island was about 105.1 km^2, equivalent to 10% of the total area of Chongming Island (Shanghai Statistical Bureau 2001).

Chongming Island, with an area of more than 1200 km^2, is the third largest island in China and the largest alluvial island in the world (Huang et al. 1993). Sedimentation of silts brought by the Yangtze River keeps Chongming Island extending eastwards to the sea. The current speed of extension is about 150 m per year at Dongtan on Chongming Island. Consequently, the area of Chongming Island is increasing by 5 km^2 per year. Simultaneously, local people built dykes and reclaimed the tidelands for the purpose of land resources since 1950. Though the tidelands keep growing, the speed of reclamation is much faster than that of natural growth of tideland. In the past decades, about 200 km^2 of tidelands were reclaimed. The width of the tidelands in the east of Chongming Island was changed from about 13 km in 1990 to about 4 km in 2000 after having been reclaimed three times in the 1990s (Huang et al. 1993; Jing et al. 2002). The most recent reclamation was carried out in 1998, during which 66 km^2 of tidelands were enclosed for various purposes. Most of the land reclaimed in 1998 was converted to aquacultural ponds (fishponds and crab ponds).

Chongming Island is located in the middle part of the East Asian–Australasian Flyway of migratory birds. It is an important stopover site for shorebirds. It is also an emergency ground for migrants under unfavorable weather conditions (Barter et al. 1997). In addition, Chongming Island is a wintering ground for waterbirds, including some rare and endangered species, such as *Grus monacha* and *Cygnus columbianus* (Zheng and Wang 1998). The total number of migrants on Chongming Island was more than one million each year in the early 1990s (Huang et al. 1993).

Chongming Island is of significance for the conservation of waterbirds. Unfortunately, intensive reclamation of tidelands for various purposes resulted in a considerable loss of natural wetlands. Most of the natural wetlands are currently located outside the dyke built in 1998 at Dongtan, Chongming Island with a total area of about 100 km^2. With further development of tidelands in the near future, artificial wetlands at Dongtan will be the major component of the wetland ecosystem. When natural wetlands are replaced by the artificial ones, a relevant question that will arise is: are artificial wetlands as good as the natural ones in relation to conservation of bird diversity? This study was aimed at answering this question through comparing species richness, abundance, and seasonal dynamics of waterbird communities of natural (here tidelands) and artificial wetlands (here aquacultural ponds) on Chongming Island. In addition, the implications of this study for the conservation of bird diversity are also discussed.

Materials and methods

Study area

This study was conducted at Dongtan, which is located at 31°25′–31°38′ N, 121°50′–122°05′E. Our observations were made on tidelands outside the dykes built in 1998 and the aquacultural ponds inside the dyke (see Figure 1).

Located at the estuary of Yangtze River, the tidelands are affected by tidewater frequently. The tide on Chongming Island is semidiurnal. There are two periods of ebb and flood tides during a day. The width of tidelands uncovered by tidewater is

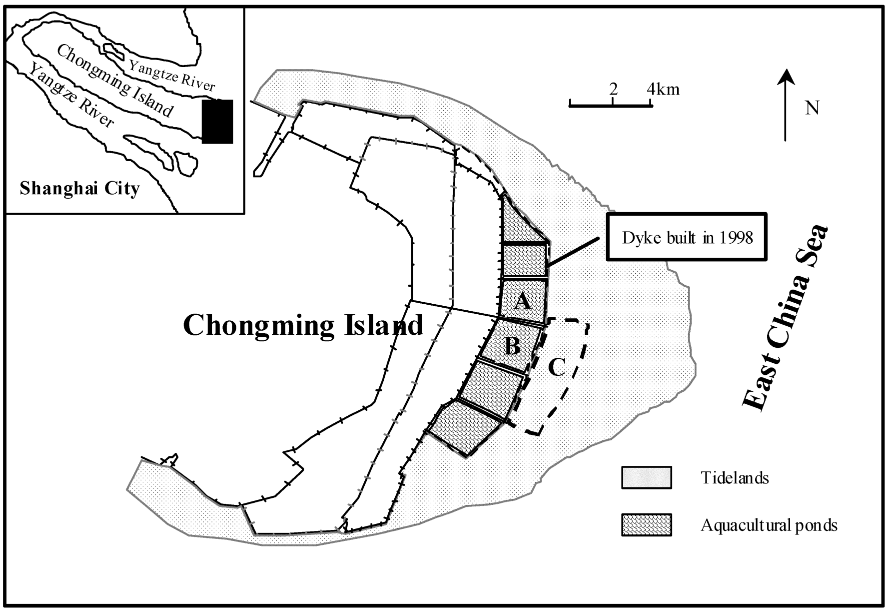


Figure 1. The location of the study area. The inset shows the study area at the estuary of the Yangtze River. Two blocks of aquacultural ponds (A and B) and one block of tidelands (C) were selected as representatives of artificial and natural wetlands, respectively.

about 1.5 km during neap tide, whereas almost all the tidelands are submerged by the tidewater during spring tide. Most of the waterbirds stay in high sites near the dyke at the spring tide. Frequent human disturbance, e.g. grazing, catching crabs, fish, seashell and eel fry, occurs on tidelands and in the nearby area at neap tide.

Fishery is the major component of aquaculture in the aquacultural ponds we surveyed. Water in aquacultural ponds is regularly drawn from a watercourse connecting directly to the estuary of the Yangtze River in March. After that, fry are put in ponds. From April to October, the depth of the water in aquacultural ponds is normally 50–70 cm for cultivating fish. Each year at the end of October, the ponds are dewatered and fish are harvested. In winter, most aquacultural ponds are dry and only shallow water remains in the lower parts of the ponds. Enclosed by dykes, aquacultural ponds are not affected by the tidal rhythms. Except for recruiting fry, giving forage and harvesting fishes, other events rarely occur in aquacultural ponds.

The dominant plant species on tidelands is sea-bulrush (*Scirpus mariqueter*); its seeds and corms are main food resources of waterbirds (Yu 1991; Yu et al. 1991). The dominant plant species in aquacultural ponds is reed (*Phragmites australis*). There is a large area of bare tidelands at the seaside end. The salinity of tidewater was about 0.6 g l^{-1}(Huang et al. 1993). Since the water in aquacultural ponds is drawn from the irrigation canals connecting to the estuary of the Yangtze River, the physical and chemical properties of water in aquacultural ponds were at least initially similar to those in the tidelands.

In order to minimize the influence of difference in area between natural and artificial wetlands, the area of selected tidelands was equal to that of selected aquacultural ponds in the study area. The area for both was 8 km^2 (measured using GPS 12XL, GARMIN International, Olathe, Kansas, USA; see Figure 1).

Waterbird survey

Bird surveys were carried out during sunny weather at 15–20 day intervals from October 2000 to October 2001. A total of 22 surveys were made both on tidelands and in aquacultural ponds, of which seven surveys were conducted in winter and five in each of the other three seasons. Each survey lasted for 4–5 h starting 1 h after sunrise. The aquacultural ponds and the tidelands were investigated on consecutive days. We counted waterbird species and their abundances as listed by Rose and Scott (1997). During each survey, we walked around the ponds along the pond levees to count birds. In addition, we searched for waterbirds in aquacultural ponds for 5–10 min on the pond levees. For tidelands, we walked on them at neap tide and counted waterbirds on the dykes at spring tide.

Flushed birds were included in our records. Birds hovering (e.g. egrets, gulls and terns) for more than 3 min were also included. However, those just passing overhead were excluded. It was difficult to distinguish between the different species of *Gallinago* in the field. We treated them as a single species in our records, though there are four species (*Gallinago gallinago, G. stenura, G. megala* and *G. solitaria*) according to historical records (Huang et al. 1993).

Data analysis

Four seasons were classified according to the patterns of passing and wintering migrants on Chongming Island and in surrounding areas (Wang and Qian 1988; Huang et al. 1993): spring (mid-March to mid-May), summer (mid-May to mid-August), autumn (mid-August to early November) and winter (early November to mid-March). The data of species richness and abundance were summarized for each of the four seasons.

Because not all species had equal detectability in different habitats and in different seasons, we used the COMDYN program (Hines et al. 1999) to compare the species richness between tidelands and aquacultural ponds. The estimators of COMDYN have been described in detail by Boulinier et al. (1998) and Nichols et al. (1998). The species richness was estimated using a jackknife estimator, which assumes that the detectability among species was heterogeneous (Burnham and Overton 1978, 1979).

The parameters considered in this paper are defined as follows: S_w and S_p are the respective observed numbers of species in natural wetlands and aquacultural ponds; N_w and N_p are the respective estimated numbers of species in natural wetlands and aquacultural ponds; λ, the relative species richness calculated by N_w/N_p; λ', an alternative form of λ, calculated by S_w/S_p when the detectability is not significantly different between the two groups compared; B_w and B_p are the respective numbers of exclusive species in natural wetlands and aquacultural ponds.

The bird abundance is also an important factor that characterizes waterbird communities. A Kolmogorov–Smirnov Z test (Li and Wang 1997) was used to compare the difference in abundance of each species between tidelands and aquacultural ponds for each season. Data analyses were performed using the software package SPSS 10.0 for Windows.

Results

A total of 78 waterbird species were identified on tidelands and in aquacultural ponds over the study period, which made a total of 120 113 waterbirds (see Appendix 1). Of all the birds, 100 667 (83.8%) were recorded on tidelands, and 19 446 (16.2%) in aquacultural ponds, indicating that most of the birds selected the tidelands rather than the aquacultural ponds. Bird abundance varied seasonally (Figure 1, Appendix 1). On the tidelands, most waterbirds were recorded in spring (85 061, i.e., 84.5% of the birds recorded on tidelands), while in aquacultural ponds most waterbirds were recorded in winter (13 922, 71.6% of the birds recorded in aquacultural ponds). More waterbirds were found on tidelands than in aquacultural ponds in spring and autumn (t-test, $P < 0.05$). However, it appeared that the number of waterbirds found on tidelands and in aquacultural ponds did not show a significant difference both in summer and winter (t-test, $P > 0.1$) (Figure 2a).

Species abundance patterns for both types of wetlands are given in Figure 3. On the tidelands, *Larus argentatus* was most abundant, accounting for 46.7% of the

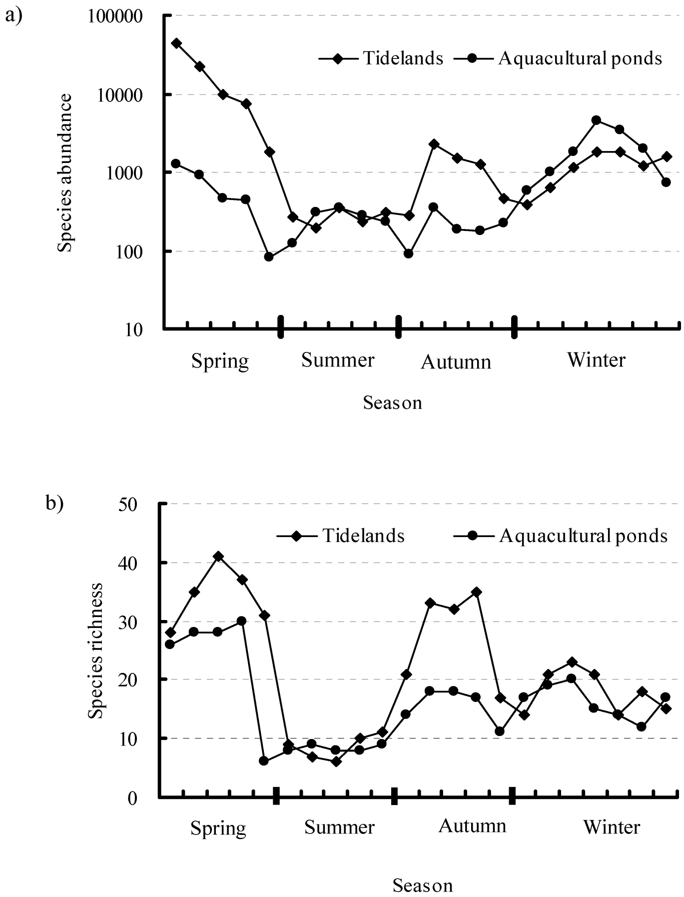


Figure 2. Seasonal variation in species abundance (a) and richness (b) of waterbirds from October 2000 to October 2001.

total birds found; and a subset of four species (*Calidris alpina, Charadrius alexandrinus, Calidris tenuirostris* and *Larus ridibundus*) comprised another 34.1%. It should be noted that these five species were represented either by low abundance or were absent in aquacultural ponds (Appendix 1). The remaining 19.2% were shared among 67 species. *Anas crecca* was the most abundant species in aquacultural ponds, accounting for 33.8% of the total birds found; and *Anas platyhynchos, A. poecilorhyncha*, and *Egretta intermedia* represented 43.5%. Other species were all of low abundance.

Of all 78 species, 72 were found on tidelands and 58 in aquacultural ponds. A regression analysis of the number of species on the tidelands against that in aquacultural ponds showed a significant linear relationship with an intercept of 4.04 and a slope of 1.11 ($R = 0.74$, $n = 22$, $P < 0.0001$), indicating that species richness was obviously higher on tidelands than in aquacultural ponds. The species richness

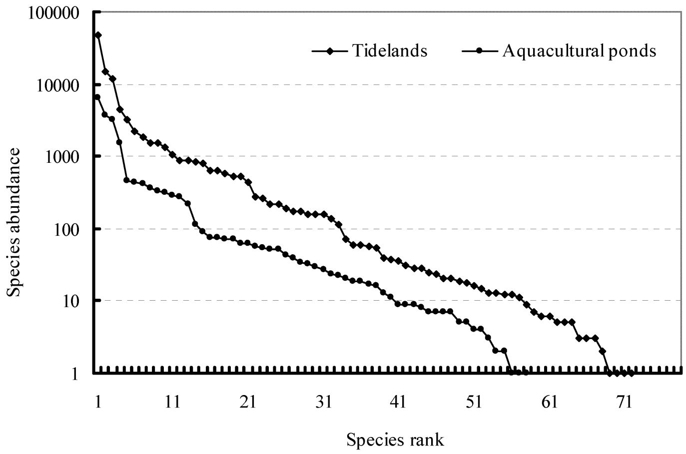


Figure 3. Relative species abundance of waterbirds on tidelands and in aquacultural ponds.

Table 1. Observed and estimated numbers of species on tidelands and in aquacultural ponds.

Habitat type	Spring		Summer		Autumn		Winter	
	S_i	$N_i \pm$ SE	S_i	$N_i \pm$ SE	S_i	$N_i \pm$ SE	S_i	$N_i \pm$ SE
Tidelands	56	60.67 ± 5.63	15	16.91 ± 4.19	50	57.44 ± 5.43	28	28.52 ± 2.58
Aquacultural ponds	46	53.2 ± 5.51	11	11.80 ± 0.9	34	44.53 ± 8.45	27	29.44 ± 2.20

also varied among the seasons: higher species richness was observed on tidelands in spring and autumn than in aquacultural ponds, whereas similar species richness occurred on tidelands and aquacultural ponds in summer and winter. Though the detectability of waterbirds varied between tidelands and aquacultural ponds, the estimated number of species was less in aquacultural ponds (N_P) than on tidelands (N_W) in spring, summer, and autumn, whereas similar estimated species richness occurred in winter (Table 1). The relative species richness also showed a similar pattern to that of the estimated number of species (Figure 4).

Waterbirds with different ecological habits showed their preferences for different types of wetlands. Most waders (shorebirds, cranes, and gulls) selected the tidelands, whereas most natatorial birds (Podicipediformes, Pelecaniformes and Anseriformes) showed a preference for aquacultural ponds. It appeared that both tidelands and aquacultural ponds were suitable for birds in Ardeidae (Appendix 1).

Over the study period, 20 waterbird species were found exclusively on tidelands (Appendix 1). In particular, *Calidris alpina* and *C. tenuirostris* were among the very abundant species on tidelands. Thus, aquacultural ponds were not suitable for them. In contrast, only six species were found exclusively in aquacultural ponds. These species were: *Phalacrocorax carbo*, *Tadorna ferruginea*, *Aix galericulata*, *Fulica atra*, *Charadrius dubius* and *Himantopus himantopus*. If seasonal variation was taken into account, more exclusive species might be identified on tidelands in spring, summer and autumn, whereas the number of exclusive species on tidelands

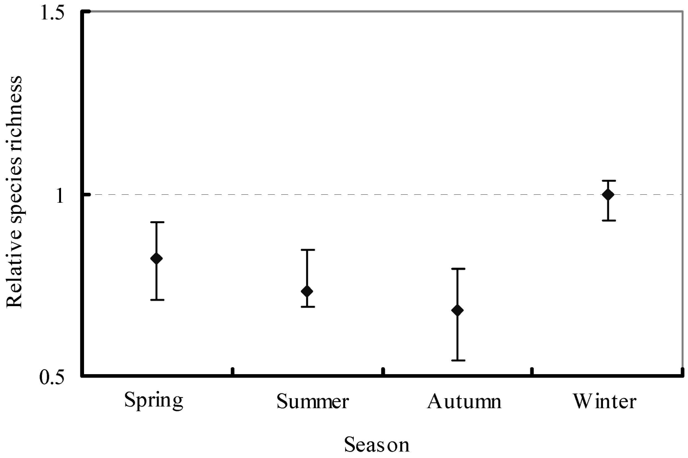


Figure 4. Relative species richness ($\lambda \pm 95\%$ CI) of waterbirds on tidelands and in aquacultural ponds in each season. A value of 1.0 means no difference in species richness between tidelands and aquacultural ponds. A value less than 1.0 means higher species richness on tidelands than in aquacultural ponds.

was the same as that in aquacultural ponds in winter (Figure 5a). When the different detectability of waterbirds was considered, the estimated number of species exclusive on tidelands was also greater than that exclusive in aquacultural ponds in spring, summer and autumn. However, the estimated number of exclusive species for aquacultural ponds was greater than that on tidelands in winter (Figure 5b).

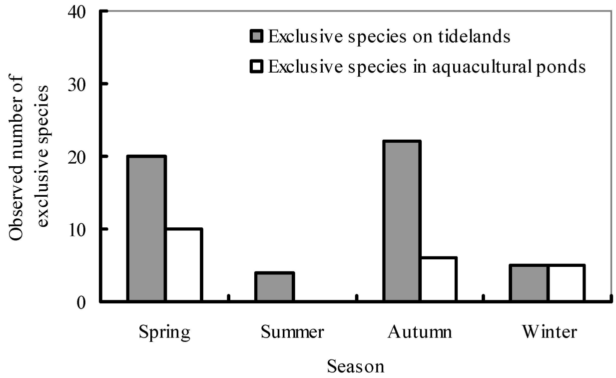
There were 11, 10 and 5 species for spring, autumn and winter respectively, which had significantly higher species abundance on tidelands than in aquacultural ponds (Z test, $P < 0.05$). In contrast, only 4, 1 and 2 species had significantly higher species abundance in aquacultural ponds than on tidelands, respectively for the three seasons (Z test, $P < 0.05$). No significant difference in species abundance between tidelands and aquacultural ponds was found in summer (Table 2).

Discussion

Wetland type and waterbird diversity

The results obtained from this study show that species abundance and richness of waterbirds both were higher on tidelands than in aquacultural ponds, while considerable variation was observed among the seasons. We could conclude that natural wetlands (tidelands) were better habitats for waterbirds than artificial wetlands on Chongming Island, whereas the artificial ones (aquacultural ponds) were also suitable habitats for certain waterbirds, especially in winter.

Most waterbirds were found in spring, autumn and winter in our study area. This was related to the special geographical position of Chongming Island. Chongming Island is located in the southern part of the north subtropics. It is an important a)



b)

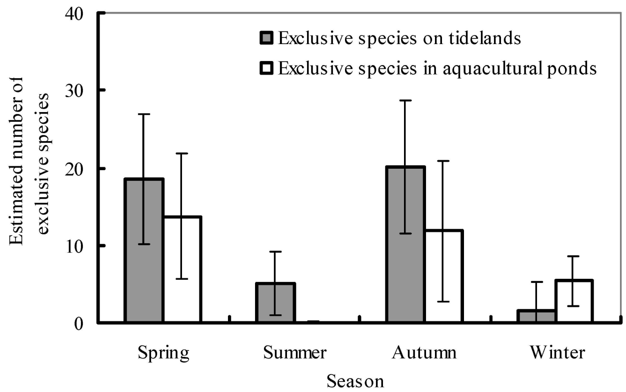


Figure 5. Observed number of exclusive species (a) and estimated number of exclusive species (b, B_i ± SE) on tidelands and in aquacultural ponds for each season.

stopover site during birds' migration and a suitable habitat in winter for waterbirds (Wang and Qian 1988). Only a small number of summer migrants and residents occurred in this region (Huang et al. 1993). Consequently, shorebirds (passing migrants) were most common in spring and autumn during their migration period, and natatorial birds (wintering migrants) occurred in winter on Chongming Island. Comparatively, fewer waterbirds stayed there in summer.

The tide rhythms greatly affected the distribution of waterbirds. The ebb and flow of tidewater created good feeding conditions for shorebirds on tidelands (Straw 1997), especially for *Calidris* sp., the dominant species in our study area. They moved around with regularly rising and falling tide on tidelands. Different water depths on tidelands and in aquacultural ponds also affected the distribution of waterbirds (Colwell and Taft 2000; Isola et al. 2000). Our results showed that some birds, e.g. *Tachybaptus ruficollis*, *Charadrius dubius*, *Himantopus himantopus*, and most ducks were recorded in aquacultural ponds with absolute majority. This implies that these waterbirds preferred aquacultural ponds to tidelands as their

Table 2. Bird species whose abundances were significantly different on tidelands and in aquacultural ponds ($P < 0.05$). The value shows the average ± SD.

Scientific name	Species abundance	
	Tidelands	Aquacultural ponds
Spring (n = 5)		
Tachybaptus ruficollis (−)	0	4.20 ± 2.77
Platalea minor (−)	0	6.80 ± 4.76
Aythya baeri (−)	0	4.00 ± 5.10
Pluvialius squatarola (+)	2.40 ± 2.30	0
Pluvialius dominica (+)	1.60 ± 1.14	0
Numenius arquata (+)	37.80 ± 20.9	2.80 ± 3.90
Calidris canutus (+)	2.40 ± 2.88	0
Calidris tenuirostris (+)	893.40 ± 655.83	0
Calidris ruficollis (+)	102.20 ± 113.14	0
Calidris acuminata (+)	283.40 ± 233.29	0
Calidris alpina (+)	2836.40 ± 1363.51	0
Calidris ferruginea (+)	203.40 ± 173.92	0
Limicola falcinellus (+)	14.00 ± 10.77	0
Himantopus himantopus (−)	0	4.40 ± 4.72
Sterna hirundo (+)	57.40 ± 49.46	0
Autumn (n = 5)		
Tachybaptus ruficollis (−)	0	1.40 ± 1.14
Charadrius leschenaultii (+)	2.40 ± 3.36	0
Numenius arquata (+)	16.20 ± 14.58	1.20 ± 2.68
Limosa limosa (+)	15.40 ± 17.6	0
Limosa lapponica (+)	11.80 ± 9.04	0
Calidris tenuirostris (+)	11.20 ± 11.8	0
Calidris ruficollis (+)	25.60 ± 32.55	0
Calidris acuminata (+)	19.80 ± 19.45	0
Calidris alpina (+)	99.20 ± 68.03	0
Limicola falcinellus (+)	23.40 ± 22.85	0
Glareola maldivarum (+)	7.20 ± 11.34	0
Winter (n = 7)		
Tachybaptus ruficollis (−)	0	4.43 ± 3.51
Tadorna tadorna (+)	7.57 ± 9.36	0.43 ± 1.13
Anas strepera (−)	1.86 ± 3.48	45.86 ± 16.61
Grus grus (+)	1.14 ± 1.07	0
Grus monacha (+)	83.14 ± 37.36	0
Larus crassirostris (+)	90.57 ± 94.68	5.29 ± 9.88
Larus canus (+)	76.86 ± 88.91	3.86 ± 6.64

(+): Bird species that showed significantly higher abundance ($P < 0.05$) on tidelands than in aquacultural ponds. (−): Bird species that showed significantly higher abundance ($P < 0.05$) in aquacultural ponds than on tidelands.

habitats. According to the historical records, these species also occurred in aquacultural ponds with shallow water (Huang et al. 1993).

Food resources have crucial effects on the habitat selection of waterbirds (Cody 1985). The corms of sea-bulrush on tidelands were the most important food source for *Grus monacha* and *Cygnus columbianus* (Yu et al. 1991). *Grus monacha* stayed on tidelands during the daytime, whereas they roosted in weedy lands with shallow water inside the dykes only at night. We did not find *Cygnus columbianus* roosting in aquacultural ponds on Chongming Island, though there were records of *Cygnus columbianus* in the ponds at other wintering grounds (Zheng and Wang 1998). This indicates that tidelands on Chongming Island are important habitats for some rare waterbirds, such as *Grus monacha* and *Cygnus columbianus*.

Our results showed that most waterbirds selected aquacultural ponds rather than the tidelands in winter. There are at least two reasons for that. First, this is related to the diurnal activities of waterbirds. The seeds of sea-bulrush on tidelands were the major food of natatorial birds, which were the major component of waterbird communities in winter (Huang et al. 1993). These birds foraged on tidelands only in the early morning (before sunrise) and late afternoon. During the daytime, most of them roosted in aquacultural ponds (Yu 1991). Since our surveys were conducted in the morning, fewer waterbirds were recorded on tidelands than in aquacultural ponds. Second, human disturbance might also have affected the habitat selection of waterbirds. Many local people caught eel fry on tidelands in winter in recent years. Thousands of boats anchored at the shallow water area around tidelands. This brought much disturbance to the waterbirds (Jing et al. 2002). Comparatively, the aquacultural ponds were little disturbed after aquatic products had been harvested in winter. Consequently, we could find more waterbirds in aquacultural ponds than on tidelands in winter. Historical records showed that waterbirds occurred on tidelands and surrounding areas with shallow water frequently in the 1980s, when there was little disturbance on tidelands (Huang et al. 1993). This implies that waterbirds might select the tidelands rather than aquacultural ponds if human activities on tidelands were reduced.

Other studies show that the abundance and species richness of waterbirds are extremely low in artificial wetlands (e.g. Tourenq et al. 2001). This extreme case may be the result of the difference in area considered between natural wetlands and artificial wetlands. Larger wetlands tend to attract more birds than the smaller ones (Erwin et al. 1991; Froneman et al. 2001). Generally, artificial wetlands of small size are susceptible to disturbance from the surrounding area (Ma et al. 2000). If the size of artificial wetlands is large enough, disturbance can be minimized. Consequently, more waterbirds would occur there [e.g. saltworks in Wang and Du (1993); crab ponds in Barter et al. (1997); artificial lakes in Ma et al. (2000); farm ponds in Froneman et al. (2001)]. This also implies that the area should be considered when artificial wetlands are constructed for waterbirds.

Management implications

The results from this study clearly show that waterbirds preferred natural wetlands (tidelands) to artificial wetlands (aquacultural ponds) on Chongming Island, though artificial wetlands were also suitable habitats for some waterbirds in winter. However, many studies (e.g. Acosta et al. 1996; Elphick and Oring 1998; Froneman et al. 2001) suggest that artificial wetlands may be suitable habitats for waterbird communities. This might be caused by the fact that suitable natural wetlands for waterbirds were lost in the regions considered (Tourenq et al. 2001). In fact, loss of natural wetlands worldwide in recent years has resulted in the construction of artificial wetlands, which are the only choice for waterbird communities in the regions where natural wetlands are unavailable. Over-emphasizing the roles of artificial wetlands in managing waterbird diversity might be dangerous, because it may inappropriately encourage landowners or managers to exploit natural wetlands, leading to the acceleratory loss of natural wetlands. It is here suggested that the plans for human exploitation of natural wetlands be made wisely. In order to provide suitable habitats for waterbirds, both quantity and quality of the wetlands should be considered at the same time. After all, many waterbird species have their preferences for the different types of habitat. In the case of artificial wetlands being the only choice for birds, appropriate management is still needed to improve the habitat quality for certain birds (Day and Colwell 1998; Lane and Fujioka 1998; Elphick 2000).

Unfortunately, the tidelands on Chongming Island have been subjected to intensive human disturbance in the past decades (Jing et al. 2002). More importantly, a new reclamation program is being developed at Dongtan on Chongming Island. It is said that another 6.6 km^2 of tidelands will be reclaimed and converted to artificial wetlands in the very near future, which will certainly have serious consequences for the waterbird communities. Because Chongming Island plays special roles in conserving waterbird diversity, the tidelands of Chongming Island should be protected so that suitable habitats (natural wetlands) can be left for migrants during their migrating and wintering periods. As a compromise, no new reclamation programs should be developed until the tidelands reach a certain width. In this way, tidelands can be reclaimed in an appropriate way, and natural wetlands can also be reserved for waterbirds.

Acknowledgements

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Appendix 1

Observed number of waterbirds on tidelands and in aquacultural ponds at Dongtan, Chongming Island. The average bird number across surveys in each season is shown.

Species	Tidelands				Aquacultural ponds			
	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
Podicipediformes								
Tachybaptus ruficollis	0	0.20 ± 0.45	0	0	4.20 ± 2.77	2.60 ± 2.19	1.40 ± 1.14	4.43 ± 3.51
Subtotal	0	0.20 ± 0.45	0	0	4.20 ± 2.77	2.60 ± 2.19	1.40 ± 1.14	4.43 ± 3.51
Pelecaniformes								
Phalacrocorax carbo	0	0	0	0	0	0	0	0.57 ± 0.98
Subtotal	0	0	0	0	0	0	0	0.57 ± 0.98
Ciconiiformes								
Ardea cinerea	11.60 ± 6.91	16.40 ± 10.55	6.60 ± 6.47	6.57 ± 4.24	16.60 ± 18.85	15.60 ± 11.67	9.00 ± 4.47	9.00 ± 4.28
Ardea purpurea	0.40 ± 0.89	0	0.80 ± 1.30	0	0.20 ± 0.45	0	1.20 ± 1.30	0
Butorides striatus	0	4.40 ± 2.07	0.60 ± 1.34	0	0	1.40 ± 1.67	0	0
Ardeola bacchus	0	2.40 ± 2.30	0	0	0	3.80 ± 1.64	1.60 ± 2.61	0
Bubulcus ibus	0	2.00 ± 1.58	2.80 ± 3.27	0	0	2.40 ± 2.30	0.20 ± 0.45	0
Egretta alba	7.60 ± 2.70	30.20 ± 6.61	61.60 ± 51.43	5.71 ± 7.91	22.80 ± 24.86	50.80 ± 29.60	16.00 ± 9.75	2.29 ± 1.60
Egretta intermedia	15.40 ± 4.04	35.60 ± 7.40	196.80 ± 248.02	9.14 ± 12.13	7.00 ± 5.70	33.60 ± 27.39	29.80 ± 22.95	10.14 ± 9.92
Egretta garzetta	11.20 ± 5.67	156.60 ± 59.43	113.00 ± 85.70	19.00 ± 10.68	12.00 ± 13.89	143.20 ± 60.61	65.60 ± 58.46	63.43 ± 40.91
Egretta eulophotes	0.20 ± 0.45	0	0	0	0	0	0	0
Nycticorax nyticorax	2.40 ± 3.91	0	1.80 ± 2.68	1.43 ± 1.13	1.00 ± 2.24	0	1.00 ± 2.24	9.29 ± 6.29
Botaurus stellaris	0	0	0	0.14 ± 0.38	0	0	0	0.14 ± 0.38
Platalea minor	0	0	0.20 ± 0.45	0	6.80 ± 4.76	0	0	0
Subtotal	48.80 ± 10.90	247.60 ± 58.45	384.20 ± 374.21	42.00 ± 19.55	66.40 ± 45.97	250.80 ± 89.21	124.40 ± 63.38	94.29 ± 40.73
Anseriformes								
Anser cygnoides	3.40 ± 6.54	0	0	6.00 ± 7.55	0	0	0	0
Cygnus columbianus	0.20 ± 0.45	0	0	25.14 ± 21.39	0	0	0	0
Tadorna ferruginea	0	0	0	0	0	0	0	1.00 ± 2.65

Appendix 1. (*Continued*)

Species	Tidelands				Aquacultural ponds			
	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
Tadorna tadorna	0.20 ± 0.45	0	1.20 ± 2.68	7.57 ± 9.36	6.00 ± 9.25	0	0	0.43 ± 1.13
Anas acuta	6.60 ± 9.10	0	0	1.00 ± 2.65	34.00 ± 57.20	0	0	6.71 ± 9.09
Anas crecca	17.00 ± 23.47	0	20.60 ± 39.70	237.86 ± 207.90	139.40 ± 124.52	0	0	839.29 ± 1079.31
Anas falcata	0	0	0	2.29 ± 6.05	11.40 ± 15.81	0	0	1.86 ± 4.91
Anas platyrhynchos	12.60 ± 13.50	0	7.60 ± 16.99	110.86 ± 98.29	88.60 ± 113.50	0	0	460.14 ± 357.00
Anas poecilorhyncha	16.60 ± 13.43	0	4.80 ± 10.73	102.29 ± 105.12	114.40 ± 185.81	0	0	382.86 ± 231.94
Anas strepera	0	0	0	1.86 ± 3.48	0	0	0	45.86 ± 16.61
Anas penelope	0	0	0	4.00 ± 5.86	5.40 ± 12.07	0	0	48.57 ± 38.54
Anas querquedula	5.80 ± 5.50	0	2.40 ± 5.37	17.14 ± 31.52	14.00 ± 9.49	0	12.40 ± 27.73	43.86 ± 94.39
Anas clypeata	1.20 ± 2.68	0	0	1.86 ± 3.18	8.00 ± 12.02	0	0	3.14 ± 5.64
Aythya baeri	0	0	0	0.71 ± 1.25	4.00 ± 5.10	0	0	4.71 ± 4.57
Aix galericulata	0	0	0	0	6.40 ± 14.31	0	0	4.14 ± 8.01
Anas acuta	6.60 ± 9.10	0	0	1.00 ± 2.65	34.00 ± 57.20	0	0	6.71 ± 9.09
Anas crecca	17.00 ± 23.47	0	20.60 ± 39.70	237.86 ± 207.90	139.40 ± 124.52	0	0	839.29 ± 1079.31
Anas falcata	0	0	0	2.29 ± 6.05	11.40 ± 15.81	0	0	1.86 ± 4.91
Anas platyrhynchos	12.60 ± 13.50	0	7.60 ± 16.99	110.86 ± 98.29	88.60 ± 113.50	0	0	460.14 ± 357.00
Anas poecilorhyncha	16.60 ± 13.43	0	4.80 ± 10.73	102.29 ± 105.12	114.40 ± 185.81	0	0	382.86 ± 231.94
Anas strepera	0	0	0	1.86 ± 3.48	0	0	0	45.86 ± 16.61
Anas penelope	0	0	0	4.00 ± 5.86	5.40 ± 12.07	0	0	48.57 ± 38.54
Anas querquedula	5.80 ± 5.50	0	2.40 ± 5.37	17.14 ± 31.52	14.00 ± 9.49	0	12.40 ± 27.73	43.86 ± 94.39
Anas clypeata	1.20 ± 2.68	0	0	1.86 ± 3.18	8.00 ± 12.02	0	0	3.14 ± 5.64
Aythya baeri	0	0	0	0.71 ± 1.25	4.00 ± 5.10	0	0	4.71 ± 4.57
Aix galericulata	0	0	0	0	6.40 ± 14.31	0	0	4.14 ± 8.01
Mergus merganser	0	0	0	2.86 ± 7.13	0	0	0	2.71 ± 7.18
Subtotal	63.60 ± 55.40	0	36.60 ± 75.31	521.43 ± 350.72	431.60 ± 423.14	0	12.40 ± 27.73	1845.29 ± 1428.90
Gruiformes								
Grus grus	2.00 ± 2.83	0	0	1.14 ± 1.07	0	0	0	0

Grus monacha	42.20 ± 58.57	0	0	83.14 ± 37.36	0	0	0	0
Gallinula chloropus	0	1.20 ± 1.79	0	0	0	1.80 ± 2.05	0.40 ± 0.89	0
Fulica atra	0	0	0	0	0.80 ± 1.10	0	0.40 ± 0.89	1.43 ± 1.99
Subtotal	44.20 ± 61.4	1.20 ± 1.79	0	84.29 ± 37.55	0.80 ± 1.10	1.80 ± 2.05	0.80 ± 1.10	1.43 ± 1.99
Charadriiformes								
Haematopus ostralegus	1.40 ± 2.19	0	0	0	0	0	0	0
Pluvialis squatarola	2.40 ± 2.30	0	0.60 ± 0.89	0	0	0	0	0
Pluvialis dominica	1.60 ± 1.14	0	0.20 ± 0.45	0	0	0	0	0
Charadrius placidus	5.60 ± 4.77	0	0	0	1.40 ± 1.95	0	0	0
Charadrius dubius	0	0	0	0	2.40 ± 3.91	0	1.00 ± 1.41	0
Charadrius alexandrinus	2298.80 ± 1639.42	0	96.20 ± 73.80	0	56.40 ± 64.89	0	10.60 ± 10.41	0
Charadrius mongolus	0.40 ± 0.89	0	0	0	0	0	0	0
Charadrius leschenaultii	102.00 ± 155.87	0	2.40 ± 3.36	0	0.80 ± 1.79	0	0	0
Numenius minutus	0.40 ± 0.89	0	0.60 ± 0.89	0	0	0	0	0
Numenius phaeopus	108.20 ± 226.89	0	9.80 ± 11.21	0	1.40 ± 3.13	0	0.40 ± 0.89	0
Numenius arquata	37.80 ± 20.95	0	16.20 ± 14.58	0	2.80 ± 3.90	0	1.20 ± 2.68	0
Numenius madagascariensis	10.20 ± 14.70	0	16.80 ± 18.73	0	7.00 ± 10.10	0	1.00 ± 1.41	0
Limosa limosa	16.40 ± 18.20	0	15.40 ± 17.62	0	0.40 ± 0.89	0	0	0
Limosa lapponica	2.60 ± 2.97	0	11.80 ± 14.20	0	0.20 ± 0.45	0	0	0
Tringa erythropus	7.20 ± 12.24	0	0.40 ± 0.55	0	1.60 ± 1.52	0	0.20 ± 0.45	0
Tringa totanus	8.20 ± 9.42	0	3.40 ± 3.78	0	2.20 ± 3.03	0	1.60 ± 2.30	0
Tringa stagnatilis	0	0	0.60 ± 1.34	0	1.00 ± 1.41	0	0.60 ± 0.89	0
Tringa nebularia	21.60 ± 13.58	0	29.80 ± 29.44	0	8.00 ± 9.97	0	3.40 ± 2.70	0
Tringa ochropus	2.20 ± 1.48	0	1.40 ± 2.61	0.29 ± 0.76	1.20 ± 1.30	0	0.60 ± 0.89	0
Tringa glareola	0	0	1.00 ± 2.24	0	0	0	0.60 ± 0.89	0
Tringa guttifer	2.00 ± 3.08	0	0.20 ± 0.45	0	0.20 ± 0.45	0	0.20 ± 0.45	0
Actitis hypoleucos	3.20 ± 0.45	1.00 ± 1.41	3.00 ± 2.35	0	7.80 ± 5.17	0	2.40 ± 2.07	0

Appendix 1. (*continued*)

Species	Tidelands				Aquacultural ponds			
	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
Xenus cinereus	20.20 ± 28.65	0	14.20 ± 15.69	0	8.20 ± 10.43	0	2.20 ± 4.92	0
Arenaria interpres	43.00 ± 60.31	0	0	0	2.80 ± 3.42	0	1.80 ± 2.68	0
Gallinago sp.	1.20 ± 2.17	0	1.40 ± 2.19	0	0.40 ± 0.89	0	0.60 ± 0.89	0
Calidris canutus	2.40 ± 2.88	0	0	0	0	0	0	0
Calidris tenuirostris	893.40 ± 655.83	0	11.20 ± 11.80	0	0	0	0	0
Calidris ruficollis	102.20 ± 113.14	0	25.60 ± 32.55	0	0	0	0	0
Calidris acuminata	283.40 ± 133.29	0	19.80 ± 19.45	0	0	0	0	0
Calidris alpina	2836.40 ± 1363.51	0	99.20 ± 68.03	0	0	0	0	0
Calidris ferruginea	203.40 ± 173.92	0	6.40 ± 14.31	0	0	0	0	0
Calidris alba	0.60 ± 1.34	0	0	0	0	0	0	0
Eurynorhynchus pygmeus	0	0	0.60 ± 1.34	0	0	0	0	0
Limicola falcinellus	14.00 ± 10.77	0	23.40 ± 22.85	0	0	0	0	0
Himantopus himantopus	0	0	0	0	4.40 ± 4.72	0	0	0
Glareola maldivarum	0	3.40 ± 5.27	7.20 ± 11.34	0	0	0	0	0
Subtotal	7032.40 ± 1797.67	4.40 ± 5.77	418.80 ± 252.35	0.29 ± 0.76	110.60 ± 59.08	0	28.40 ± 21.64	0
Lariformes								
Larus crassirostris	307.40 ± 543.95	0.20 ± 0.45	9.80 ± 11.45	90.57 ± 139.15	0.60 ± 1.34	0	0.60 ± 1.34	5.29 ± 9.8
Larus canus	13.80 ± 18.42	0	2.80 ± 4.76	76.86 ± 88.91	0.40 ± 0.89	0	0	3.86 ± 6.64
Larus argentatus	9042.40 ± 7663.87	4.80 ± 10.73	59.20 ± 84.35	221.14 ± 213.02	17.40 ± 25.74	0.60 ± 1.34	2.40 ± 5.37	26.29 ± 14.49
Larus ridibundus	385.60 ± 692.64	2.80 ± 6.26	17.60 ± 11.74	166.29 ± 166.24	4.20 ± 3.90	0	1.40 ± 3.13	6.71 ± 7.83
Larus saundersi	3.00 ± 5.20	0	6.80 ± 14.11	9.57 ± 10.31	0	0	0	0.71 ± 1.25
Chlidonias leucopterus	3.60 ± 8.05	0	175.80 ± 317.12	0	2.20 ± 3.03	0	20.20 ± 21.29	0
Sterna hirundo	57.40 ± 49.46	0	28.80 ± 28.54	0	0	0	0.20 ± 0.45	0
Sterna albifrons	10 ± 14.85	5.40 ± 12.07	16.80 ± 18.32	0	1.80 ± 2.68	3.40 ± 5.27	13.20 ± 20.75	0
Subtotal	9823.20 ± 8961.32	13.20 ± 18.57	317.60 ± 301.82	564.43 ± 400.26	26.60 ± 28.68	4.00 ± 4.95	38.00 ± 37.24	42.86 ± 28.60
Total ± SD	17012.20 ± 9633.78	266.60 ± 59.71	1157.20 ± 806.70	1212.43 ± 549.86	640.20 ± 467.88	259.20 ± 84.98	205.40 ± 96.53	1988.86 ± 1466.18

It was impossible to distinguish between different species of *Gallinago* in the field, thus we considered them as a single species, though there were four species (*Gallinago gallinago*, *G. stenura*, *G. megala* and *G. solitaria*) in historical records. Five surveys were conducted in spring, summer and autumn; and seven surveys in winter.

References

Acosta M., Mugica L., Mancina C. and Ruiz X. 1996. Resource partitioning between glossy and white ibises in a rice field system in south-central Cuba. Colonial Waterbirds 19: 65–72.

Barter M., Tonkinson D., Tang S.X. and Qian F.W. 1997. Wader number on Chongming Dao, Yangtze Estuary, China, during early 1996: northward migration and the conservation implications. Stilt 30: 7–13.

Boulinier T., Nichols J.D., Sauer J.R., Hines J.E. and Pollock K.H. 1998. Estimating species richness: the importance of heterogeneity in species detectability. Ecology 79: 1018–1028.

Burnham K.P. and Overton W.S. 1978. Estimation of the size of a closed population when capture probabilities vary among animals. Biometrika 65: 625–633.

Burnham K.P. and Overton W.S. 1979. Robust estimation of population size when capture probabilities vary among animals. Ecology 60: 927–936.

Cody M.L. 1985. Habitat Selection in Birds. Academic Press Inc., Orlando, Florida.

Colwell M.A. and Taft O.W. 2000. Waterbird communities in managed wetlands of varying water depth. Waterbirds 23: 45–55.

Day J.H. and Colwell M.A. 1998. Waterbird communities in rice fields subjected to different post-harvest treatments. Colonial waterbirds 21: 185–197.

Duncan P., Hewison A.J.M., Houte S., Rosoux R., Tournebize T., Dubs F. et al. 1999. Long-term changes in agricultural practices and wildfowling in an internationally important wetland, and their effects on the guild of wintering ducks. Journal of Applied Ecology 36: 11–23.

Elphick C.S. 2000. Functional equivalency between rice fields and semi-natural wetland habitats. Conservation Biology 14: 181–191.

Elphick C.S. and Oring L.W. 1998. Winter management of Californian rice fields for waterbirds. Journal of Applied Ecology 35: 95–108.

Erwin R.M., Dawson D.K., Stotts D.B., Mcallister L.S. and Geissler P.H. 1991. Open marsh water management in the mid-Atlantic region – Aerial surveys of waterbird use. Wetlands 11: 209–228.

Froneman A., Mangnall M.J., Little R.M. and Crowe T.M. 2001. Waterbird assemblages and associated habitat characteristics of farm ponds in the Western Cape, South Africa. Biodiversity and Conservation 10: 251–270.

Guillemain M., Fritz H. and Guillon N. 2000. The use of an artificial wetland by Shoveler *Anas clypeata* in western France: the role of food resources. Revue D'Ecologie – La Terre Et La Vie 55: 263–274.

Hines J.E., Boulinier T., Nichols J.D., Sauer J.R. and Pollock K.H. 1999. COMDYN: software to study the dynamics of animal communities using a capture–recapture approach. Bird Study 46: 209–217.

Huang Z.Y., Sun Z.H., Yu K., Zhou M.Z., Zhao R.Q. and Gao J. 1993. Bird Resources and Habitats in Shanghai. Fudan University Press, Shanghai, China.

Isola C.R., Colwell M.A., Taft O.W. and Safran R.J. 2000. Interspecific differences in habitat use of shorebirds and waterfowl foraging in managed wetlands of California's San Joaquin Valley. Waterbirds 23: 196–203.

Jing K., Tang S.M., Chen J.K. and Ma Z.J. 2002. Primary research on the characteristics of feeding sites of *Grus monacha* in the east tide flat of Chongming Island. Chinese Zoological Research 23: 84–88.

Kennish M.J. 2001. Coastal salt marsh systems in the US: a review of anthropogenic impacts. Journal of Coastal Research 17: 731–748.

Lane S.J. and Fujioka M. 1998. The impact of changes in irrigation practices on the distribution of foraging egrets and herons (Ardeidae) in the rice fields of Central Japan. Biological Conservation 83: 221–230.

Li C.X. and Wang W.L. 1997. Biostatistics. Science Press, Beijing, China.

Lu J.J. 1990. Wetlands in China. East China Normal University Press, Shanghai, China.

Lu J.J., Sun X.K. and He W.S. 1998. Study on wetlands in Shanghai area. In: Lang H.Q., Lin P. and Lu J.J. (eds), Conservation and Research of Wetlands in China. East China Normal University Press, Shanghai, China, pp. 297–309.

Ma Z.J., Li W.J. and Wang Z.J. 2000. Conservation of Red-crowned Crane. Tsinghua University Press, Beijing, China.

Ma Z.J., Wang Z.J. and Tang H.X. 1999. Habitat use and selection by red-crowned crane *Grus japonensis* in winter in Yancheng Biosphere Reserve, China. Ibis 141: 135–139.

Nichols J.D., Boulinier T., Hines J.E., Pollock K.H. and Sauer J.R. 1998. Inference methods for spatial variation in species richness and community composition when not all species are detected. Conservation Biology 12: 1390–1398.

Ogden J.C. 1991. Nesting by wood storks in natural, altered, and artificial wetlands in central and northern Florida. Colonial Waterbirds 14: 39–45.

Rose P.M. and Scott D.A. 1997. Waterfowl Population Estimates, 2nd edn. Publication 44. Wetlands International, Wageningen, The Netherlands.

Scott D.A. 1989. A Directory of Asian Wetlands. IUCN, Gland, Switzerland.

Shanghai Statistical Bureau 2001. Shanghai Statistical Yearbook – 2001. Chinese Statistics Press, Beijing, China.

Straw P. 1997. Shorebird conservation in the Asia-Pacific region. Australasian Wader Studies Group of Birds Australia, Melbourne, Australia.

Streever W.J., Portier K.M. and Crisman T.L. 1996. A comparison of dipterans from ten created and ten natural wetlands. Wetlands 16: 416–428.

Tourenq C., Bennetts R.E., Kowalski H., Vialet E., Lucchesi J.L., Kayser Y. et al. 2001. Are ricefields a good alternative to natural marshes for waterbird communities in the Camargue, southern France? Biological Conservation 100: 335–343.

Turner R.K., Van den Berg J.C.J.M., Soderqvist T., Barendregt A., Van den Straaten J., Maltby E. et al. 2000. Ecological-economic analysis of wetlands: scientific integration for management and policy. Ecological Economics 35: 7–23.

Wang T.H. and Qian G.Z. 1988. Shorebirds in the Yangtze Estuary and Hangzhou Bay. East China Normal University Press, Shanghai, China.

Wang H. and Du J.J. 1993. Primary study on the waterbirds in Sheyang Saltworks. Chinese Journal of Zoology 28: 21–23.

West T.L., Clough L.M. and Ambrose W.C. 2000. Assessment of function in an oligohaline environment: lessons learned by comparing created and natural habitats. Ecological Engineering 15: 303–321.

Yang J. 1998. Development of fishery and international trade of fishery products in China. Economic Research on Chinese Fishery 2: 7–8.

Yu K. 1991. Waterfowls and their conservation at Dongtans of Chongming Island. Chinese Wildlife 2: 15–18.

Yu K., Tang Z.M., Tang S.H. and Jiang X.L. 1991. The food habits and habitats of *Cygnus columbianus* at Dongtans of Chongming Island. In: Gao W. (ed.), Ornithology Research in China. Science Press, Beijing, China, pp. 32–34.

Zheng G.M. and Wang Q.S. 1998. China Red Data Book of Endangered Animals: Aves. Science Press, Beijing, China.