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IMPACT OF COASTAL WETLAND RESTORATION STRATEGIES IN THE CHONGMING DONGTAN WETLANDS, CHINA: WATERBIRD COMMUNITY COMPOSITION AS AN INDICATOR

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This paper aims to evaluate the success of coastal wetland restoration by quantifying the waterbird community composition at three restored sites and on one natural coastal wetland, which served as a reference site, from September 2011 to May 2012 in the Chongming Dongtan wetlands in China. The Shannon–Wiener diversity index was calculated to describe habitat diversity in the four study sites. Significant differences in habitat heterogeneity and species group diversity, richness, and waterbird density were observed in the sites, but a significant difference among three seasons was observed only in the waterbird density. Significant interactions between site and season were noted for species group diversity, richness, and waterbird density. The densities of four dominant waterbird groups exhibited significant differences in the four sites, and the density of Anatidae and Ardeidae exhibited significant differences among three seasons. Significant interactions were noted between site and season for the densities of Charadriidae, Anatidae, and Ardeidae. In conclusion, the restored coastal wetlands served as a suitable habitat for waterbirds to some extent, although not all restored wetlands were used equally by waterbirds. The restored wetlands with higher habitat heterogeneity supported a greater abundance of waterbirds. However, the same restored wetland was not used equally by waterbirds among different seasons. Multi-functional restored wetlands could be created for different seasons to attract a diverse group of waterbirds to forage and roost in the coastal wetlands of Yangtze River during their migration from Australia to Siberia.

Key words: Chongming Dongtan wetlands, coastal wetland, habitat heterogeneity, multi-functional wetland, waterbirds, wetland restoration.

INTRODUCTION

The Yangtze River Estuary is one of the 50 sensitive ecological regions in the world (MAFFI *et al.* 2000). The Chongming Dongtan wetlands, a critical coastal wetland in the Yangtze River estuary, were included in the Ramsar Convention's List of Wetlands of International Importance in 2002. The annual use of coastal wetlands in Chongming Dongtan by thousands of migratory waterbirds indicates that these habitats are important stopover, winter-

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ing, and breeding sites for birds migrating from Australia to Siberia (Barter & Wang 1990, Ma *et al.* 2002, Xu & Zhao 2005). Waterbird surveys conducted by Shanghai Chongming Dongtan National Reserve from 2006 to 2011 indicated that the most common species was *Calidris alpine*, followed by *Egretta garzetta*, *Anas poecilorhyncha* and *Larus argentatu*s, accounting for over 60% of the total waterbird individuals counted (Shanghai Chongming Dongtan National Reserve Annual Report 2006 to 2011). The success of bird migration depends on intact migratory routes and stopovers (Moore *et al.* 2005) because birds generally do not deposit enough fat to enable them to fly between breeding and wintering areas without stopovers (Buler *et al.* 2007). The Chongming Dongtan wetlands are also a critical area for threatened species, including *Grus monacha* and *Platalea minor*; the population of these species in the Chongming Dongtan wetlands accounts for approximately 1% of the total global population.

During the past decades, the Chongming Dongtan wetlands have been subjected to loss and deterioration caused by the invasion of *Spartina alterniflora* (hereafter *Spartina*) which has gradually replaced native plant communities (i.e., *Scirpus mariqueter* and *Phragmites australis*, hereafter *Scirpus* and *Phragmites*) (Wang *et al.* 2006, Gan *et al.* 2010, Ma *et al.* 2011). Habitat loss and deterioration has negative impacts on species and composition of waterbird communities and has been especially disadvantageous to migrants which chose Chongming Dongtan wetlands as their important stopover site for energy replenishment in the East Asian–Australasian Flyway (Gan *et al*. 2009 & 2010, Ma *et al*. 2011). Most waterbirds in the Chongming Dongtan wetlands are long-distance migratory waterbirds coming from Australia and Siberia (Barter & Wang 1990, Ma *et al.* 2002, Xu & Zhao 2005). Thus, wetlands in Chongming Dongtan must be restored or created to compensate for habitat loss and deterioration. In recent years, restorations have been completed to protect waterbirds in the Chongming Dongtan wetlands, particularly the long-distance migratory waterbirds from Australia and Siberia. A wetland park was restored in 2006 to enhance biological conservation and ecological tourism. In 2008, *Spartina* communities were removed prior to restoring aquacultural ponds in Beibayao. In 2010, the wetlands in Buyugang were restored by removing the *Spartina* communities prior to broadening tidal creeks and constructing mudflat wetlands.

The preference of waterbirds for the restored wetlands could indicate wetland restoration success (Frederick *et al.* 2009, Robledano *et al.* 2010, Ke *et al.* 2011). However, caution must be taken when dealing with generalist species which may exploit both suitable and unsuitable habitats (Bock & Jones 2004). In the Chongming Dongtan wetlands, migratory waterbirds, particularly the four dominant species groups (Charadriidae, Anatidae, Ardeidae, and Laridae), have habitat preferences which appear to be relatively stable (Ma *et al.* 2002, Xu & Zhao 2005, Tian *et al.* 2008). Because these species exhibit very little site fidelity, their habitat preferences can indicate the habitat quality of natural and restored wetlands (Frederick *et al.* 2009, Robledano *et al.* 2010, Ke *et al.* 2011). However, few studies have been conducted to assess the restoration success in the Chongming Dongtan wetlands with the use of waterbird community composition as an indicator of restored wetland quality. Previous studies indicated that waterbirds could use restored artificial wetlands (e.g., aquacultural ponds) as alternative habitats to compensate for the loss of natural wetlands (Ge *et al*. 2006, Liu 2006, Zhang *et al*. 2013, Zhao *et al*. 2008, Zhao *et al*. 2003). Ma *et al*. (2004) recognized that waterbirds might use restored artificial wetlands only when natural wetlands are unavailable or of poor quality.

This study aims to (1) determine whether coastal wetland restoration status strongly influences the use of restored coastal wetlands by waterbirds, (2) evaluate how waterbirds behave across seasons (migration and winter periods), focusing specifically on whether waterbird density, diversity, evenness, and richness differ among four study sites (three restored coastal wetland sites and a natural coastal wetland site). We expect that this study will encourage the wetland managers to develop a wetland restoration or creation strategy to protect migratory waterbirds in the coastal area of the Yangtze River.

METHODS

Study sites

This study was conducted in the Chongming Dongtan wetlands, a Ramsar site at the mouth of the Yangtze River Estuary of Eastern China (121°50′–122°05′E, 31°25′–31°38′N) (Fig. 1) that covers an area of approximately 326 km^2. A total of 17 orders, 50 families, and 288 species of birds have been recorded in the Chongming Dongtan wetlands in the past decades. A number of rare species, such as *Ixobrychus minutus*, *Grus monacha*, *Ciconia nigra*, *Platalea minor*, *Platalea leucorodia*, *Cygnus columbianus*, *Aix galericulata*, *Grus grus*, and *Grus vipio*, had also been observed here (Ma *et al.* 2002, Xu & Zhao 2005). The dominant waterbird families are Anatidae, Charadriidae, Ardeidae, and Laridae (Ma *et al.* 2002, Xu & Zhao 2005). This area was recognized as an important stopover and wintering site for bird migration between Australia and Siberia (Barter & Wang 1990, Ma *et al.* 2002, Xu & Zhao 2005).

Three restored wetlands (A to C) and a natural wetland (D) were chosen as study sites (Fig. 1). Site A was restored to a wetland park in 2006 for biological conservation and ecological tourism. Site B was restored in 2008 by removing *Spartina* communities prior to excavating aquacultural ponds. Site C was restored in 2010 by removing *Spartina* communities prior to broadening tidal creeks and constructing mudflat wetlands. Site D was a natural wetland which served as a reference site that was compared with the restored habitats (A to C) to evaluate the restoration success. In this site, the main habitat types included *Scirpus* habitat and mudflats and shallow water habitat without any vascular plants.

Table 1. Habitat characteristics of each site (A, B, C, and D) based on remote sensing images.

	A	B	C	D
Total area (ha)	139.85	105.34	61.38	56.04
Phragmites (% total area)	45.56	5.8	44.21	7.22
Scirpus (% total area)	N/A	N/A	N/A	52.82
Mudflat (% total area)	N/A	N/A	6.68	39.96
Other vegetation (% total area)	26.34	N/A	N/A	N/A
Open water (% total area)	28.1	94.2	49.11	N/A
SHDI	2.07	0.47	2.44	1.98

N/A denotes not applicable.

Habitat characteristics

Habitat characteristics (Table 1) were obtained from Formosat–2 image (acquired on October 17, 2011) with a pixel size of 2 m on one side (4 m^2 pixel area). With the help of ENVI (Environment for Visualizing Images) 4.5 version and ArcGIS 10.0 version, the habitats were divided into five types, i.e., *Phragmites*, *Scirpus*, mudflats, open water, and

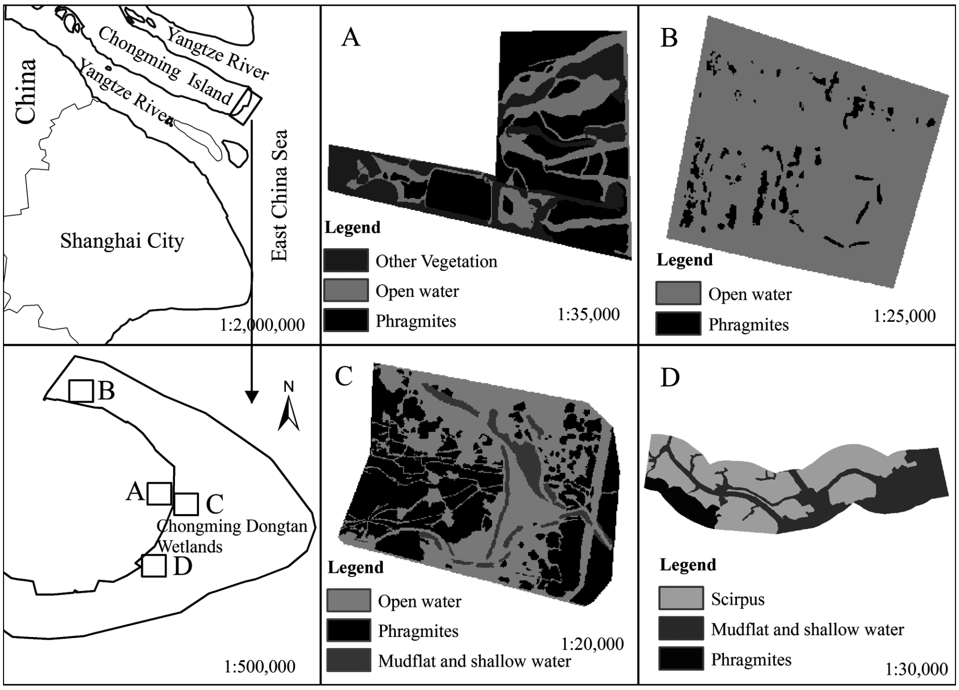

Fig. 1. Location of the study sites (A–D).

other. The percentage of each habitat types in the four study sites was calculated. Similar to Armitage *et al.* (2007), the Shannon–Wiener diversity index (*SHDI*) was calculated to describe the habitat diversity in the four study sites, where $SHDI = -\Sigma(p_i)(\ln p_i)$ and p_i is the percentage of the *i*th habitat type.

Waterbird surveys

Waterbird surveys were carried out 15 times on each of the four study sites (for a total of 60 times) from September 2011 to May 2012, covering two peak migration periods (spring and autumn) and the wintering period. The sample size was five in each season in each site. Waterbird surveys were carried out in 4–5 days, including 2 days before and after the neap tide, respectively. Each survey started 1 hour after sunrise and lasted 4–5 hours every day. Two or three investigators counted waterbirds using 10 × 42 binoculars and 20×–60× spotting scopes by walking at a speed of 1–2 km per hour.

The number of waterbird species and their population sizes in the four study sites from September 2011 to May 2012 were calculated and analyzed. In most situations, waterbird species from the same family generally exhibit same habitat preferences. It is more powerful and recommended to analyze restored habitat preferences of the dominant waterbird families, rather than each species respectively. In this study, the most species-rich families were Charadriidae, Anatidae, Ardeidae, and Laridae (details are presented in the part of results), similar to previous studies (Ma *et al.* 2002, Xu & Zhao 2005). Thus, we chose to analyze the four dominant waterbird families Anatidae, Charadriidae, Ardeidae, and Laridae in the study sites.

Data analysis

Similar to Armitage *et al.* (2007), *SHDI* was calculated to describe the waterbird diversity in the four study sites, where $SHDI = -\Sigma(p_i)(\ln p_i)$ and p_i is the proportion of the waterbirds that belong to the *i*th species (Krebs 1994). The Shannon–Wiener evenness index was calculated to describe the waterbird evenness in the four study sites, where $SHEI = SHDI / \ln S$ and S is the total number of observed waterbird species (Krebs 1994). Waterbird species richness is the total number of species observed in each site. Waterbird density (individuals per hectare) of each of the four dominant waterbird species groups was calculated to describe the waterbird density in the four study sites.

D'Agostino–Pearson omnibus test is a versatile and powerful normality test, and is recommended (D'Agostino *et al*. 1990). So, we chose D'Agostino–Pearson omnibus test to analyze whether waterbird species diversity, richness, evenness, density of all waterbird species, and densities of four dominant waterbird species groups were normally distributed. Results of D'Agostino-Pearson omnibus tests indicates that waterbird species diversity, richness, evenness in different seasons as well as in different sites all passes normality tests (all $p > 0.05$), however, density of all waterbirds was only normally distributed in different sites ($p > 0.05$). But other variables were not normally distributed (all $p < 0.05$). As a result, diversity, richness, and evenness of all waterbird species were analyzed by using two-factor ANOVA, where the factors were sites (A to D) and seasons (autumn, winter, and spring). Qualitative post hoc Games-Howell interpretations of patterns that contribute to significant interactions between site and season were based on an overlap of one standard error. Differences in density of all waterbird species among four sites (A to D) were analyzed by one-way ANOVA, followed by post hoc Games-Howell multiple comparison test. However, differences in density of all waterbird species among three seasons, and densities of four dominant waterbird species groups among four sites as well as three seasons were analyzed by the nonparametric Kruskal-Wallis test, followed by post hoc pairwise comparison test (a multiple comparison test similar to LSD which was inserted into the Kruskal-Wallis test in IBM SPSS Statistics Version 20.0). Normality tests were performed using GraphPad Prism version 6.0 for Windows. For all nonparametric Kruskal-Wallis tests, we used the Software Package for Social Statistics (IBM SPSS Statistics Version 20.0).

RESULTS

Habitat characteristics

The areas of the four selected study sites ranged from 56.04 ha (site D) to 139.85 ha (site A). In site A, the dominant habitat type was *Phragmites*, followed by open water, and other vegetation. In site B, the dominant habitat type was open water followed by *Phragmites*. In site C, the dominant habitat types were open water and *Phragmites*, followed by mudflats. In site D, the dominant habitat types were *Scirpus* and mudflats, followed by *Phragmites*. Among the four sites, site C had the highest habitat heterogeneity (*SHDI* = 2.44), with a mix of open water, *Phragmites*, and mudflat. Site B had the lowest habitat heterogeneity (*SHDI* = 0.47), with open water dominating.

Waterbird community composition

A total of 35,593 individuals, which correspond to 62 species, were recorded during the 60 waterbird surveys. The most species-rich families were Charadriidae (23 species), Anatidae (17 species), Ardeidae (8 species), and Laridae (6 species), which accounted for 87.1% of all species. Overall, 4 waterbird families, i.e., Charadriidae (5,752), Anatidae (25,393), Ardeidae (1,024), and Laridae (1,042), dominated the waterbird community in the four study sites, which accounted for 93.31% of all recorded individuals. Ten rare species (listed by IUCN) were observed, of which 2 species (*Ixobrychus minutus*, *Anas formosa*) was listed as least concern, 6 species were vulnerable (*Grus monacha*, *Egretta eulophotes*, *Anser cygnoides*, *Numenius madagascariensis*, *Calidris tenuirostris*, and *Larus saundersi*), and 2 species were near-threatened (*Anas falcata* and *Limosa limosa*). Ninety individuals of *Grus monacha* were observed in a single survey in site D in December 2011, which is six times the 1% threshold (species of global conservation importance for which population size was >1% of their estimated global flyway population).

Table 2. Results from two-factor ANOVA of site and season on waterbird species group diversity, species group evenness, species group richness, and waterbird density.

	df	Diversity		Evenness		Richness		Waterbird density*	
		F	*p*	F	*p*	F	*p*	F	*p*
Site	3	7.31	<0.01	0.13	0.94	21.34	<0.01	23.81	<0.01
Season	2	0.15	0.86	0.37	0.69	1.78	0.18	#	#
Season × Site	6	3.24	<0.01	0.98	0.45	2.79	0.02	#	#

* denotes waterbird density in three seasons not passed D'Agostino-Pearson omnibus test. Differences in waterbird density among four sites were analyzed by one-way ANOVA.
# denotes not analyzed.

Waterbird community distribution patterns

Significant differences in species group diversity, richness, and waterbird density were observed in the four study sites (Table 2), but a significant difference among three seasons (autumn, winter, and spring) was observed

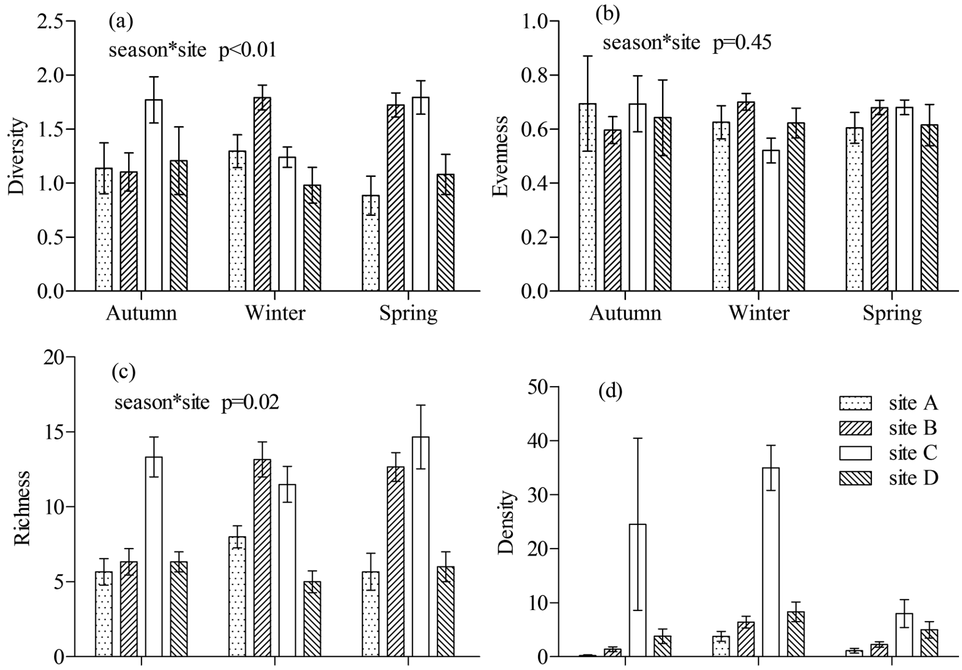

Fig. 2. Species group diversity (a), species group evenness (b), species group richness (c), and waterbird density (d) during autumn, winter, and spring in four sites. Significant p values from two-factor ANOVA are noted. Error bars represent ±1 SE.

Table 3. Results from Kruskal-Wallis test (χ^2) of difference in waterbird density among three seasons, and differences in four dominant waterbird density among four sites as well as three seasons.

	df	Waterbird density*		Charadriidae density		Anatidae density		Ardeidae density		Laridae density	
		χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p
Site	3	#	#	17.80	<0.01	11.24	0.02	20.82	<0.01	12.15	<0.01
Season	2	13.10	<0.01	1.01	0.60	17.02	<0.01	6.86	0.03	0.39	0.82

* denotes waterbird density in three seasons not passed D'Agostino-Pearson omnibus test. Differences in waterbird density among three seasons were analyzed by Kruskal-Wallis test. # denotes not analyzed.

only in the waterbird density (Table 3). The least significant difference obtained during post hoc comparisons indicated higher species group diversity and richness in sites B and C than in sites A and D (Figs 2a & 2c). The waterbird density was higher in site C than in the other three sites and was higher in winter than in autumn and spring (Fig. 2d). No significant difference in species group evenness was observed in the four study sites or in the three seasons (Table 2, Fig. 2b).

Significant interactions were noted between site and season for species group diversity, richness, and waterbird density, except waterbird species group evenness (Table 2). Specifically, species group diversity was higher in site B than in sites A ($p < 0.05$), C ($p < 0.01$), and D ($p < 0.01$) in winter, and higher in sites B and C than in sites A ($p < 0.01$) and D ($p < 0.05$) in spring (Fig. 2a). Species group diversity was higher in winter and spring than in autumn in site B (both $p < 0.01$), but lower in winter than in autumn and spring in site C (both $p < 0.05$) (Fig. 2a). Richness was higher in site C than in the other three sites in autumn (all $p < 0.01$), higher in sites B and C than in sites A and D both in winter and spring (all $p < 0.01$), and higher in site A than in site D in winter ($p < 0.05$) (Fig. 2c). Richness was higher in winter and spring than in autumn in site B (both $p < 0.01$) (Fig. 2c). Waterbird density was higher in site C than in other three sites in winter (all $p < 0.01$), and higher in site C than in sites A ($p < 0.01$) and B ($p < 0.05$) in spring (Fig. 2d). Waterbird density was higher in winter than in autumn and spring in sites A and B (all $p < 0.01$), and higher in winter than in spring in site C ($p < 0.01$) (Fig. 2d).

The densities of the four dominant waterbird families (Charadriidae, Anatidae, Ardeidae, and Laridae) exhibited significant differences in the four study sites, while the density of Anatidae and Ardeidae exhibited significant differences in the three seasons (Fig. 3, Table 3). The four dominant waterbird groups exhibited distinct site and season preferences and appeared to be specific to the ecological group (Fig. 3). Specifically, Charadriidae density was higher in sites C and D than in sites A and B (all post hoc $p < 0.05$); Anatidae density was higher in site C than in other three sites (all post hoc $p < 0.05$), and higher in winter than in autumn and spring (both post hoc $p < 0.01$); Ardeidae density was higher in sites B and C than in A and D (all post hoc $p < 0.01$), and higher in winter than in autumn and spring (both post hoc $p < 0.05$); Laridae density was higher in site D than in the other three sites (all post hoc $p < 0.01$).

Significant interactions were also noted between site and season for densities of Charadriidae, Anatidae, and Ardeidae (Table 3). Particularly, Charadriidae density was higher in site C than in the other three sites (all post hoc $p < 0.01$) in winter, and higher in site C than in sites A (post hoc $p < 0.01$) and B (post hoc $p < 0.05$) in spring (Fig. 3a); Charadriidae density was higher in winter than in spring in site A (post hoc $p < 0.05$), higher in spring than in winter (post hoc $p < 0.01$) and autumn (post hoc $p < 0.05$) in site C, and higher in winter than in autumn in both sites A (post hoc $p = 0.071 < 0.1$) and B (post hoc $p = 0.096 < 0.1$) (Fig. 3a); Anatidae density was higher in site C than in the other three sites in winter (all post hoc $p < 0.01$), higher in site C than in site A in autumn (post hoc $p < 0.05$), and higher in site C than in sites B and D in spring (both post hoc $p < 0.05$) (Fig. 3b); Anatidae density was higher in winter than in autumn and spring in sites A (both post hoc $p < 0.05$), B (both post hoc

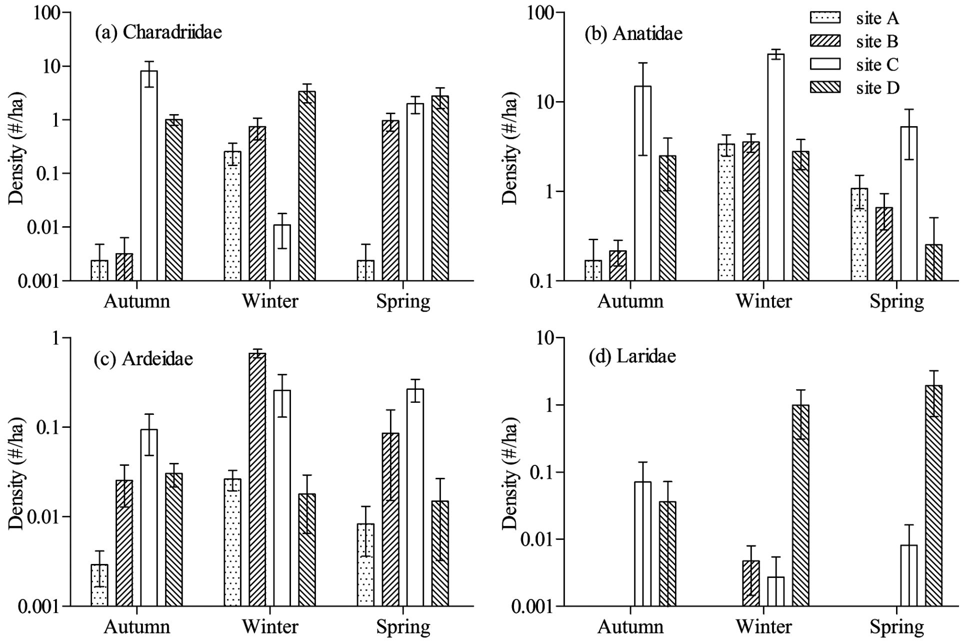

Fig. 3. Densities of Charadriidae (a), Anatidae (b), Ardeidae (c), and Laridae (d) among autumn, winter and spring in four sites. Error bars represent ±1 SE.

$p < 0.01$), and C (both post hoc $p < 0.01$), and was higher in winter than spring in site D (post hoc $p < 0.05$) (Fig. 3b); Ardeidae density was higher in site B than in the other three sites (all post hoc $p < 0.01$) and higher in site C than in sites A and D (both post hoc $p < 0.05$) in winter, and higher in site C than in sites A (post hoc $p < 0.01$), B (post hoc $p < 0.05$), and D (post hoc $p < 0.01$) in spring, but lower in site A than in site C in autumn (post hoc $p < 0.05$) (Fig. 3c); Ardeidae density was higher in winter than in autumn and spring both in sites A (both post hoc $p < 0.05$) and B (both post hoc $p < 0.01$) (Fig. 3c).

DISCUSSION

The coastal wetlands at Chongming Dongtan have undergone drastic changes over the last two decades. *Spartina* is the invasive vegetation that has colonized the area since the mid-1990s and has rapidly spread throughout Chongming Dongtan (Wang *et al.* 2006, Gan *et al.* 2010, Ma *et al.* 2011). It gradually replaced the native plant communities (i.e., *Scirpus*, and *Phragmites*) and has become one of the most dominant plants on the intertidal flats. *Spartina* habitats, which are characterized by short and dense vegetation and reduced diversity and abundance of food resources, are unavailable for shorebird and other saltmarsh bird specialists (Guntenspergen & Nordby 2006, Wang *et al.* 2006, Gan *et al.* 2010, Ma *et al.* 2011). During the last decade, several wetlands (e.g., sites B and C in this study) were restored by removing *Spartina* and incorporating native habitat types (mudflats, open water, and *Phragmites*) to attract a diverse group of waterbirds. Previous studies indicated that these restored wetlands could be used by diverse group of waterbirds to some extent (Zhang *et al*. 2013).

Migratory waterbirds exhibit relatively little site fidelity, and as a result, their preferences for foraging and roosting locations can indicate the habitat quality of natural and restored wetlands (Frederick *et al.* 2009, Robledano *et al.* 2010, Ke *et al.* 2011). Previous studies indicated that waterbirds could colonize restored wetlands rapidly (Passell 2000, Armitage *et al.* 2007). In this study, a total of 35,593 individuals, corresponding to 62 species, were observed, including 11 rare species (listed by IUCN) were also noted. In this study, numerous restored sites (e.g. site C) had a similar or higher species diversity, richness, and waterbird densities as the natural wetland (Figs 2 & 3), which revealed that waterbirds could colonize restored wetlands rapidly, and the restored coastal wetlands served as a suitable habitat for waterbirds to some extent.

High habitat heterogeneity can increase species diversity, richness, and density, although some waterbirds may prefer homogeneous habitats (Danufsky & Colwell 2003, Armitage *et al.* 2007). In our study, higher habitat heterogeneity in site C (*SHDI* = 2.44), with a mix of open water, *Phragmites*, and mudflat, was probably the proximate cause of the higher species diversity, richness, and waterbird density in site C than in sites A, B, and D (Table 1, Fig. 2). On the other hand, the higher species diversity and richness and lower *SHDI* in site B was probably due to sufficient food resources for Natatores (e.g., Anatidae, *Tachybaptus ruficollis*, etc.) and Grallatores (Ardeidae, *Gallinula chlorpus*, *Fulica atra*, etc.).

Restored wetlands were not used equally by different waterbirds (Brawley *et al.* 1998, Snell-Rood & Cristol 2003, Armitage *et al.* 2007, O'Neal *et al.* 2008). Charadriidae preferred sites C (roosting) and D (foraging) which have more mudflats (sites C and D) and *Scirpus* (site D). Anatidae preferred site C (roosting) which has a mix of open water and *Phragmites* (site C). Ardeidae preferred site B (foraging) which has sufficient food resources and site C (roosting) which has a mix of open water, *Phragmites*, and mudflat. Laridae preferred site D (foraging) which has sufficient food resources and a mix of open water, *Scirpus*, and mudflat. Similar to other wetland restoration studies (Danufsky & Colwell 2003, Armitage *et al.* 2007), differences in habitat preference among species illustrated that wetlands should be restored by incorporating diverse habitat types (Danufsky & Colwell 2003, Armitage *et al.* 2007). Mudflats and *Scirpus* are important foraging and roosting habitats for Charadriidae and Laridae (Ma *et al.* 2002, Xu & Zhao 2005, Tian *et al.* 2008, Fan *et al.* 2011). Open water, particularly the mix of open water and *Phragmites*, could serve as roosting habitat for Anatidae (Yu *et al.* 1995), while *Scirpus* could serve as foraging habitat (Ma *et al.* 2002, Xu & Zhao 2005, Tian *et al.* 2008, Fan *et al.* 2011).

Different characteristics of restored wetlands should be constructed by incorporating different habitat types among different seasons to meet the needs of various waterbirds, e.g., a larger area of mudflat for roosting should be constructed for Charadriidae and Laridae by lowering water depth during migration season (spring and autumn), but a larger area of open water mixed with *Phragmites* for roosting should be constructed for Anatidae by increasing water depth during wintering season (winter). However, usage of the restored wetlands by waterbirds could also be affected by anthropogenic disturbances (Miller *et al.* 2003, Rosa *et al.* 2003). In this study, lower species diversity, richness, and waterbird densities in site A was negatively related to the anthropogenic disturbances within higher habitat heterogeneity (Figs 2 & 3).

Furthermore, restored wetlands were used by most waterbirds as roosting sites (except site B). However, natural wetlands should not be replaced by restored wetlands because natural wetlands, particularly *Scirpus*, mudflats, and shallow water wetlands, are important foraging habitats for waterbirds (Yu *et al.* 1995, Tourenq *et al.* 2001, Ma *et al.* 2004, Tian *et al.* 2008, Fan & Zhang

2012). Similar studies also indicated that restored wetlands could not serve as a full ecosystem replacement for natural wetlands (Snell-Rood & Cristol 2003). We expect that multi-functional restored wetlands could be created, including roosting (similar to site C) and foraging habitats. The foraging habitat for waterbirds can be effectively accomplished via the re-establishment of *Scirpus* and the re-introduction of tidal flow.

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