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The importance of artificial habitats to migratory waterbirds within a natural/artificial wetland mosaic, Yellow River Delta, China

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Summary

Anthropogenic conversion of natural wetlands into artificial wetland habitats has produced complex wetland landscapes worldwide. In this study we investigated the responses of migratory and wintering waterbirds to five artificial wetland habitats (aquaculture ponds, paddyfields, irrigation canals, open water reservoirs and saltpans) within a novel natural-artificial wetland landscape, Yellow River Delta (YRD), eastern China from October 2007 to May 2008. The results showed that almost all bird community indicators in the YRD natural wetlands were higher than those in adjacent artificial wetlands. Across the landscape, natural wetlands remained most important for all waterbird guilds, and more than 90% of waterbird populations were dependent on these habitats. Artificial wetlands mainly provided a secondary role, supporting about 70% of waterbird species (including six species that reached 1% of their global or biogeographical flyway populations), but with distinctive functional capacity for specific waterbird guilds in different artificial wetlands. The conservation value of artificial wetlands is often ephemeral, mainly during autumn, for specific migratory waterbirds and complements that of remaining areas of natural wetlands. Therefore, the utilisation patterns of artificial wetlands are highly temporal and the majority of species are dependent on areas of natural wetland. A comprehensive study of the inter-seasonal and inter-annual variations in these different habitats and dependence by the various guilds in the YRD is required to enable the true value of these habitats to be understood. We suggest that the conservation of artificial wetlands should not be at the expense of natural wetlands, which should remain the priority for wetland landscape management. Management to maintain the existing artificial wetlands for migrating and wintering water birds should target habitat features that are absent or limited in natural wetlands thus increasing the carrying capacity of the YRD landscape.

Introduction

The extensive loss of natural wetlands globally (Goudie 2006) has reduced the quality of wintering habitats for many populations of migratory waterbird species, and has severely eroded the ecological integrity of migratory flyways (e.g. Cao *et al.* 2008, Rendón *et al.* 2008, Yang *et al.* 2011). Increased land-use for agriculture and aquaculture has created numerous artificial wetlands adjacent to and/or interspersed within remnant natural wetlands (Revenga *et al.* 2000, Czech and Parsons 2002). The resulting landscape presents new challenges for many wetland-dependent waterbird populations (Bellio *et al.* 2009, Kloskowski *et al.* 2009). Recent evidence suggests that in some instances, artificial wetlands can provide supplementary habitats for some migratory waterbirds (e.g. Ma *et al.* 2004, Elphick *et al.* 2010, Navedo *et al.* 2011) and reduce the impact of natural wetland habitat loss in some areas (Sebastián-González *et al.* 2010). Artificial wetlands may therefore represent a more cost-effective alternative to the conservation of natural wetlands (Elphick 2000, Huner *et al.* 2002, Longoni 2010).

Despite a growing consensus that artificial wetland habitats have a secondary, yet significant, role in avian conservation (Sánchez-Zapata *et al.* 2005, Taft and Haig 2005), critics point out that artificial wetlands cannot completely replace the functionality of natural wetlands, since specific ecological functions exist only in natural wetlands (Tourenq *et al.* 2001, Murray and Hamilton 2010). Furthermore, the entire natural/artificial wetland landscape may function as one ecosystem, with distinctive functional values of each component for different waterbird species (e.g. Kloskowski *et al.* 2009). The management of artificial wetlands often leads to temporary hydrological regimes and simplified physicochemical and topographical environments (Elphick 2000, Ma *et al.* 2010). Variations in cultivation practices and large fluctuations in seasonal environmental conditions are typical of artificial wetlands and may influence the patterns of habitat use by some waterbird guilds (Maeda 2001, Lourenco and Piersma 2009, Toral *et al.* 2011). Habitat use in artificial wetlands is influenced not only by characteristics of the habitat itself, but also by the nature of the surrounding landscape (Elphick 2008, Fasola and Brangi 2010, King *et al.* 2010). Within this framework, evaluating whether different artificial wetlands provide complementary habitats for migratory waterbird populations within natural/artificial wetland complexes remains an urgent global conservation priority (Bellio *et al.* 2009, Kloskowski *et al.* 2009).

The Yellow River Delta (YRD) is situated in the middle of the East Asian-Australasian flyway (EAAF), and has long been recognised as an important stopover site and wintering area for millions of migratory waterbirds, particularly Anatidae species and shorebirds (Barter 2002, Bamford *et al.* 2008, Zhu *et al.* 2000). More than 21 waterbird species have been reported to repeatedly reach 1% of their global or flyway population during migration merely in part of the Yellow River Delta Nature Reserve (Li *et al.* 2011), and more internationally important populations may use the large area of YRD wetlands during migration (Zhu *et al.* 2000). However, natural wetlands within the YRD continue to be degraded and replaced by a wide range of artificial wetlands (Cui and Liu 2001), resulting in the creation of a highly heterogeneous and novel wetland mosaic. Here we describe patterns of bird community, seasonal habitat use and associated anthropogenic effects on waterbird populations within this natural-artificial wetland landscape. We were particularly interested in the degree to which species or guilds are able to utilise natural and artificial wetlands within the landscape, or whether certain types of artificial wetlands can temporarily provide complementary habitats to natural wetlands by supporting an exclusive suite of species or guilds.

Methods

Study area

The Yellow River Delta (36°55′-38°16′ N, 117°31′-119°18′ E; Figure 1), one of the largest deltas in China, is located to the north-east of Dongying City, Shandong Province. It has evolved since the change in the Yellow River channel from the Xuhuai route to the Bohai Sea in 1855, along with several shifts in the river course, which ultimately produced a fan-delta with complicated patterns of land accretion and erosion (Li *et al.* 2009). The entire delta includes a large area of wetlands (6,237 km^2), with an average elevation below 15 m, of which 4,582 km^2 (73.5%) are natural and 1,655 km^2 (26.5%) are artificial wetlands (Cui and Liu 2001). Most of the wetlands occur on the coastline of the fan, whereas farmland and human residential areas are mainly present at the base of the fan. In the last decade, natural wetlands have evidently decreased mainly as a result of limited run-off and sediment discharge (Cui and Liu 2001, Li *et al.* 2009), whereas several kinds of artificial wetlands have continued to increase, either from the transformation of natural wetlands or their construction on other land bases. Artificial wetlands also occur near and within the Yellow River Delta National Nature Reserve, which contains two new deltaic lobes formed before and after the artificial change of the river course in 1976, with a total area of 1,530 km^2, of which 964.8 km^2 (63.1%) are wetlands. YRD is characterised by a temperate, semi-humid continental monsoon climate with a mean annual temperature of 12.1°C. Mean annual rainfall is 551.6 mm, occurring mainly in summer (Cui *et al.* 2009). This nature reserve was

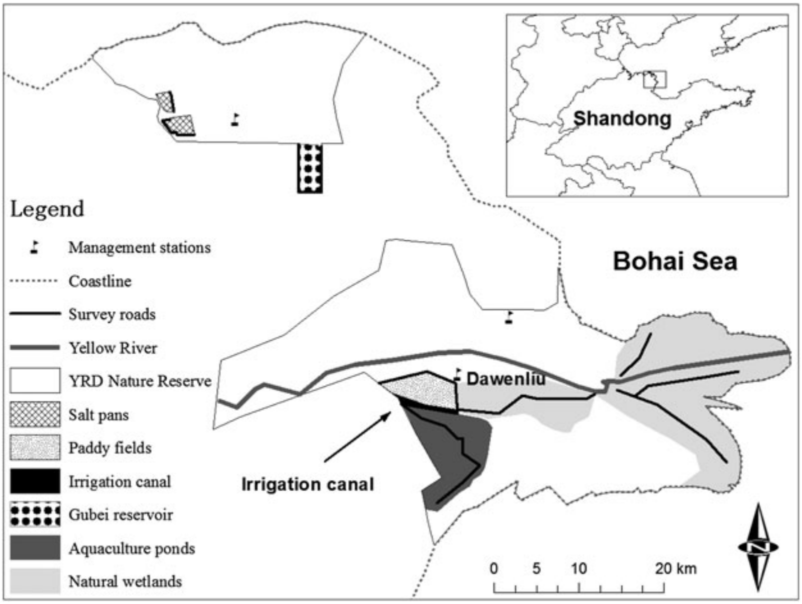

Figure 1. Location and distribution of the principal habitat components of the natural/artificial wetland landscape, Yellow River Delta, eastern China.

established mainly to protect the Yellow River wetland ecosystem and rare and endangered birds (Zhao and Song 1995).

Natural and artificial wetland habitats

For the purposes of this study we selected about 189 km^2 of typical natural wetland habitats, including estuarine wetlands, intertidal habitats, reed swamps and open water. We considered these to represent a single 'natural wetland habitat type' due to the lack of any contrasting (sharp) vegetation boundaries between them (with the possible exception of the vegetation-water edge). This area of natural wetland is adjacent to a series of artificial wetland habitats (see below). We also included some areas of restored wetland in the natural wetlands, such as reed marshes and open-water habitats, which are very similar to natural wetlands in other regions. Further details can be found in Li *et al.* (2011) and we will refer to these habitats as natural wetlands throughout.

In contrast, several distinctive artificial wetland habitat types are present and identifiable within the YRD landscape. Aquaculture ponds, primarily in intertidal mudflats, were recently created for commercial shrimp and fish farming. The ponds (1,140 ha) are situated near the southern Dawenliu Management Station along the shoreline, and hold brackish water pumped in from surrounding channels. Water levels are managed on an annual schedule, fluctuating in depth from five to 100 cm during April–November, after which the ponds are drained for harvest with only shallow water remaining. From December to March, the majority of aquaculture ponds remain dry.

Gubei reservoir (1,200 ha) represents another artificial wetland and is one of the largest reservoirs (n = 10) within the YRD. Gubei reservoir is located on the northern side of the nature reserve, where water depth is maintained at more than 1 m annually and aquatic vegetation and fish are abundant. Saltpans are one of the most widespread artificial wetland habitats along the coast of eastern China, although they cover the smallest area of all the artificial wetland types at our study site (750 ha). These ponds vary seasonally in salt content from brackish to saturated, range from a few centimetres to a few metres in depth, and contain simple but productive assemblages of algae and invertebrates.

Rice fields cover a small area, about 1,700 ha around the mouth of the YRD. The fields tend to be dry or partially wet without ploughing and other practices during post-harvest period (November–March). During this stage, abundant rice grains and other vegetation attract birds to these habitats. The final artificial wetland habitat type consists of one of the major irrigation canals of the YRD. Mean water levels within this 150 ha canal vary between 0.5 and 1 m annually, and it is dominated by the common reed *Phragmites australis*.

Waterbird surveys

Waterbird surveys were conducted at 8–10-day intervals in natural wetlands, aquaculture ponds, the irrigation canal, and paddyfields from October 2007 to May 2008. Monthly censuses were conducted in Gubei reservoir and saltpan habitats from October 2007 to May 2008 as they are too far from Dawenliu Management Station (Figure 1). These dates correspond to the entire wintering and migration periods of waterbirds along the East Asian–Australasian Flyway (Zhang *et al.* 2004). Direct counts were used in waterbird surveys which were conducted by fully trained observers using binoculars and telescopes. Each count consisted of a single scan of the study area to document the species, number of individuals, and habitat being used by all waterbirds (Bibby *et al.* 2000). Counts were of individual birds and flocks composed of > 500 individuals were estimated by counting blocks of 10, 20, 50, and 100 individuals (Zhang *et al.* 2004, Yang *et al.* 2011). The surveys were along possible pond levees, dykes or small roads through wetland landscape. As there was no high vegetation or sight barrier in most wetland habitats, almost all bird populations could be counted with the assistance of binoculars or telescopes. In order to minimise disturbance to birds, observers were positioned along pond levees and dykes > 50 m from the water. All surveys were conducted during suitable weather conditions (low wind, sunny days) between 06h00 and 16h00 in order to standardise each count period (Bibby *et al.* 2000).

Data analyses

Three distinct seasons were distinguished based on functions of non-breeding waterbird communities: southward migration (northern autumn; 1 September to 15 November), non-breeding period (northern winter; 16 November to 5 March) and northward migration (northern spring; 6 March to 1 May). We considered both autumn and spring to be migratory periods. We classified all waterbird species into nine guilds according to morphological characteristics and taxonomic groupings to reflect their different habitat requirements: (1) pelicans; (2) cormorants and grebes; (3) cranes; (4) coots; (5) large-bodied waterbirds (herons, egrets, bitterns, storks and spoonbills; (6) terns (*Chlidonias* spp., *Gelochelidon* spp. *and Sterna* spp.); (7) gulls (*Larus* spp.); (8) waterfowl (Anseriformes) and (9) shorebirds. The waterfowl and shorebird guilds were further divided into three sub-guilds respectively on the basis of the sensory mechanisms of food detection and the feeding style (Pöysä 1983, Barbosa and Moreno 1999): (8a) grazing swans and geese, (8b) dabbling ducks (*Aix* spp., *Anas* spp. *Tadorna* spp.), and (8c) diving ducks (*Aythya* spp., *Bucephala* spp. and *Mergus* spp.); (9a) pelagic foraging shorebirds (stilts, avocets, marsh sandpipers, redshanks, and greenshanks), (9b) visual surface-foraging shorebirds (plovers, sandpipers, lapwings, oystercatchers and snipes), and (9c) tactile surface-foraging shorebirds (curlews, godwits, knots and stints).

Waterbird species richness of each wetland was represented by both the observed species richness (OSR) and the estimated species richness (ESR). OSR was defined as the total number of species observed at each site. For ESR we used the Jackknife 1 estimator (Heltshe and Forrester 1983), calculated using the program EstimateS v. 7.5 (Colwell 2005) with sample order randomised 100 times to reduce the influence of the sample addition (Gotelli and Colwell 2001). Bird species diversity was represented by the Shannon–Wiener index (H'), which takes into account both species richness and the relative abundance of each species (Magurran 1988). Species evenness was represented by Pielou's Evenness (E) (Pielou 1966) and calculated using Bio-Dap software (Thomas and Clay 2000).

The abundance of waterbird species in each wetland was expressed as both the mean abundance (MA), representing the number of individuals per survey, and the maximum observed abundance (MaxA), representing the maximum observed number of birds of a given species per wetland type (e.g. Ma *et al.* 2009). MaxA was used because it provides better information on waterbird count data, particularly during the non-breeding season when the number of birds varied considerably among repeated surveys (Goss-Custard *et al.* 2002). Mean density (MD), representing the density of mean individual waterbird per survey (namely MD = MA/wetland area), and maximum observed density (MaxD), representing the density of the sum of maximum abundance of each waterbird species (MaxD = MaxA/wetland area), were calculated to compare of relative populations of waterbirds between wetlands of different sizes.

In order to determine the complementary habitat value between artificial wetlands versus natural wetlands, we calculated the exclusive and shared suite of species from the total waterbird community. Seasonal utilisation of wetland habitats were represented by comparing seasonal variation in the number of waterbird species and density. We used non-parametric Mann-Whitney U-tests to examine seasonal differences in both number of species and density measures following examination of all variables for normality using Kolmogorov-Smirnov tests. Statistical analysis was carried out in SPSS 16.0 for window (SPSS Inc., Chicago, IL, USA). All tests were two tailed and significance levels were established at $P < 0.05$. Values given are means ± SE, unless otherwise stated.

Results

Bird community measures

In total, 308,910 waterbirds representing 80 species were recorded during the surveys (see Table 1 for the number of surveys in each wetland). Of these, 284,897 (92.2%) individuals representing 73 species were recorded in natural wetlands and 24,013 (7.8%) individuals of 58 species were recorded in artificial wetlands. A greater number ($n = 17$) of species of conservation importance (>1% of their estimated global or flyway populations according to the most recent population estimates (Delany and Scott 2006) were recorded in natural wetlands than in artificial wetlands ($n = 6$) across the landscape (Table S1 in the online Supplementary Material). Five of these species important for conservation – Oriental White Stork *Ciconia boyciana*, Red-crowned Crane *Grus japonensis*, Hooded Crane *G. monacha*, White-naped Crane *G. vipio* and Spotted Redshank *Tringa erythropus*, were recorded in aquaculture ponds during October and November, while Hooded Crane and Common Crane *Grus grus* were recorded in paddyfields in October and February, respectively.

Both measures of species richness, relative abundance and mean density (MD), were considerably higher in natural wetlands (Table 1; Figure 2). The maximum observed density (MaxD) in natural wetlands was higher than in all artificial wetland types with the exception of aquaculture ponds and the irrigation canal. The Shannon–Weiner diversity index H′ of natural wetlands was higher than the indices of five artificial wetlands, but with slightly higher evenness E′ for aquaculture ponds, paddyfields, and saltpans (Table 1).

Bird community measures varied across all five artificial wetlands (Table 1). The majority of waterbird populations were recorded in aquaculture ponds (55.1%) and the Gubei reservoir (23.2%), both of which also had higher relative abundances (MA, MaxA) and mean densities (MD) of waterbirds. Species richness (OSR and ESR) and the Shannon–Wiener index H′ were also higher in aquaculture ponds. The Gubei reservoir and saltpan habitats had higher relative species richness than paddyfields or the irrigation canal, and the estimated species richness curves for the former two artificial habitats did not reach asymptotes (Figure 2).

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Table 1. Comparisons of waterbird communities between natural and artificial wetland habitats across the Yellow River Delta wetland landscape, eastern China. Values given are means ± SE.

Variable	Aquaculture ponds	Paddyfields	Irrigation canal	Saltpans	Gubei reservoir	Natural wetlands
Area (km^2)	11.4	17	0.8	7.5	12	139
Number of surveys	24	31	22	7	8	27
Observed species richness (OSR)	36	22	19	27	24	73
Estimated species richness (ESR)	44.5 ± 0.5	28.3 ± 0.5	25.6 ± 0.7	40.4 ± 0.4	45.8 ± 0.5	81.7 ± 0.5
Mean abundance (MA)	545.4 ± 207.2	87.2 ± 32.8	34.6 ± 8.8	267.9 ± 123.2	698.3 ± 245.9	10,552 ± 1,527
Mean density (MD)	47.8 ± 18.2	5.1 ± 1.9	43.2 ± 11.0	35.7 ± 16.4	58.2 ± 20.5	75.9 ± 10.9
Maximum abundance (MaxA)	6,412	1,653	540	1,452	3,514	49,639
Maximum density (MaxD)	562.5	97.2	675.0	193.6	292.8	357.1
Shannon–Wiener *H′*	1.41 ± 0.09	1.22 ± 0.09	1.01 ± 0.15	1.50 ± 0.10	1.16 ± 0.19	2.37 ± 0.07
Pielou's Evenness *E′*	0.70 ± 0.04	0.77 ± 0.03	0.65 ± 0.08	0.73 ± 0.03	0.58 ± 0.08	0.67 ± 0.02

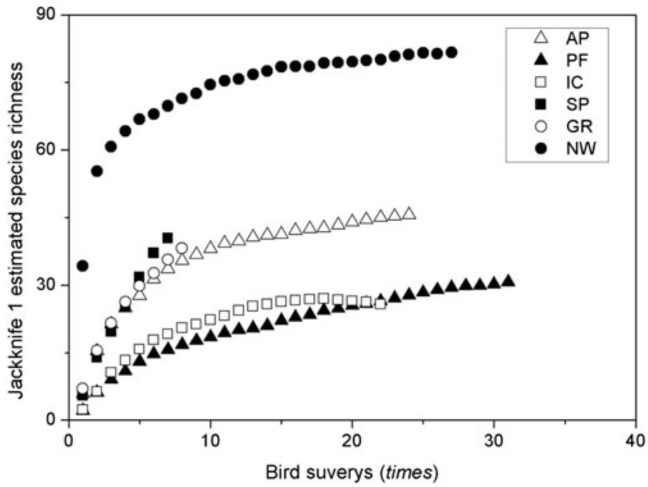

Figure 2. Sample-based rarefaction curves for Jackknife 1 estimated species richness (ESR) in natural and five different artificial wetland habitats across the YRD landscape, eastern China. AP, aquaculture ponds; GR, Gubei reservoir; PF, paddyfields; IC, irrigation canal; SP, saltpans; NW, natural wetlands.

Across all guilds, both the number of species and the maximum observed number of birds of a given species per guild were highest in natural wetlands except for Coots *Fulica atra* in the Gubei reservoir and pelagic foraging shorebirds in aquaculture ponds (Table 2). The main differences in both community measures between natural and artificial wetlands were attributed to the waterfowl (Anseriformes) and shorebird guilds. Further differences were seen in these two community measures across all five artificial habitats (Table 2). Aquaculture ponds had a higher number of species and larger populations of cranes, storks, egrets and herons, as well as all shorebird sub-guilds. Gubei reservoir had the highest number of coots, cormorants and grebes, as well as dabbling

Table 2. Relative number of species (N) and abundance (MaxA) of different waterbird guilds across different natural and artificial wetland landscape components. Abbreviations of wetland types as in Figure 2.

Guild	AP		PF		IC		SP		GR		Natural wetlands	
	N	MaxA	N	MaxA	N	MaxA	N	MaxA	N	MaxA	N	MaxA
Pelicans	0	0	0	0	0	0	0	0	0	0	1	13
Cormorants and grebes	2	764	2	74	3	37	2	8	3	220	3	3,146
Coots	0	0	1	16	0	0	0	0	1	2,000	1	1,162
Cranes	5	155	3	196	1	111	0	0	0	0	5	299
Large-body waders	6	316	5	18	3	46	2	39	1	1	10	938
Terns	1	253	0	0	1	20	4	350	1	2	3	567
Gulls	4	556	0	0	4	67	3	183	1	1	5	4,848
Grazing swans and geese	2	112	2	461	0	0	1	98	2	355	6	4,469
Dabbling ducks	4	465	4	37	2	162	5	347	9	802	13	22,303
Diving ducks	1	5	0	0	1	60	2	14	3	114	6	1,275
Pelagic foraging shorebirds	5	1,782	3	7	3	34	4	350	3	19	4	539
Visual foraging shorebirds	3	528	1	4	1	3	2	11	0	0	8	1,825
Tactile foraging shorebirds	3	1,476	1	840	0	0	2	52	0	0	8	8,255
All birds	36	6,412	22	1,653	19	540	27	1,452	24	3,514	73	49,639

duck and diving duck sub-guilds, although the number of Anatidae species was only a half that found in natural wetlands. Saltpans were the most species-rich habitat for terns and gulls and also had a relatively high number of shorebird and dabbing duck species. Paddyfields had the highest population of cranes and some herbivorous ducks and geese (see also Table 2).

Wetland habitat utilisation

The majority of the 80 species ($n = 51$, or 63.8%) were distributed in both natural and artificial wetlands throughout the landscape. More species were restricted to natural (22 species) than artificial wetlands (7 species), although the overall population percentages of exclusive species are relatively very low (Figure 3b). The majority of species restricted to natural wetlands belonged to the waterfowl guild (e.g. Tufted Duck *Aythya fuligula*, Tundra Swan *Cygnus columbianus*) and shorebird guild (e.g. Eurasian Curlew *Numenius arquata*, Great Knot *Calidris tenuirostris*), which depend on open water habitats and coastal tidal mudflats, respectively. Of the artificial wetlands, Green Sandpiper *Tringa ochropus*, Common Snipe G*allinago gallinago*, Little Curlew *Numenius minutus* were found exclusively in paddyfields, whereas Whiskered Tern *Chlidonias hybridus*, Little Tern *Sterna albifrons*, Common Sandpiper *Actitis hypoleucos*, and Marsh Sandpiper *Tringa stagnatilis* were exclusive to saltpans. Both these artificial wetlands also had a relatively higher percentage of exclusive bird species than the other artificial wetlands (Figure 3a, b), suggesting that they may play a more important role in habitat complementarity within the wetland landscape. The majority of the waterbird communities in the remaining artificial wetlands were shared with the natural wetlands.

Utilisation of both natural and artificial wetlands by birds varied seasonally, but changes in the overall patterns of utilisation were quite different between natural and the majority of artificial wetlands (Figure 4a, b). Natural wetlands functioned as the core habitats for waterbird communities throughout the year, and were predominantly utilised by birds during the two migration seasons (density: Mann-Whitney U- test, $U = 8.0$, $P = 0.004$). The majority of waterbird species used artificial wetlands, particularly aquaculture ponds (number of species and density: Mann-Whitney U- test, all $P < 0.05$), during the autumn, and less so during winter and spring (Figure 4a, b). Similar results are apparent for exclusive species, where most of the waterbird species restricted to artificial wetlands were recorded during autumn, particularly those utilizing aquaculture ponds, paddyfields and saltpans (Figure 5a, b). During the spring season, natural wetlands served as the most important habitats for northern migrants.

Discussion

Almost all bird community measures in the YRD natural wetlands were higher than those in the adjacent artificial wetlands. Natural wetlands also provided suitable habitat for almost all guilds and represented the core habitat for migratory waterbird species, whereas artificial wetland habitats appear to fulfil a more secondary role for waterbirds within the YRD landscape. There are exceptions to this trend, as aquaculture ponds supported the most species of cranes, storks, egrets and herons, as well as shorebird guilds. This is probably related to the temporal availability of shallow water and mudflats during the post-harvest stage (Young and Chan 1997), as a greater diversity and biomass of fish, shrimp, and macro-invertebrates typically occur in the shallow water and exposed mudflats. These observations contrast starkly, however, with a previous study from the Yangtze River estuary, Shanghai, China, where aquaculture ponds were mainly used by numerous Anatidae species in winter due to their deeper water habitat (Ma *et al.* 2004). In the YRD, aquaculture ponds are exposed to long dry periods during winter and early spring, forcing waterbirds to move into other wetland habitats nearby (Li *et al.* 2011).

Our results can be partially attributed to the survey methodology and effort employed. For example, the area of artificial wetlands surveyed was approximately only a third of the total area of

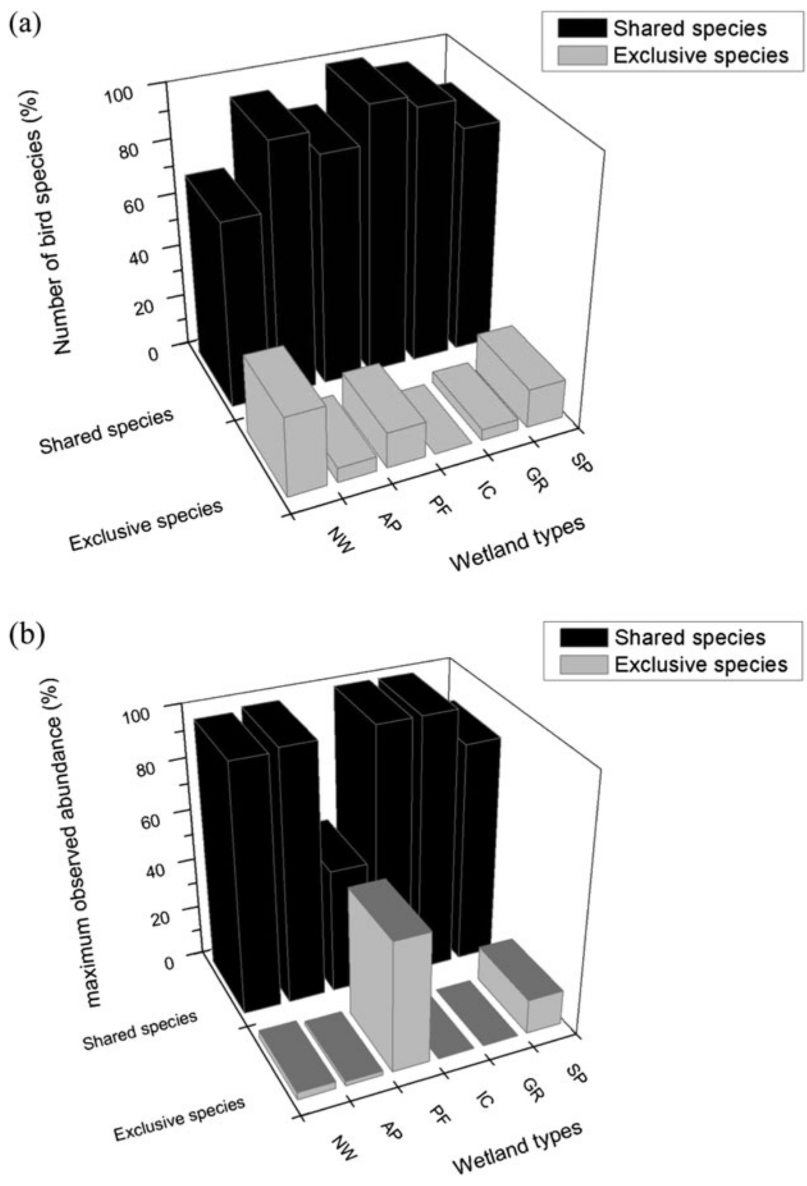

Figure 3. Percentage of species (a) and maximum observed abundance (b) of exclusive species between natural and artificial wetlands in YRD wetlands, eastern China. Abbreviations of wetland types as in Figure 2.

natural wetland surveyed, and surveys were conducted less frequently in reservoir and saltpan habitats. Nevertheless we still identified guilds that were specific to some of the artificial wetlands e.g. Gubei reservoir serves as an important permanent habitat for dabbling ducks and diving ducks within the landscape. Furthermore, there were clear differences in guild composition between artificial wetlands (Table 2), possibly reflecting the variation in ecological resources provided by different habitats. Interestingly our five artificial wetlands together included almost all the guilds present in the natural wetlands. This phenomenon may also be very scarce in the natural/artificial

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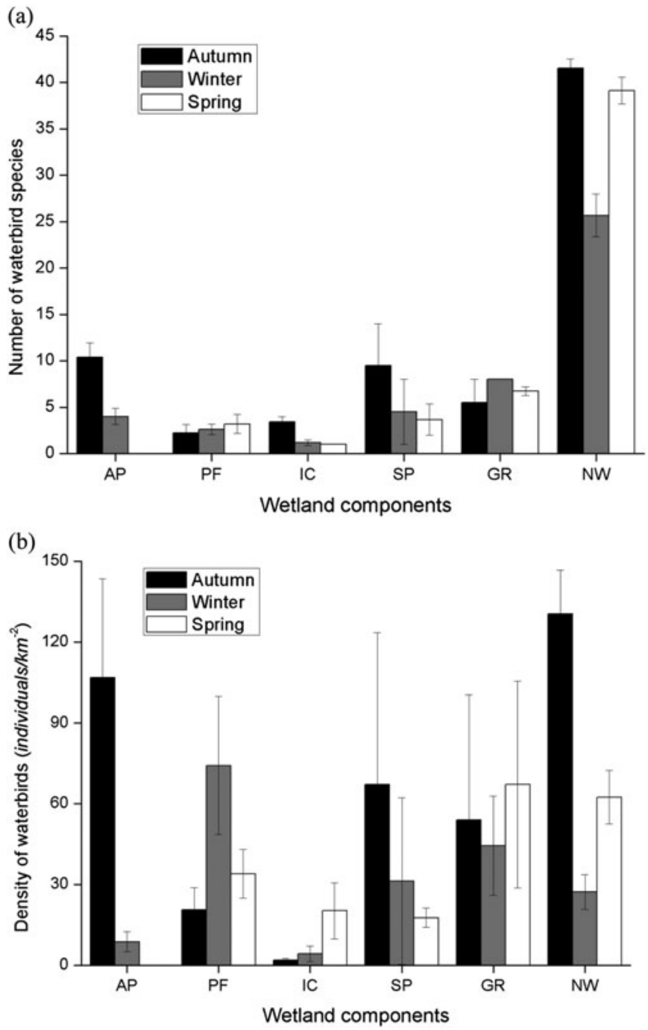

Figure 4. Seasonal variations in waterbird species richness (a) and waterbird density (b) in natural and artificial wetland habitats across the Yellow River Delta landscape. Abbreviations of wetland types as in Figure 2. Values given are means ± SE.

wetland landscape as the transformation of natural wetland is always driven by special human economic interests (Elphick 2000, Ma *et al.* 2004, Dias 2009). A uniform artificial wetland would greatly erode the diversity of waterbirds, even though some bird guilds would benefit (Richardson and Taylor 2003, Navedo *et al.* 2011).

In comparison with other studies which were limited to examining fewer types of artificial wetland, we found that the five artificial wetlands supported more waterbird species and higher populations than those previously reported (Fujioka *et al.* 2001, Tourenq *et al.* 2001). Nearly 75% of all waterbird species and 10% of numbers were found in artificial wetlands, with about 50% of the waterbird populations in paddyfields alone being distinctive from those found in the natural wetlands. Seven waterbird species used artificial habitats exclusively and six species reached 1% of their estimated biogeographical flyway populations in the YRD artificial wetlands. This suggests that the mosaic of artificial and natural wetland habitats is of critical importance for YRD

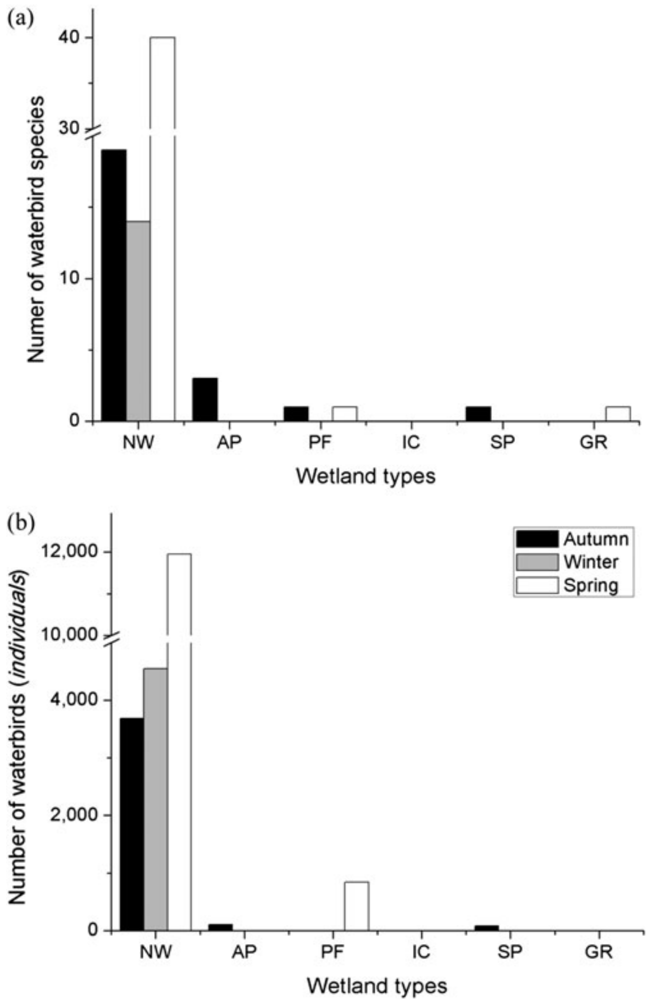

Figure 5. Seasonal variation in number of species (a) and maximum observed abundance (b) in different wetland types, YRD wetlands landscape, eastern China. Abbreviations of wetland types as in Figure 2

regional waterbird diversity, similar to previous studies in Doñana, south-west Spain (Rendón *et al.* 2008, Kloskowski *et al.* 2009) and south-east Sri Lanka (Bellio *et al.* 2009).

The high percentage of shared species between natural and artificial wetlands may be attributed to similar spatial and structural characteristics. For example, Gubei reservoir offers a similar open body of water to some natural wetlands. Saltpans provided shallow water habitat for shorebirds and gulls, mirroring the findings of other waterbird research (Warnock *et al.* 2002, Masero 2003). Of particular conservation interest was the large number of Whooper Swans *Cygnus cygnus* assembled in saltpans during mid-winter, when other freshwater bodies nearby had become frozen. Movement of waterbirds between natural and artificial wetlands as part of daily flights between roosting sites and feeding sites (e.g. Dodd and Colwell 1998, Guillemain *et al.* 2002) may also account for these results. Aquaculture ponds and paddyfields within the YRD may serve as a rich food resource in both these artificial habitats, and they occur in close proximity to natural wetlands (Figure 1). White-naped Cranes and Common Cranes mainly subsisted on rice grains during the post-harvest period within paddyfields. Studies on Korean waterbird populations found that post-harvested paddyfields can be substantially utilised by Red-crowned and White-naped Cranes (Lee *et al.* 2007). Further research on habitat quality and use by the different guilds to understand species specific food and feeding requirements through detailed field observations to clarify the daily and seasonal movements by waterbird species between adjacent natural and artificial wetlands within the YRD (such as through radio-telemetry studies) is necessary.

Patterns of seasonal use of artificial wetlands by waterbirds were very different from those in natural wetlands. Natural wetlands were extensively used throughout the non-breeding season, whereas artificial wetlands were predominantly utilised during autumn, and less so during winter and spring. This seasonal pattern highlights the supplementary role of artificial wetlands in providing important temporal resources for many waterbird guilds within the YRD wetland landscape. The temporal importance of artificial wetlands and neighbouring fields for waterbird conservation has been highlighted in recent studies elsewhere (Elphick and Oring 2003, Richardson and Taylor 2003, Toral *et al.* 2011). A comprehensive study of the inter-seasonal and inter-annual variations of these different habitats and dependence by the various guilds in the YRD is urgently required to enable the true value of these habitats to be understood.

Whilst our results are encouraging, we stress caution in emphasising the role of artificial wetlands for waterbird conservation in the YRD on the basis of our preliminary analysis, since it may inadvertently encourage further exploitation and accelerate the loss of natural wetlands.

Implications for wetland landscape conservation

Complex mosaics of natural and artificial habitats are becoming increasingly prevalent across wetland landscapes (e.g. Rendón *et al.* 2008, Bellio *et al.* 2009). Our study is an example of how such mosaics influence patterns of waterbird community composition and abundance. Artificial wetlands have a temporal conservation value for specific waterbird guilds within these landscapes that is complementary to that of remaining natural wetlands. Nonetheless, patterns of utilisation are highly temporal and the majority of waterbirds across these novel landscapes are dependent on natural wetlands. We stress that the conservation of artificial wetlands should not be at the expense of natural wetland landscape components, which should remain the priority for wetland management. Management to maintain existing artificial wetlands for migrating and wintering waterbirds should target habitats that are absent or limited in natural wetlands by taking into account the requirements of various guilds of birds (e.g. Taft *et al.* 2002) thus increasing the carrying capacity of the YRD wetland landscape.

Supplementary Material

The supplementary materials for this article can be found at journals.cambridge.org/bci

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