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ORIGINAL ARTICLE

Industrial rice farming supports fewer waterbirds than traditional farming on Chongming Island, China

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Abstract

Natural wetlands in coastal areas have been reclaimed in China and other regions of Asia. The reclaimed lands have been used for large-scale industrial farming, replacing traditional farming methods, especially in rice fields. To understand the impact of land-use conversion on biodiversity, particularly of coastal migratory waterbirds, we selected two study sites in Chongming Island, China, representing traditional rice fields versus industrial rice farms. At each site, we carried out waterbird population surveys, measured the environmental factors hypothesized to be important in determining waterbird abundance, and analyzed the effects of the different farming patterns on waterbird populations. Over two annual cycles (from August 2013 to May 2015), 39 waterbird species were observed, with a mean density of 29.3 ± 5.4/ha, on traditional rice fields, compared with 16 species with a mean density of 2.8 ± 0.4/ha on large-scale industrial rice farms. Our results demonstrated that waterbird diversity was higher on traditional rice fields than on industrial rice farms. Analyses of habitat characteristics and waterbird populations showed that traditional rice fields had more preferred habitats for waterbirds, such as more open-water cover areas, lower bare mud cover areas, lower rice plant density, no concrete-covered areas and flooding in the winter. The results suggested that the replacement of traditional rice fields with large-scale industrial rice farms has had a significantly negative impact on migratory waterbirds using the East Asian–Australasian Flyway; such a change could also have detrimental effects on waterbird conservation efforts in China and other countries along this important migration route.

KEYWORDS

Chongming Shanghai, EAAF, rice farming, traditional versus industrial agriculture, waterbird conservation

1 | INTRODUCTION

Globally, migratory waterbirds are facing serious threats, and declines in waterbird populations are widespread among the nine major flyways of the world (Szabo, Battley, Buchanan, & Rogers, 2016; Wetlands International, 2014). The East Asian–Australasian Flyway (EAAF) is one of the world's most important shorebird flyways, and has the highest proportion (19%) of threatened waterbird populations (MacKinnon, Verkuil, & Murray, 2012). The EAAF begins in overwintering sites in Australia and New Zealand, skirts the coastline of China and other regions of Southeast Asia and East Asia to reach the breeding sites in Siberia and Alaska (Szabo, Battley, et al., 2016). A higher number and greater proportion of waterbirds are globally threatened in the EAAF than in any of the other major flyways of the world (Studds et al., 2017; Yong et al., 2018). Observed percentages of waterbird species decline in the EAAF are among the highest of any major flyway worldwide (Amano, Székely, Koyama, Amano, & Sutherland, 2010). The annual

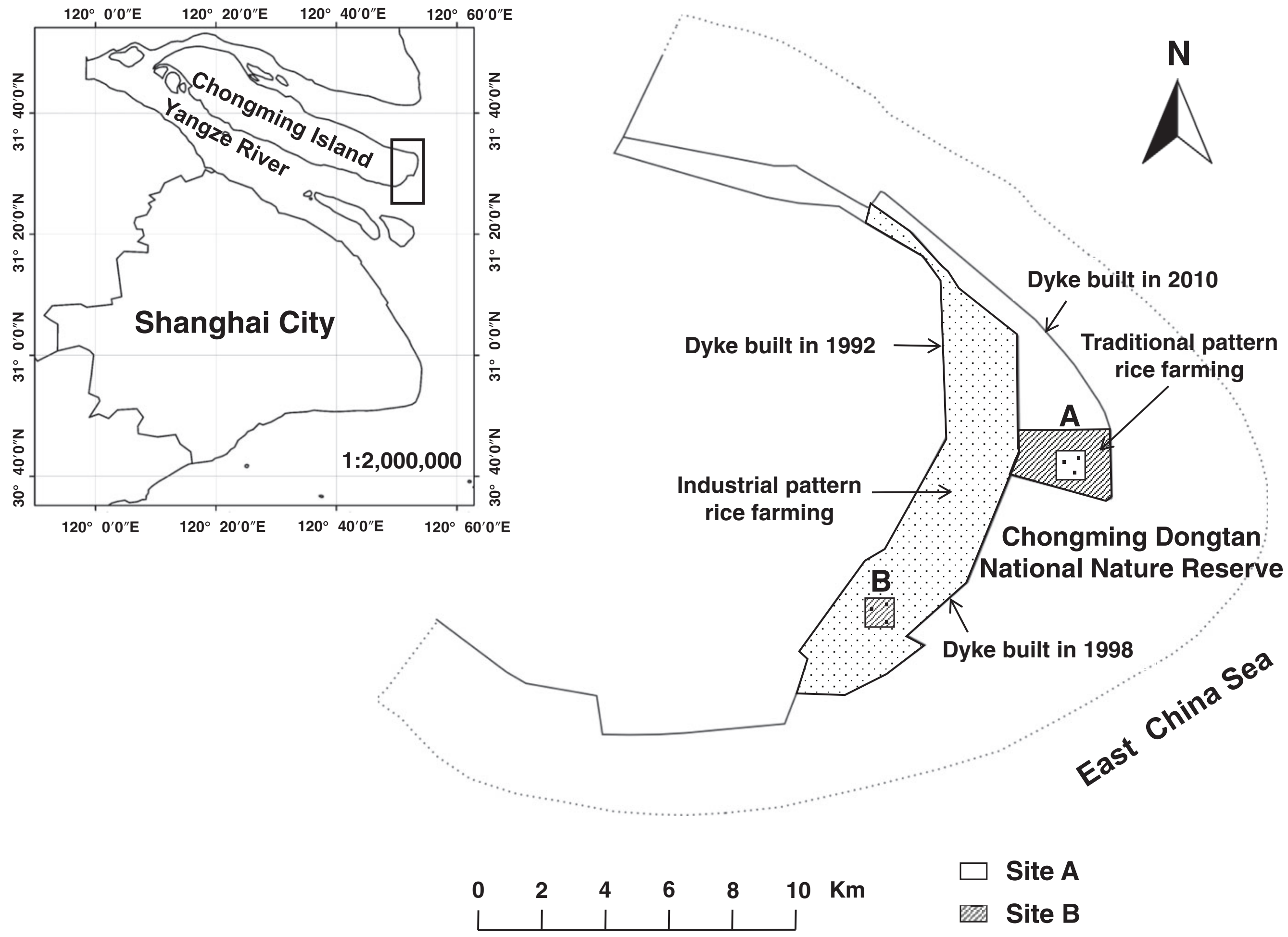

FIGURE 1 The location of the study area (Chongming Dongtan, Shanghai) and study quadrats. The inset shows the study area in the Yangtze River Estuary. Site A represents traditional rice fields, located between Dyke 1998 and Dyke 2010, and Site B represents industrial rice farms, located between Dyke 1998 and Dyke 1992. Three quadrats were selected in each study site

of traditional rice fields is low, with a mean density of 1.5×10^5 plants/ha. Roads and drainage channels in traditional rice fields are nonconcrete.

By contrast, Site B (Figure 1), located between Dyke 1998 and Dyke 1992, with a total area of approximately 1,500 ha, is owned by the local government and managed by a local farming company using an industrial farming model. In general, industrial rice farms are rice monocultures, occur on a large scale and are managed by collaborations with mechanized planting. The rice planting density of industrial rice farms is high, with a mean density of 2.4×10^5 plants/ha. Roads and drainage channels in industrial rice farms are concrete-covered.

Traditional rice fields and industrial rice farms have the same rice planting and harvesting times, with rice seedlings planted during early May and transplanted during early June, and tassels form during late August and harvesting begins during late October. Traditional rice fields remain flooded after harvesting, with a water level of 5 and 25 cm, whereas industrial rice farms are drained during the nongrowing season.

2.2 | Data collection

2.2.1 | Sampling methods

Rice field units in traditional rice fields and on industrial rice farms have the same construction, with a length of approximately 120 m, width of approximately 70 m, and an area of 0.9 ± 0.1 ha. Both rice field units include a rice paddy with roads and irrigation canals, and surrounded by levees. We chose one rice field unit as a study quadrat, and three quadrats were randomly selected in each study site (Figure 1). Each quadrat was located in the distance of 0.5 and 1 km from the intertidal zone; this zone was characterized by mudflats and shallow water, and provides an optimal foraging habitat for waterbirds, according to previous studies in Chongming Dongtan (Ma et al., 2009; Zou et al., 2014). For systematic and comparable investigations, we selected three quadrats within a 600×600 m^2 zone in each site; to minimize the effects of quadrats on each other and the autocorrelation of differences between quadrats, each quadrat was separated from the next by at least 500 m; to minimize the marginal habitat effect on waterbird abundance and diversity, no quadrats were placed on field margins in either study site (Figure 1).

2.2.2 | Waterbird surveys

Surveys were performed over two complete years. Four seasons were identified according to the patterns of spring and autumn migration and the arrival of winter migrants: autumn (mid-August–early November), winter (early November–mid-March), spring (mid-March–mid-May) and summer (mid-May–early August) (Wang & Qian, 1988). Previous reports showed that waterbirds were most abundant in spring, autumn and winter in the study area, with only a few migrants and residents occurring during the summer (Ma et al., 2004; Zou et al., 2014). Therefore, we surveyed the waterbird population during the autumn and winter of 2013 and 2014, and the spring of 2014 and 2015. Five waterbird surveys were performed semimonthly in each season, making a total of 30 waterbird surveys across the 2 years.

Surveys began 2 hrs after sunrise so that enough light was available to aid species identification (Ibáñez, Curcó, Riera, Ripoll, & Sánchez, 2010). Each quadrat was scanned for at least 2 minutes; there was no maximum time limit for completing a count, although we completed the count as rapidly as possible to avoid double counting birds (Strum et al., 2013). All quadrats were surveyed from around the paddies (along either the levees or roads). All waterbirds were identified to species level and all individuals in the survey area were counted; however, any waterbird that only flew over the survey area was not included in the survey.

Waterbirds in rice fields in Chongming Dongtan are dominated by four main waterbird groups: shorebirds (Charadriidae), dabbling ducks (Anatidae), long-legged waders (Ardeidae) and "Others," including other waterbird orders, such as Gaviiformes (little grebe [*Tachybaptus ruficollis*]), Pelecaniformes (great cormorant [*Phalacrocorax carbo*]) and Gruiformes (common moorhen [*Gallinula chloropus*] and Eurasian coot [*Fulica atra*]). Therefore, these four waterbird groups were the main groups studied here. The names of the waterbird species were taken from the IOC World Bird List (version 8.2) (Gill & Donsker, 2018).

2.2.3 | Environmental characteristics

Habitat characteristics were measured in the quadrats where waterbirds were counted during each survey. The environmental characteristics monitored at each study site are shown in Table 1. We visually estimated the percentage of open-water cover areas, bare mud cover areas and rice cover areas in each survey area. With little microtopography, rice fields have no significant fluctuations in water levels; thus, we recorded water depth to the nearest centimeter during each survey using two color-coded wooden stakes placed along the center of each survey quadrat at 10 and 20 m from the survey point (Strum et al., 2013).

TABLE 1 The environmental characteristics measured at each study site

Environmental characteristic	Description	Measuring unit
Open-water cover areas	Percentage of open-water cover areas in each rice paddy	%
Water level	Water depth in each rice paddy	cm
Rice cover areas	Percentage of rice cover areas in each rice paddy	%
Rice planting density	Row spacing and planting distance of rice units used to calculate mean density of rice in each rice paddy	No./ha
Bare mud cover areas	Percentage of bare mud cover areas in each rice paddy	%
Concrete-covered areas	Percentage of concrete roads and drainage areas in each rice paddy	%

Concrete-covered areas in industrial rice farms included roads and drainage areas. There were no concrete-covered areas on traditional rice fields. GPS trajectory calculations and tape measures were used to estimate the percentage of concrete-covered areas only once during the study period, because it was unlikely to change year by year.

In the study region, the rice growing season covers both summer and autumn. Rice planting density and the percentage of rice cover areas in each rice paddy were measured once during each autumn; we selected three $2 \times 2\ m^2$ rice paddy quadrats to calculate the mean density of rice planting in the six study quadrats. The percentage of open-water cover areas, bare mud cover areas, and water level were measured once during each survey (Table S1).

2.3 | Data analysis

The distribution of waterbirds in each study site was described using the following measures: (a) species richness, expressed as the number of species: the total number of waterbird species observed over five repeated surveys was treated as waterbird species richness in one study quadrat in each season; and (b) waterbird density, expressed as the number of individuals/ha both in total and for each of the four waterbird groups (Charadriidae, Anatidae, Ardeidae and Others): the mean waterbird density over five repeated surveys was treated as the waterbird density in one study quadrat in each season, and the mean environment variable over five repeated surveys was treated as one environment variable in one study quadrat in each season.

The data of species richness and waterbird densities were analyzed using the Shapiro–Wilk test to determine whether they conformed to the assumptions of normality, and an independent t test was used to determine any differences between traditional rice fields versus industrial rice farms. To examine any differences in species richness and waterbird densities between the first and second years, we used a nonparametric two related samples test followed by a sign test.

Pearson correlation was used to calculate the correlation coefficients between waterbird variables and environmental variables. Redundancy analysis (RDA) was used to investigate the relationship between species richness, waterbird densities, the densities of four waterbird groups (Charadriidae, Anatidae, Ardeidae, and Others), and six environmental variables at the sampling stations to determine which environmental variables were the major factors influencing the waterbird populations in the rice fields (Choi, Battley, Potter, Ma, & Liu, 2014). RDA was calculated using CANOCO (version 5.1).

The statistical analyses were carried out using the software package SPSS (version 23.0). A significance level of $p < 0.05$ was used for all statistical tests. Data were expressed as the mean ± *SE*.

3 | RESULTS

There was no significant difference in the species richness (40 species recorded in each year) and waterbird densities ($p = 0.692$, $n = 18$, seasonal times = 5) between the first and second years. Therefore, we used the total number of waterbirds recorded across the 2 years in the statistical analyses, the test sample size was 6 (two rice farming patterns × three quadrats) with five repeated surveys in each season across the 2 years.

3.1 | Species richness

A total of 43 waterbird species were recorded during the study, 39 species from traditional rice fields and 16 species from industrial rice farms (Table S2). Thus, the total number of species observed per quadrat in traditional rice fields in 1 year was 25.7 ± 1.4, which was significantly higher than in industrial rice farms (9.5 ± 1.9) ($t = 6.775$, $p < 0.001$, $n = 6$, seasonal times = 5).

When seasonal variation was taken into account, during the autumn, there were 27 waterbird species, with a species richness of 13.7 ± 1.8 in each quadrat on traditional rice fields and 12 species with a species richness of 6.5 ± 1.1 on industrial rice farms. During the winter, there were 21 waterbird species with a species richness of 13.8 ± 0.3 in each quadrat on traditional rice fields and nine species with a species richness of 4.2 ± 1.4 in each quadrat on industrial rice farms. During the spring, there were 20 waterbird species with a species richness of 10.7 ± 1.3 in each quadrat on traditional rice fields and eight species with a species richness of 3.8 ± 1.1 in each quadrat on industrial rice farms. Traditional rice fields had significantly more species than industrial rice farms during autumn ($t = 3.380$, $p = 0.010$, $n = 6$, seasonal times = 5), winter ($t = 6.972$, $p < 0.001$, $n = 6$, seasonal times = 5), and spring ($t = 4.080$, $p = 0.002$, $n = 6$, seasonal times = 5) surveyed across the two study years.

Over the study period, the most abundant species on traditional rice fields were: green-winged teal (*Anas carolinensis*) (22.9% of the total number of waterbirds recorded at Site A), eastern spot-billed duck (*Anas zonorhyncha*) (12.7%), spotted redshank (*Tringa erythropus*) (8.6%), common greenshank (*Tringa nebularia*) (7.2%), wood sandpiper (*Tringa glareola*) (5.8%), and dunlin (*Calidris alpina*) (5.3%). Near-threatened species were found on traditional rice fields, such as curlew sandpiper (*Calidris ferruginea*), rufous-necked stint (*Calidris ruficollis*) and falcated duck (*Mareca falcata*), as well as endangered species, such as black-faced spoonbill (*Platalea minor*) (IUCN, 2018).

The most abundant species on industrial rice farms over the study period were: little egret (*Egretta garzetta*) (22.2%), little grebe (17.8%), eastern cattle egret (*Bubulcus coromandus*) (13.0%), common moorhen (12.5%), common sandpiper (*Actitis hypoleucos*) (5.3%), and northern lapwing (*Vanellus vanellus*) (5.3%). Near-threatened species were found on industrial rice farms, such as northern lapwing (*V. vanellus*) (IUCN, 2018).

3.2 | Waterbird densities

Over the 2-year study, a total of 2,405 individuals was recorded by the 30 surveys; 2,197 individuals (91.6% of the total number of waterbirds recorded in the survey) were recorded from traditional rice fields, with a density of 29.3 ± 5.4/ha, whereas only 208 individuals (8.6%) were recorded on industrial rice farms, with a density of 2.8 ± 0.4/ha. Thus, most waterbirds showed a preference for traditional rice fields rather than industrial rice farms ($t = 4.879$, $p < 0.001$, $n = 18$, seasonal times = 5) (Figure 2).

Waterbird densities were significantly higher on traditional rice fields (31.5 ± 14.3/ha) than on industrial rice farms (4.0 ± 0.5/ha) during the autumn ($t = 2.947$, $p = 0.015$, $n = 6$, seasonal times = 5). Waterbird densities were significantly higher on traditional rice fields (36.0 ± 7.7/ha) than on industrial rice farms (2.6 ± 1.0/ha) during the winter ($t = 6.067$, $p < 0.001$, $n = 6$, seasonal times = 5). Similarly, waterbird densities were significantly higher on traditional rice fields (20.4 ± 3.2/ha) than on industrial rice farms (1.8 ± 0.5/ha) during the spring ($t = 7.880$, $p < 0.001$, $n = 6$, seasonal times = 5) (Figure 2).

3.3 | Density of waterbird groups

Most of the waterbirds recorded by the 30 surveys, regardless of study site, were Charadriidae (47.8%) and Anatidae (39.8%), followed by Ardeidae (7.7%) and Others (4.7%). Most of the waterbirds on traditional rice

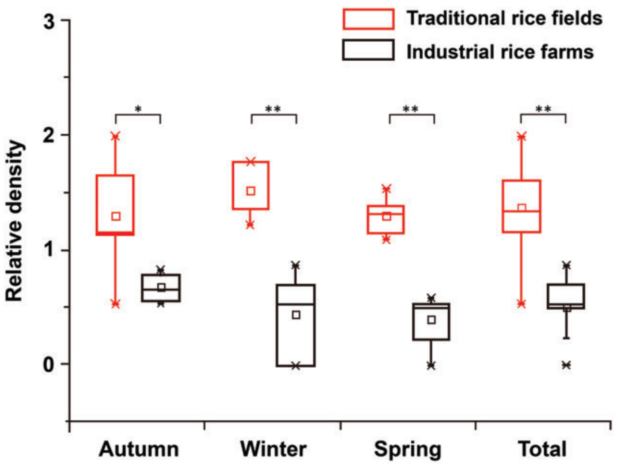

FIGURE 2 Boxplot of the relative density of waterbirds differentiation in traditional rice fields versus industrial rice farms in different seasons. The relative densities were transformed from waterbird densities [$\log_{10}(x + 1)$]. Asterisks denote significant differences (*: $p < 0.05$; **: $p < 0.01$) from *t* test. Upper and lower borders of the box, 75th percentile and 25th percentiles; horizontal line, median; upper and lower whiskers, maximum and minimum; asterisks, outliers defined as values above or below the box by $a > 1.5$-fold of the interquartile range

fields were Charadriidae (50.3%) and Anatidae (43.4%). On industrial rice farms, most of the waterbirds were Ardeidae (44.7%), followed by Others (32.2%), and Charadriidae (21.6%).

During the autumn, most of the waterbirds on traditional rice fields were Charadriidae (95.7%), whereas on industrial rice farms, most of the waterbirds were Ardeidae (66.7%), Charadriidae (18.2%) and Others (15.2%), with no Anatidae. During the winter, most of the waterbirds were Anatidae (72.1%) and Charadriidae (18.6%) on traditional rice fields, whereas on industrial rice farms, most of the waterbird were Others (58.5%), Ardeidae (21.5%) and Charadriidae (16.9%). During the spring, most of the waterbirds were Anatidae (58.7%) and Charadriidae (36.0%) on traditional rice fields, whereas on industrial rice farms most of the waterbirds were Charadriidae (36.4%), Ardeidae (31.8%) and Others (29.6%).

Charadriidae density on traditional rice fields (14.7 ± 5.1/ha) was significantly higher than on industrial rice farms (0.6 ± 0.1/ha) ($t = 2.744$, $p = 0.014$, $n = 18$, seasonal times = 5). Anatidae density on traditional rice fields (12.7 ± 3.6/ha) was significantly higher than on industrial rice farms (0.1 ± 0.1/ha) ($t = 3.519$, $p < 0.003$, $n = 18$, seasonal times = 5). There was no significant difference in Ardeidae density on traditional rice fields (1.2 ± 0.3/ha) compared with industrial rice farms (1.2 ± 0.3/ha) ($t = 0.000$, $p = 1.000$, $n = 18$, seasonal times = 5). Similarly, there was no significant difference in "Others" density on traditional rice fields (0.6 ± 0.1/ha) compared with industrial rice farms (0.8 ± 0.3/ha) ($t = -0.735$, $p = 0.457$, $n = 18$, seasonal times = 5).

3.4 | Impacts of environment characteristics on waterbird community composition

The correlation coefficient matrix of six environmental variables showed that there were correlations between environmental variables (Table S3). The results of the RDA ordination showed that all the canonical axes explained approximately 59.6% of the explained variation in the waterbird data and 99.9% of the explained fitted variation in the environment data; the cumulative explanation of the first two axes reached 51.0% of the explained variation (approximately 39.9 and 11.1% of the variation were explained by axis 1 and axis 2, respectively) and 85.6% of the explained fitted variation. Monte Carlo permutation tests for all canonical axes were significant (F = 8.8, $p = 0.002$) (Table S4). On the whole, the first two canonical axes explained the relationship between waterbird variables and environmental variables well.

The results of RDA suggested that species richness was significantly positively correlated with open-water cover areas ($r = 0.564$, $p < 0.001$) and water level ($r = 0.643$, $p < 0.001$), whereas it was significantly negatively correlated with concrete-covered areas ($r = -0.789$, $p < 0.001$) and bare mud cover areas ($r = -0.597$, $p < 0.001$). Waterbird densities were significantly positively correlated with open-water cover areas ($r = 0.527$, $p = 0.001$) and water level ($r = 0.677$, $p < 0.001$), whereas they were significantly negatively correlated with concrete-covered areas ($r = -0.641$, $p < 0.001$) and bare mud cover areas ($r = -0.442$, $p = 0.007$) (Figure 3, Table S5).

Charadriidae densities were significantly negatively correlated with concrete-covered areas ($r = -0.426$,

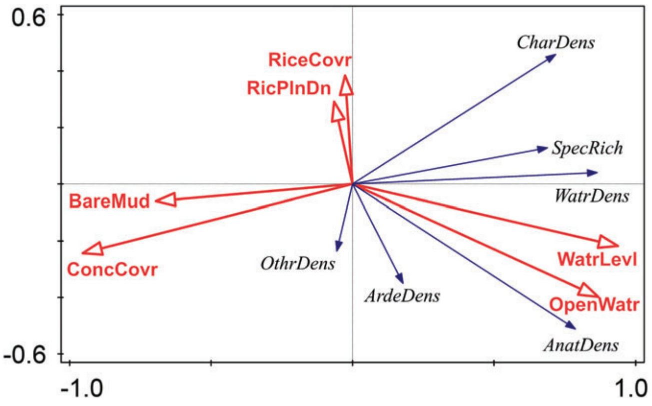

FIGURE 3 First and second axis of the redundancy analysis involving waterbird and environmental variables in rice fields in reclaimed coastal areas. Red arrows are the explanatory variables of environment factors. AnatDens, Anatidae density; ArdeDens, Ardeidae density; BareMud, bare mud cover areas; CharDens, Charadriidae density; ConcCovr, concrete-covered areas; OthrDens, others density; OpenWatr, open-water cover areas; RiceCovr, rice cover areas; RicPlnDn, rice planting density; SpecRich, species richness; WatrDens, waterbird density; WatrLevl, water level. The "Others" group comprises other waterbird orders, such as Gaviiformes (little grebe), Gruiformes (common moorhen and Eurasian coot) and Pelecaniformes (great cormorant)

$p = 0.010$). Anatidae densities were significantly positively correlated with open-water cover areas ($r = 0.808$, $p < 0.001$) and water level ($r = 0.843$, $p < 0.001$), but significantly negatively correlated with concrete-covered areas ($r = -0.517$, $p < 0.001$), rice cover areas ($r = -0.362$, $p = 0.030$), and rice planting density ($r = -0.354$, $p = 0.034$). Ardeidae densities and "Others" densities were correlated neither significantly positively nor significantly negatively with environmental variables (Figure 3, Table S5).

4 | DISCUSSION

4.1 | The replacement of traditional rice farming with industrial rice farming has had a significant negative impact on migratory waterbirds

Chongming Dongtan is a wintering area for waterbirds, and an important refueling site in the EAAF for migratory shorebirds (Wang & Qian, 1988; Zou et al., 2016). Waterbird abundance has decreased markedly at Chongming Dongtan over the past two decades (Tian et al., 2008; Zou et al., 2016). From 1988 to 2009, wetlands have been gradually converted into traditional farmland and aquaculture ponds (Ma et al., 2009) and, from 2009 to 2014, more than 80% of farmland had been converted into industrial rice farms. In 2006, a total of 123,593 waterbirds was recorded in Chongming Dongtan, but this had dropped to only 85,512 waterbirds by 2014 (data from SCDNNR annual report 2006 to 2014; www.dongtan.cn/sites/dongtan/chubanwu.aspx), representing a loss of approximately 30% of the total waterbird population in just 8 years.

Our research suggests that waterbird diversity was higher on traditional rice fields (species: 39; waterbird density: 29.3 ± 5.4/ha) than on industrial rice farms (species: 16; waterbird density: 2.8 ± 0.4/ha), and traditional rice fields are a higher value habitat for waterbirds versus industrial rice farms. These results support the hypothesis that the change from a traditional to an industrial rice farming system could be a cause of the decline of waterbird population in Chongming Dongtan over the past two decades.

Among the global flyways, the EAAF is a migratory route for the highest proportion (19%) of threatened waterbird populations (MacKinnon et al., 2012). The annual rate of decline in waterbird species along the EAAF is 5 to 9%, which is among the highest of any ecological system on Earth (MacKinnon et al., 2012). Among all the explanations for waterbird declines, coastal reclamation is the main driver, resulting in the decline of natural wetlands and in the quality of waterbird habitats (Ma et al., 2014; MacKinnon et al., 2012; Tian et al., 2016). However, the impacts of land-use conversion on biodiversity, particularly of coastal migratory waterbirds in the coastal reclaimed areas, should also not be ignored.

Both coastal reclamation and agricultural industrialization have occurred in Chongming Dongtan (Ma et al., 2009), as in other coastal regions of China (Ma et al., 2014), and in other counties in Asia (Haq, Eiam-Ampai, Ngoprasert, Sasaki, & Shrestha, 2018; Moores, Rogers, Rogers, & Hansbro, 2016; Szabo, Choi, Clemens, & Hansen, 2016). Traditional farmland converted into industrial rice farms is a common occurrence along the EAAF (Szabo, Choi, et al., 2016), such as the Saemangeum region of Korea (Moores et al., 2016), northeastern Thailand and the Mekong Delta (Frei & Becker, 2005). Thus, we suggest that the decline of waterbird populations along the EAAF could be related to the large-scale conversion of traditional rice fields to industrial rice farms along the coastline of Asia, the impact of which requires further investigation.

4.2 | The key environmental factors influencing waterbird community composition

4.2.1 | Winter floods

In this study, waterbird densities were higher on traditional rice fields than on industrial rice farms all year round, especially during the winter (Figure 2). Species richness and waterbird density, especially of Anatidae, were significantly positively correlated with open-water cover areas and water level (Figure 3, Table S5).

Anatidae prefer open-water cover areas for foraging (Elphick, Baicich, Parsons, Fasola, & Mugica, 2010; Toral & Figuerola, 2010) and feed on aquatic vegetation and rice grains or fish and snails (Elphick & Oring, 1998, 2003; Tourenq et al., 2001; Tourenq, Sadoul, Beck, Mesléard, & Martin, 2003). Winter flooding benefits aquatic vegetation and animals, providing a rich food source for waterbirds (Elphick, Taft, & Lourenco, 2010; Strum et al., 2013; Zhang et al., 2016). Our results showed that open-water cover areas of rice paddies (i.e., traditional rice framing pattern) are suitable habitats for dabbling ducks, in agreement with previous results for waterbird richness (e.g., Martínez-Abraín, Jiménez, Gómez, & Oro, 2016; Strum et al., 2013; Sulai et al., 2015). Conversely, drought fields have low waterbird conservation value, and our results are in agreement with those from studies of waterbirds in rice fields in other regions (Fujioka, Lee, Kurechi, & Yoshida, 2010; Maeda, 2001; Natuhara, 2013).

Water level is an important factor that influenced the use of rice fields by waterbirds (Figure 3, Table S5), and it could affect waterbird foraging in, and inhabiting, these areas (Baschuk, Koper, Wrubleski, & Goldsborough, 2012; Bolduc & Afton, 2008). Our results indicated that open-water cover areas with high water levels in rice fields during the nongrowing season were determining factors for waterbirds (Figure 3, Table S5).

4.2.2 | Concrete-covered and bare mud cover areas

Species richness and waterbird density were significantly negatively correlated with concrete-covered areas and bare mud cover areas (Figure 3, Table S5). On industrial rice farms with concrete roads and drainage channels, there is only one crop per year followed by a long fallow period, where the fields are abandoned and remain bare mud, with no irrigation during the winter and early spring; therefore, this has a negative impact on waterbirds (Figure 3, Table S5). This could explain the exceptionally lower use of industrial rice farms by wintering waterbirds in reclaimed coastal areas.

4.2.3 | Rice planting density

Anatidae density was negatively correlated with rice planting density (Figure 3, Table S5). In the current study, rice planting density (1.5×10^5 plants/ha) on traditional rice fields was lower than on industrial rice farms (2.4×10^5 plants/ha), because of the RFCSs in the former. The RFCSs enables the cultivation of fish and other aquatic fauna, resulting in rest sites, foraging sites and a rich food resource for waterbirds (Stafford, Kaminski, & Reinecke, 2010; Tsuruta, Yamaguchi, Abe, & Iguchi, 2011). Waterbirds avoid fields with dense vegetation (Elphick, 2008; Huner, Jeske, & Norling, 2002), and it is not surprising that waterbirds avoid industrial rice farms, which have a high rice planting density.

4.3 | Waterbird community composition on traditional rice fields and industrial rice farms

In the current study, most of the waterbirds on traditional rice fields were Charadriidae (50.3%) and Anatidae (43.4%). The waterbird community composition on traditional rice fields was the same as that reported for natural marshes in the surrounding area (Ma et al., 2004; Zou et al., 2014). The black-faced spoonbill and Eurasian spoonbill (*Platalea leucorodia*), both under state protection (category II), were exclusively found on traditional rice fields. In particularly, the black-faced spoonbill is classified as an endangered species by the IUCN (IUCN, 2018), with an estimated global population in 2018 of approximately 3,941 individuals (Hong Kong Bird Watching Society, 2018). This suggests that traditional rice fields on Chongming Island are important habitats for these rare species.

On industrial rice farms, most of the waterbirds recorded during the study were Ardeidae (44.7%) and Others (32.2%). In this study, Ardeidae were found to select industrial rice farms as feeding habitats, because Ardeidae have stronger adaptability to a variety of environments (Ma et al., 2004). The gray-headed lapwing was also found on industrial rice farms, and they might nest on dry rice fields (Fujioka, Armacost, Yoshida, & Maeda, 2001).

4.4 | Reasons why industrial rice farming is replacing traditional rice farming

Previously, because produce from farmland was the only income source for farmers, RFCSs were developed, which maintained flooded fields after the rice harvest, even during winter. This resulted in ecosystems on such farms, with a high diversity of environmental characteristics, establishing them as preferred habitats for many waterbirds. However, economic development has led to increased labor costs in China (almost fivefold from 1995 vs. 2012), whereas the rice yield has increased by only 13% (6,024.8 kg/ha in 1995 vs. 6,813.2 kg/ha in 2014, data.stats.gov.cn/index.htm). Thus, it has become difficult for farmers to earn a living only by rely on agricultural income, resulting in many farmers abandoning their farmlands. These farmlands have been merged and transformed into large-scale industrial rice farms, with mechanized planting and low habitat diversity, with a resulting negative impact on the biodiversity of such areas. Thus, governments should consider incorporating a land-sparing/sharing perspective when planning agricultural land, especially as part of the current period of organic agriculture encouraged in China. Another suitable approach would be to enhance agricultural intensification, while maintaining and restoring natural habitats.

5 | CONCLUSIONS

This study confirms that waterbird diversity in rice fields is linked to rice farming patterns. There were significant differences in species richness, waterbird density across the two patterns of rice farming, with both being generally higher on traditional rice fields. Traditional rice fields, with more open-water cover areas, lower rice plant density and no concrete-covered areas, with flooding in the winter, provided more of habitats preferred by waterbirds. The results of this study suggest that replacing traditional rice farms with large-scale industrial rice farms has had a significant negative impact on migratory waterbirds using the EAAF over the past two decades, and that such a change has also had a detrimental effect on waterbird conservation efforts in China and other countries along this important migration route. These findings are also of regional importance because they provide important baseline information for the long-term monitoring of waterbirds in an ecosystem disturbed by anthropogenic activities.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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