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Restored coastal wetlands with low degree of separation and high patch connectivity attract more birds

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Coastal wetlands, the major component of coastal ecotones with indispensable ecosystem services, are threatened by anthropogenic disturbance, resulting in continuous loss of ecosystem functions. Coastal wetland restoration can be implemented to deter the ecosystem losses; however, it is unclear whether it could provide appropriate habitat for the birds using on coastal ecotones. Here, we utilize a newly restored wetland as an example to investigate the impacts of coastal restoration on bird diversity, and test the hypothesis - if a reasonable habitat pattern is created, more birds will be attracted, thereby helping decision-makers develop efficient and sustainable coastal restoration strategies. We used Fragstats for landscape pattern analysis, and derived the variability in different habitat patterns by independent sample T-test and Mann-Whitney U test. The results suggested that the restored wetland exhibited a positive effect on attracting birds, with a total of 70 species, 35 families, and 15 orders of birds being recorded over a three-year period after restoration. Passeriformes are the main species, and accounted for 52.8% of bird species. Additionally, waterbird species, i.e., Ciconiiformes and Anseriformes, accounted for 24.67% of the total number of species. The number of bird species in the wetlands increased annually, especially during the overwintering and the breeding period. Furthermore, the results of this study indicate that water-centered mosaic-type habitat consisting of a relatively low degree of separation and high patch connectivity was beneficial to attracting different types of birds. The number of bird species, density, bird biodiversity index, evenness index, and dominance index for mosaic-type habitats were all higher than those for even habitat pattern with independent patches and sharp boundaries. In particular, the mosaic-type habitat attracted migratory waterbirds such as *Anas zonorhyncha*, *Aix galericulata*, *Mareca penelope*, *Hydrophasianus chirurgus*, *Emberiza pallasi*, *Xenus cinereus*, and *Spatula querquedula*, which expanded the range of birds attracted by coastal restoration projects. This study illustrated that coastal wetland restoration combined with a creation of water-centered mosaic-type habitat attracted more birds and could provide a reference for the restoration of degraded ecosystems in coastal zones.

KEYWORDS
coastal wetlands, ecological restoration, bird diversity, habitat pattern, landscape separation

1 Introduction

As a buffer zone that connects and intersects terrestrial and marine systems, coastal wetlands are one of the most valuable ecosystems in the world due to their unique structure and biogeochemical cycle processes. Coastal wetlands are the major component of coastal ecotones and provide areas with high biodiversity and important habitats for plant and animal communities, especially birds (Amano et al., 2010). In recent years, due to the impact of natural and anthropogenic disturbances, such as sea level rise and coastal reclamation, coastal wetlands have been increasingly threatened (Jiang et al., 2015), resulting in the continuous destruction of wetland structures and the degradation of ecosystem functions (Wang et al., 2012; Yang et al., 2020). Therefore, coastal wetland restoration has become a hot topic in international ecological research, and many non-governmental and governmental organizations have elevated habitat restoration to be a primary method for wetland conservation (Renzi et al., 2019). Coastal wetland restoration is usually implemented to combat ecosystem losses with the goal of establishing self-sustaining coastal wetlands, that may be a set of specific objectives (e.g., presence of particular species, plant cover, biomass, etc.) or functional equivalency with natural habitats (Borja et al., 2010). However, many restored wetlands fail to completely achieve the restoration targets in a timely manner (Borja et al., 2010). Wetlands diversity through restoration can take decades which can limit the ecosystem services they provide, especially the restoration of biodiversity (Das, 2017). So we need to improve wetland restoration eficiency and implement restoration designs that support the rapid creation of natural, high functioning wetlands (Renzi et al., 2019).

Birds, active components of wetland ecosystems, are sensitive to environmental changes, and they are therefore frequently used as indicators in various ecological studies and are often considered a good surrogate of biodiversity in a particular area (Alexandrino et al., 2016). Wetland bird community composition and species numbers are important indicators for monitoring and evaluating the effectiveness of coastal restoration. Comparing changes in wetland bird populations enhances our knowledge of the ecological value of a restored coastal wetland system (Hughes et al., 2018). Restored wetlands and natural wetlands differ in their ability to perform basic functions (improving water quality, reducing food damage, and supporting food webs), but all provide habitats for plants and animals (Borja et al., 2010). Some endangered birds also choose to restore wetlands as alternatives to natural habitats (Chen et al., 2012). Some recent studies have argued that restored or artificial wetlands compensate for wetland losses and are valuable for waterbird conservation, and indicated that wetland creation may be the best alternative when restoration is not possible due to irreversible damage to former wetlands. Some studies have emphasized the importance of restored wetlands for waterbirds (Sripanomyom et al., 2011; Márquez-Ferrando et al., 2014) and suggested that restored wetlands promote bird diversity to a level similar to that in natural wetlands (Desrochers et al., 2008; Bantilan-Smith et al., 2009). The construction of artificially restored wetlands has increased the diversity of coastal habitats, attracting waterbirds to roost or escape environmental stresses (Piersma et al., 2017) and increasing species diversity. The use of coastal restoration projects for wetland restoration and habitat function enhancement has become an important method to protect coastal bird habitats (Cooke and Suski, 2008). The relationships between the distribution of most waterbirds and habitat characteristics, were in agreement with the birds' ecological requirements. For instance, the shorebirds are significantly concentrated in the mudflat wetlands (Clemens et al., 2014; Murray and Fuller, 2015). The wintering ducks and coots clearly preferred the water area next to the wastelands cover and avoided dry forest cover (Ma et al., 2010). In China, a study of restoration project in Dianchi Lake suggested that distinct habitat requirements of different waterbird groups, indicating different types of restoration and arrangements should be implemented. Although there are mounting evidences that habitats characteristics are the important driver for the waterbird assemblages, the mechanisms behind habitat patches and wetland bird diversity at landscape scales still need explore (Angelini et al., 2015). On the other hand, habitat patterns are the basis for maintaining bird diversity, as different habitat patterns have different effects on attracting birds (Ma et al., 2010). Studies have shown that birds have certain preferences for different habitats. Their distribution and habits will be affected by the factors such as waters, aquatic plants and beaches in wetlands (Guan et al., 2015). Different habitat patch structures show the current status and potential trends of the habitat quality in the coastal wetland, while there are differences in water birds for their needs and adaptability (Dias et al., 2013). Therefore, whether the distribution and diversity of bird communities will be affected by coastal restoration measures and wetland habitat patterns is also a key issue that should be further explored in coastal restoration projects.

Hangzhou Bay is an important stopover site for migratory waterbirds on the East Asia–Australasia Flyway (EAAF). Since 2016, coastal restoration projects have been launched on the north shore of Hangzhou Bay with the goal of recovering salt marshes and improving ecosystem services. After the implementation of coastal restoration projects, the ecosystem service value of the coastal zone was significantly enhanced, and the restored wetlands provided good habitat conditions and abundant food resources for various types of organisms (Chen et al., 2020). To assess whether coastal restoration projects have played an important role in attracting birds, our team has been observing and recording the dynamics of bird populations in these restored wetlands since 2018. By comparing the differences in wetland bird diversity under different habitat patterns, we sought to reveal the habitat selection tendency of birds, thereby providing practical experience and references for future coastal restorations.

2 Materials and methods

2.1 Study area

The Yingwuzhou wetland is located in Jinshan District in Shanghai, China (N30°42′26.73″, E121°20′04.15″), and covers a total area of 23.2 ha. It was originally a silty muddy tidal flat formed by sediment accumulation in the estuary. Under the combined effect of anthropogenic disturbance and natural erosion, the ecosystem functions of the coastal wetland have degraded, with wildlife habitats being lost. In order to restore the coastal wetland ecosystem and salt marsh landscape, comprehensive coastal restoration projects have been carried out to build a diverse coastal wetland and recover the ecosystem functions in the coastal zone since 2016, that adopted technologies such as beach protection, wetland water purification, native plant planting, and tidal hydrodynamics regulation (Figure 1).

2.2 Habitat pattern construction

The purpose of the Yingwuzhou wetland restoration was to remediate the degraded coastal wetland with the help of the ecological engineering measures and to restore the structural, functional, and biological characteristics of the wetland. Therefore, it is necessary to comprehensively consider the diversified habitats of salt marsh plants, plankton, fish and birds in wetlands and reconstruct habitat patches, as well as landscape elements such as water, reeds, woodlands, grasslands, and roads, in coastal restoration projects. Considering the comprehensive relationship between wetland habitat and ecological function, we constructed two typical wetland habitat patterns in the core wetland (Figure 2).

Habitat pattern A is located in the northern site of the Yingwuzhou wetland and consists consisted of four core units: "Ecological pond I, surface flow wetland, ecological pond II, and salt marsh restoration area", forming a combined ecological restoration and purification system. This site restored water quality by combining the water system regulation with the purification function of wetland plants (mainly reeds). The ecological pond I was arranged with plants floating islands and submerged plants. The surface flow wetland was mainly planted with *Phragmites communis* and *Typha latifolia*. The ecological pond II was automatically controlled to provide tidal water flow for salt marsh restoration area. The salt marsh restoration area was composed of several shallow ponds and tidal ditches, and the area was mainly planted with *Phragmites communis* and *Scirpus mariqueter*. The roads in Habitat Pattern A divided the water area and reed community into scattered patches with relatively uniform spacing. These patches were independent of each other, with clear boundaries and regular edges, presenting an even habitat pattern.

Habitat Pattern B is located in the south of the wetland, and it is the main area designed for attracting wetland bird, which is formed of a series of habitat patches with the central water as the core. The edges of each patch were linked to generate a composite mosaic-type habitat. Engineering measures were taken to build deep pits, shallow ponds, shoals, plant islands and hills to form diversified wetland hydrological and habitat conditions at this site, and diversified patches such as woodlands, grasslands and reeds were arranged around the water to provide habitat for wetland animals of different trophic levels. A sandy beach and a pebble beach were constructed at the intersection of land and water. *Phragmites communis* and *Scirpus mariqueter* were planted. The two habitat patterns are connected by a small streamway that acted as the ecological corridor connecting them together (Table 1).

2.3 Bird survey

The survey period was from January 2018 to August 2021. The bird surveys were conducted in the middle of each month (the survey was not conducted from January 2020 to July 2020 due to the pandemic) and were performed along a fixed route through the core area of the wetland. At 08:00-10:00 on each survey day, three people moving at a normal walking speed (1.0-1.5 km/h), used binoculars (8*42 mm) and long-focal-length cameras to observe and take photos of the birds within the range of the wetland. The species, number, and area in which the birds were observed were recorded, and the activities of the birds and habitat conditions were noted. *Birds of China* (Liu and Chen, 2021) and *A Checklist on the Classification and Distribution of the Birds of China* (Zheng, 2017) were referenced for the identification of bird species.

2.4 Data analysis

2.4.1 Landscape pattern analysis

The remote sensing images of the study area were obtained by using Google Earth Pro. The images were registered and geometrically corrected in ArcMap 10.2 and then converted into a raster map (grid resolution 1 m*1 m) for export as soon as a vector map of the habitat patch was generated using manual interpretation. After

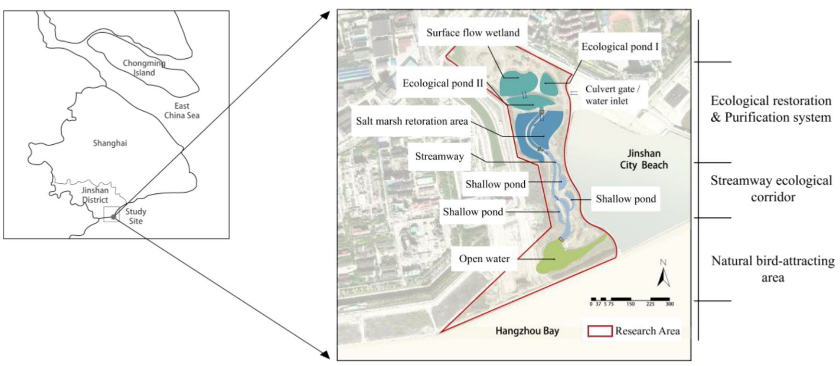

FIGURE 1
Location of the Study Area and Engineering Zoning.

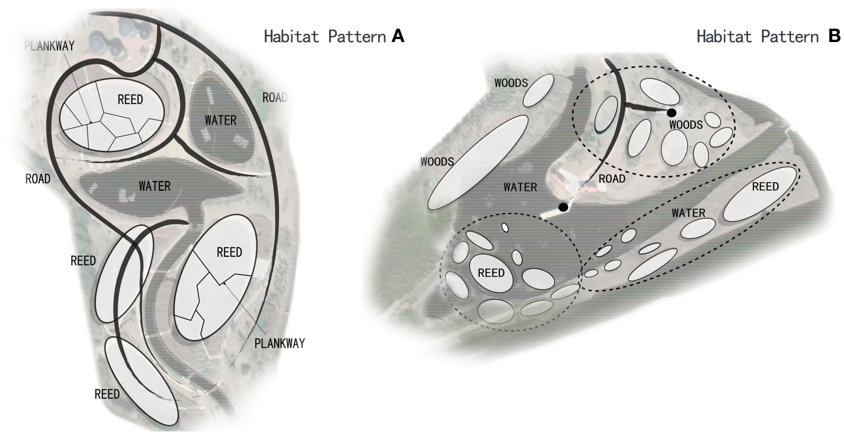

FIGURE 2
The diagram of Habitat Pattern A and Habitat Pattern B in the wetland.

interpretation, the landscape pattern index was analyzed in Fragstats 4.2. The landscape level was analyzed by selecting five indices: total landscape area (TA, hm^2), which represents the total area of the landscape; landscape sprawl index (CONTAG, %), which represents the aggregation degree or extension trend of different patch types in the landscape; landscape splitting index (SPLIT), which represents the degree of separation of the different patches in the landscape to evaluate the landscape shape and fragmentation in the study area; and Shannon's Diversity Index (SHDI) and Shannon evenness index (SHEI), which can reflect the heterogeneity of landscape. The meaning and calculation method of the 5 landscape pattern indicies are detailed in the Fragstats 4.2 instructions (Wu et al., 2021).

2.4.2 Bird data analysis

We used the Berger-Parker dominance index (D) to determine the degree of bird dominance. Specifically, $D \geq 0.05$ represents dominant species, $0.005 \leq D < 0.05$ represents common species, and $D < 0.005$ indicates rare and/or accidental species. We calculate the bird density of each habitat according to the number of birds in different habitat areas (hm^2). Besides, we estimated bird diversity using Shannon–Wiener diversity index (*H'*), Pielou evenness index (*J'*), Simpson dominance index (*D'*) and Gleason index (*G'*). These four indices reflect richness (*H'*), evenness (*J'*), dominance (*D'*) and within-habitat diversity (*G'*) dimension of bird diversity and thus provide complementary information.

TABLE 1 Location of the Study Area and Habitat Pattern Zoning.

Habitat Pattern	Habitat Pattern A				Habitat Pattern B
	Ecological pond I	Surface flow wetland	Ecological pond II	Salt marsh restoration area	
Total area (hm^2)	9.58				6.21
Water depth (m)	1.5-2.5	0.1	1.5-2.5	0.1	1.5-2.5
Reed area (hm^2)	0.52	0.81	0.52	0.81	0.52
Grasslands area (hm^2)	0.58	0.33	0.51	0.64	2.95
woodlands area (hm^2)	0.30	0.14	0	0.34	11.88
Water area (hm^2)	0.16	0	0.16	0	0.16
Floating island	3	0	3	0	3
Habitat characteristics	Each patch was relatively independent, and different patches had obvious boundaries. The waters and reeds were scattered and distributed in series through roads and water systems to form an even distribution pattern.				A large area of water was the core patch, and the surrounding woodlands, grasslands and other patches were mosaicked. The edges of different patches were nested and interlaced with each other.

The reeds were primarily wetland areas covered (full coverage or patchy coverage) by reed-based aquatic plants.

The data statistical analysis and mapping were completed by using SPSS 26.0, Excel and GraphPad Prism, and the normal distribution was tested by Shapiro-Wilk test. The species and number of birds in different habitats were tested by independent sample T-test under the condition of normal distribution, but the Mann-Whitney U test was used for the nonnormal distribution.

3 Results and discussion

3.1 Effect of coastal wetland restoration on bird attraction

A total of 70 species of birds belonging to 35 families and 15 orders (Table 2) were recorded in the study area within 3 years. Among them, there was 1 China's first-class key protected bird (*Emberiza aureola*) and 6 China's second-class key protected birds (*Aix galericulata*, *Paradoxornis heudei*, *Falco tinnunculus*, *Falco subbuteo*, *Pandion haliaetus*, and *Hydrophasianus chirurgus*); there was 1 (*Emberiza aureola*) critically endangered species (CR) on the International Union for Conservation of Nature (IUCN) Red List (IUCN, 2020) and 2 near-threatened species (NT) (*Paradoxornis heudei* and *Anas falcata*). Members of Passeriformes were the main species, accounting for approximately 52.8% of the wetland birds. This order was dominant because the coastal restoration project has created near-natural ecological zones in the Yingwuzhou wetland, consisting of ponds, salt marshes, grasslands and woodlands that provide various types of terrestrial habitat for birds to forage, rest and escape from predators. Among the non-Passeriformes species, the number of waterbird species was relatively high, including members of the Ciconiiformes (Jacanidae, Charadriidae, Scolopacidae, and Laridae), Anseriformes (only Anatidae), and Ciconiiformes (only Ardeidae), each with six species, accounting for 9.6% of the total number of species recorded. There were seven dominant species of wetland birds, i.e., *Remiz consobrinus*, D=0.135; *Gallinula chloropus*, D=0.084; *Acridotheres cristatellus*, D=0.080; *Tachybaptus ruficollis*, D=0.065; *Sturnus cineraceus*, D=0.065; *Passer montanus*, D=0.058; and *Hirundo rustica*, D=0.057. In addition, there were 15 common species and 51 rare and accidental species were observed in the restored wetland.

In 2018, 33 species of birds were observed in the wetland, consisting of 22 species of resident birds, seven species of wintering migratory birds, and four species of summering migratory birds. In 2019, 41 species of birds were observed in the wetland, consisting of 24 species of resident birds, 12 species of wintering migratory birds, three species of summering migratory birds, and two species of passing birds. Sixty-one species of birds were observed in the wetland from September 2020 to August 2021, consisting of 31 resident birds, 18 wintering migratory birds, 8 summering migratory birds, and 4 passing birds (Figure 3, left). The number of wetland bird species during the overwintering period and the breeding period exhibited an increasing trend annually (Figure 3, right). Since 2018, the cumulative number of wetland bird species has increased linearly (Figure 3, bottom). Compared with 2018, 13 new species were added in 2019. The newly added birds were mainly winter migratory birds (seven species), including *Mareca falcata*, *Aix galericulata*, and *Emberiza pallasi*. There were 20 new species of wetland birds recorded from September 2020 to August 2021, primarily resident birds and wintering migratory birds. There were nine species of resident birds, including *Ardeola bacchus* and *Phasianus colchicus*, and seven species of wintering migratory birds, including *Chroicocephalus ridibundus* and *Mareca penelope*. In addition, four species of summering migratory birds, including *Hydrophasianus chirurgus* and *Vanellus cinereus*, and four species of passing birds, including *Xenus cinereus*, were added.

TABLE 2 Composition of different bird taxa in the Yingwuzhou wetland.

Order	Family	Genus	Species	Percentage (%)
Columbiformes	1	2	2	2.74
Podicipediformes	1	1	1	1.37
Suliformes	1	1	1	1.37
Cuculiformes	1	1	1	1.37
Ciconiiformes	1	5	6	8.22
Gruiformes	1	3	3	4.11
Coraciiformes	1	1	1	1.37
Passeriformes	18	25	37	52.79
Anseriformes	1	1	6	8.22
Falconiformes	1	1	2	2.74
Charadriiformes	4	4	6	8.22
Galliformes	1	1	1	1.37
Accipitriformes	1	1	1	1.37
Bucerotiformes	1	1	1	1.37
Apodiformes	1	1	1	1.37

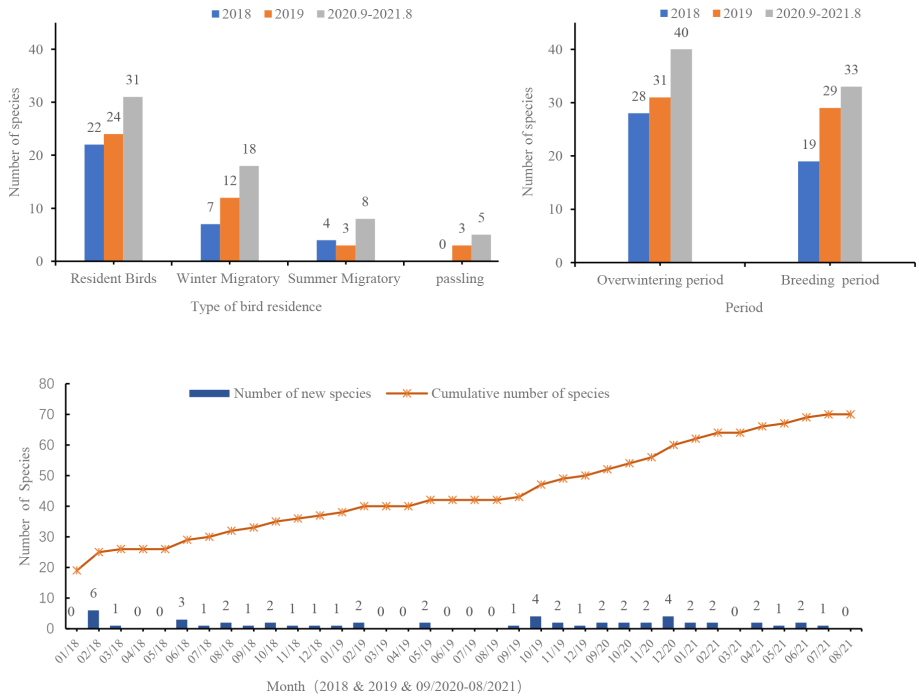

FIGURE 3
Changes in bird species number.

(Left: residential types; Right: bird species in the migration period; Bottom: monthly changes of bird number)

3.2 Effect of the wetland habitat structure on bird diversity

Increasing attractiveness to birds mainly depends on wetland restoration measures, habitat structure, and management mode (Jackson et al., 2019). The landscape characteristics of wetlands also influence bird ecological processes such as habitat dependencies, foraging, and distribution (Lee and Carroll, 2014). Over the 3 years, a total of 1,737 birds of 53 species were recorded in Habitat Pattern A, and a total of 1,510 birds of 55 species were recorded in Habitat Pattern B (Table 3). However, no significant differences were found in the number of birds between the two habitats (Z=-2.005, P=0.64) by using the Mann-Whitney U test, and the density of birds in Habitat Pattern A was far lower than that in Habitat Pattern B.

In addition, the diversity of bird species under the different habitat patterns was different, and the evenness index and dominance index of Habitat Pattern B over the years were all greater than those of Habitat Pattern A. The Gleason Diversity Index and Shannon-Wiener Diversity Index were significantly higher in Habitat B than in Habitat A (Figure 4). The above results indicated that the bird species diversity of Habitat Pattern B was relatively high.

Figure 5 shows that the number of resident bird species in Habitat Pattern A was slightly higher than that in Habitat Pattern B, primarily because the area of Habitat Pattern A was larger and the reeds and sparse forests provided more habitats for resident birds such as

TABLE 3 The records of bird diversity during the research.

Time	Habitat Pattern	Bird richness index			Bird diversity index		
		Species	Individuals	Density	*H′*	*J*	*D′*
01/2018-12/2018	Habitat A	26	623	66.6	2.547	0.782	0.873
	Habitat B	22	356	57.8	2.647	0.856	0.912
01/2019-12/2019	Habitat A	26	410	43.9	2.583	0.793	0.896
	Habitat B	31	456	74.0	2.746	0.800	0.900
09/2020-08/2021	Habitat A	45	677	72.4	2.924	0.768	0.923
	Habitat B	45	653	106.0	3.019	0.793	0.929
Total	Habitat A	52	1737	182.3	2.911	0.733	0.916
	Habitat B	55	1510	245.1	3.055	0.762	0.933

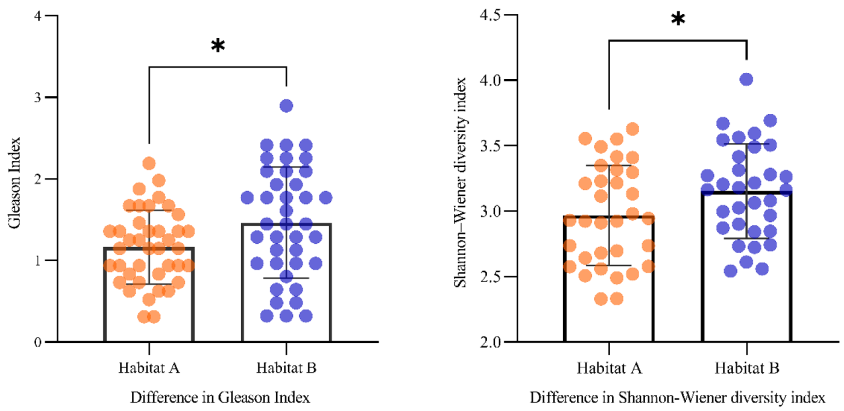

FIGURE 4
Variability of different diversity indices in different habitat patterns (*P < 0.05).

Passeriformes. The number of migratory bird species in Habitat Pattern B was higher than that in Habitat Pattern A, and the total number of bird species in Habitat Pattern B was higher than that in Habitat Pattern A regardless of the period (overwintering period or breeding period). As shown in Table 4, there were 37 bird species in both habitats and 15 bird species endemic to Habitat Pattern A, primarily Passeriformes (nine species). There were 18 species endemic to Habitat Pattern B, primarily Anseriformes and Charadriiformes, which mainly inhabit open waters.

Table 5 shows that the area in Habitat Pattern B was only two-thirds of that in Habitat Pattern A, but Habitat Pattern B had a higher CONTAG value and a lower degree of landscape SPLIT than Habitat Pattern A, indicating that the water-centered mosaic-type habitat patches in this area had good connectivity and low separation. Habitat Pattern B has a complex habitat structure and diversified patches, such as large areas of water, woodlands, grasslands, reeds and other patches were nested and interlaced to form a large wetland composite habitat, which is conducive to attracting different types of birds. On the other hand, high connectivity between habitat patches is important for the safe dispersal of individuals, providing them with optimal foraging and mating conditions. The SHDI index and SHEI index of Habitat Pattern A were higher than those of Habitat Pattern B, indicating that Habitat Pattern A had abundant land use, with numerous patches and an even distribution of different patch types in the wetland, a high degree of habitat fragmentation and a lack of dominant patches.

4 Discussion

4.1 Coastal restoration projects provide good habitat for birds and effectively increase the abundance of wetland birds

In recent years, coastal restoration projects have been conducted worldwide to restore degraded ecosystems and improve the ecological service functions of coastal zones (Chen et al., 2012). The results of bird observations at the Yingwuzhou wetland suggested that the number of bird species has increased after restoration. Approximately 70 species of birds in 35 families were observed over 3 years, including some key protected species. The dominant birds were Passeriformes (over 50%), which inhabited reeds and woodlands. This order was dominant because the coastal restoration project created near-nature ecotones in the Yingwuzhou wetland, composed of ponds, salt marshes, grasslands, and woodlands, providing various types of terrestrial habitats for Passeriformes in which to forage, rest, and escape from predators (Hughes et al., 2018).

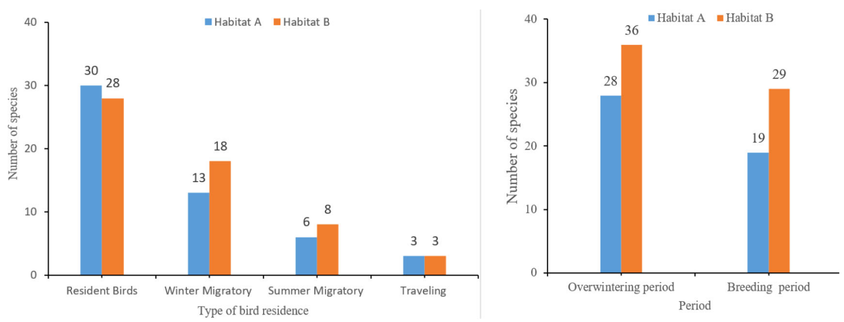

FIGURE 5
Changes in bird residential types and bird species during the migration season in different habitats.

TABLE 4 The records of bird species numbers in different habitat pattern.

Habitat Pattern	Number of species				
	Total	Resident Birds	Winter Migratory	Summer Migratory	Passing Birds
Species only observed in Habitat A	15	7	3	2	3
Species only observed in Habitat B	18	3	8	4	3
Species observed in both habitats	37	24	10	4	0

The results of field investigation suggested that the number of wetland bird species increased yearly after restoration. The proportion of resident bird species was close to 50% of the wetland bird species, significantly different from that of the surrounding coastal mudflat wetlands, where the species are primarily migratory waterbirds such as Anatidae, Charadriiformes, and Ardeidae (Chen et al., 2012). The restored wetland habitats were more suitable for resident birds, because they consisted of a large area of water, reeds, woodlands, and grasses, with much higher heterogeneity than the nearby tidal flat wetlands or artificial wetlands (fishponds and rice fields) (Giosa et al., 2018). For instance, *Gallinula chloropus* and *Tachybaptus ruficollis* were observedbreeding and brooding on the floating islands, and *Paradoxornis heudei*, which exclusively inhabited reed patches.

Since 2019, more migratory birds have entered the wetland from surrounding waters and mudflats to overwinter or breed, such as *Fulica atra*, *Anas zonorhyncha* and *Egretta garzetta*, et al. The newly added bird species were mainly members of the Charadriiformes and Anatidae, indicating that in addition to providing a suitable habitat for resident birds, the wetland is becoming more attractive to migratory birds. The main reason is that Yingwuzhou wetland created a certain water area with high connectivity and complex shapes, and has diversified tidal flat features composed of open water, pebble beach and vegetation through regulating water level through tidal flow, which provide a suitable habitat for migratory birds such as *Anas zonorhyncha*, *Bubulcus coromandus*, and *Fulica atra*.

The number of birds observed during the overwintering period and the breeding period increased annually, indicating that the wetland gradually attracted more migratory birds. There were more waterbird species observed during the overwintering period than during the breeding period. In particular, from October to November, a large number of wintering waterbirds moved into the wetland, while from December to January of the following year, Anatidae entered the wetland from adjacent waters, resulting in a significant increase in wintering waterbirds, including X*enus cinereus*, *Chroicocephalus ridibundus*, *Mareca penelope*, *Anas crecca*, and *Spatula querquedula*. Bird species richness in different period which may be related to breeding demand, food availability and suitable foraging areas. Birds tend to be highly mobile in winter, moving to the suitable wetlands in response to factors such as cold weather and changes in water levels and in food resources (Zhang et al., 2022).

4.2 Habitats with a low degree of separation and high patch connectivity have a more positive impact on bird diversity

The location of the coastal wetlands affected the variation in bird populations, and the interaction between habitat patches also increased uncertainty regarding habitat selection by birds (Kleijn et al., 2014). Studies have shown that the quality of wetland habitats and the areas of core patches exert a positive impact on bird diversity, and that wetlands with high bird diversity generally have larger woodlands and open waters (Chapman and Reich, 2006) which were the main characteristics of Habitat Pattern B and might had a more positive impact on attracting birds. In addition, the degree of habitat patch separation has an important impact on bird diversity and has a negative effect on species evenness (Chen et al., 2012). There were heterogeneous small patches in Habitat Pattern B. For instance, the woodlands and reeds were scattered around a large area of water, and the floating islands covered the central water area. Therefore, the patches have a mosaic-type layout, and the habitat structure in this area is more complex, which could provide stepping-stones and reduce interspecific competition for birds within the patches. Furthermore, the tidal flat patches in Habitat Pattern B were affected by the movement of outside water and characteristics of patch patterns (uneven distribution and complex edge shape), which are conducive to the restoration of hydrological fluctuations and support for bird feeding and habitation. This condition should be the reason why Pattern B could attract *Anas zonorhyncha, Mareca penelope, Hydrophasianus chirurgus, Xenus cinereus, Spatula querquedula* and other migratory waterbirds from the nearby waters. The patch types in Habitat Pattern A were mainly waters and reeds, were clearly separated and evenly distributed, which low heterogeneity might impede the distribution of birds to a certain extent and reduce the number of bird species. In addition, the vegetation in Habitat Pattern A is dominated by large areas of grasslands and reeds, with relatively little woodland, so the vegetation biomass is relatively low, and the interior areas of the habitat are more exposed to the disturbance, which affects the bird diversity. Therefore, the total number of bird species observed in Habitat Pattern A, as well as the endemic species, density, and bird diversity index, were lower. Compared with Habitat Pattern A,

TABLE 5 Analysis of wetland habitat landscape patterns.

Habitat pattern	TA (hm^2)	CONTAG (%)	SPLIT	SHDI	SHEI
Habitat Pattern A	9.35	47.60	21.77	1.58	0.88
Habitat Pattern B	6.16	56.39	7.13	1.37	0.57

Habitat Pattern B has more woodland patches scattered in groups in addition to water and reeds, which can be used as ecological stepping-stones to avoid the exposure of birds. The rich vegetation layers and stable community structure increase the spatial heterogeneity and improve the vegetation biomass in this area, providing birds with complex survival opportunities for foraging, nesting, and avoiding natural enemies (McCain, 2009).

Birds' preference for wetlands is influenced by a complex of characteristics such as water chemistry, aquatic vegetation, and physical features (Patra et al., 2011). The study showed that the inorganic nitrogen, reactive phosphate and suspended solids in the water of the Yingwuzhou wetland were reduced after purification from Habitat Pattern A into Habitat Pattern B (Chen et al., 2020) which might also lead birds to choose Habitat Pattern B with better water quality as their habitat. However, the effectiveness of wetland water quality characteristics on bird diversity has yet to be confirmed by in-depth studies based on actual data. In addition, the disturbance could have a relatively large impact on wetland bird diversity. In most areas of Habitat Pattern B, visitors are not allowed to enter daily to minimize the anthropogenic disturbance to the greatest extent. Under normal circumstances, visitor's activities in Habitat Pattern A would be relatively frequent and the disturbance would be greater. However, as the construction of the wetland had just been completed, and due to the epidemic in recent years, there had been few visitors. Therefore, we did not pay special attention to the effect of disturbance on the habitat selection of birds in this study. However, the increase of visitors and the surrounding construction in the future will inevitably have an impact on the diversity of wetland birds. How to reduce the disturbance to help wetland waterbirds conservation is the focus of wetland management.

4.3 Lessons from the Yingwuzhou wetland for coastal ecological restoration projects

Coastal wetlands provide key ecosystems for many species with important ecological and economic functions, including food web support, nutrient cycling, and stable habitat (Minello et al., 2003). However, only approximately 10% of biodiversity studies manipulate the diversity of ecological restoration projects with the aid of purposeful design (Hughes et al., 2018). The main purpose of coastal wetland restoration is rarely to protect important biological species, and most biodiversity assessments only focus on the rationality of ecological restoration interventions (Fitzgerald et al., 2021). Moreover, bird diversity research in ecological restoration projects is less than research on microorganisms, fish, etc. (Mahoney et al., 2021).

The studies showed that bird communities are related to the landscape heterogeneity of wetlands, and the richness & abundance of bird species are closely related to the use of patches in wetland landscapes. On the scale of wetland habitat, the structure and characteristics will also directly or indirectly affect the utilization of wetlands by bird, thereby affecting the structure of bird communities. Compared with the Eastern Chongming Tidal Flat and the Hangzhou Bay National Wetland Park around Shanghai (Lv et al., 2011; Cao et al., 2018), the scope of the Yingwuzhou wetland is relatively smaller and the range of the wetland habitat is relatively narrower, so the results of bird species and individual number are lower than those of the above wetlands. However, the bird diversity index of the Yingwuzhou wetland is relatively higher, and the biological maintenance value per unit area of wetland is higher than that of other surrounding coastal wetlands (Wu et al., 2021), indicating that the ecological restoration project of the Yingwuzhou wetland has improved the bird diversity in this region. The results of this study indicated that the two typical habitat patterns in the Yingwuzhou wetland both had high bird diversity. In particular, water-centered mosaic-type habitats consisting of a relatively low degree of separation and high patch connectivity had more positive impacts on bird diversity. The heterogeneity of mosaic-type habitat could provide high habitat structural diversity, thereby offering more places for birds to feed, hide, roost, and nest and producing more positive effects on the number, and evenness of wetland bird species. The results provide important information for understanding relationship between bird diversity and habitat patterns in a smaller landscape scale, and we can gain experience from the bird diversity studies of the Yingwuzhou wetland, and further provide "guidance" for the implementation of similar coastal ecological restoration projects.

The bird observation in the Yingwuzhou wetland lasted for 3 years. However, the lack of long-term experiments and comparative analysis in a larger environmental range may led to an underestimate of the intensity of the biodiversity effect. Therefore, it is very important to carry out long-term bird diversity observations with restoration projects and analyze the impact of wetland habitat patterns on bird diversity on a larger terrestrial-marine spatial scale, the results of which will help improve the understanding of the effectiveness of coastal wetland biodiversity restoration. In addition, wetland vegetation biomass, water quality, and other factors would affect bird diversity, which we also need to focus on in further research.

5 Conclusions

The coastal ecological restoration project in the Yingwuzhou wetland explicitly incorporated the habitat requirements of various birds by creating a mosaic of inter-connected habitat patches. The comprehensive restoration of wetland ecosystem provides a appropriate habitat for birds. The restored wetland has exhibited a positive effect on attracting birds, with 70 species of birds recorded over a three-year period. Passeriformes are the main species, accounting for 52.8% of wetland bird species, while waterbird species accounted for 24.67% of bird species. The number of bird species in the wetlands increased annually, especially during the overwintering and the breeding period. The water-centered mosaic-type habitat was located in the south of the wetland with a relatively low degree of separation and high patch connectivity, which are beneficial to attracting different types of birds. The number of bird species, density, bird biodiversity index, evenness index, and dominance index were all higher than those of the even habitat pattern with independent patches. The practice provided important information for understanding the relationship between bird diversity and restored wetland habitat patterns.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval were not required for the animal study because no specific permits were needed for the described field studies. All experiments were conducted in accordance with the regulations of the local and central governments.

Author contributions

KH and XC conceived and designed the experiments. AS and ZZ participated in the research and wrote the paper. NR analyzed the data and revised the paper. KH and XC acquired the funding. JW and WW participated in the research. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2023.1081827/full#supplementary-material

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