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Loss and self-restoration of macrobenthic diversity in reclamation habitats of estuarine islands in Yangtze Estuary, China

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ABSTRACT

In this study, macrobenthic diversity data were collected from intertidal habitats of island wetlands in Yangtze Estuary before and after reclamation. Three survey regions based on habitat features were investigated: protected region, normal region, and self-restored region. The pattern of diversity variation showed a sharp decrease in reclamation sites and an obvious increase in vegetated sites of the self-restored region before and after reclamation. A declining trend in habitat health was observed in reclamation sites, but the degree of perturbation was relatively weaker in protected region than in normal region. The vegetated site showed a better self-restoration of biodiversity than the bald site. These results suggest that reclamation may have a negative influence on biodiversity and habitat health status in the intertidal wetland. Also, there is a possibility of self-restoration in tidal flats disturbed by reclamation and the resistance effect in nature reserve may reduce the disturbances resulting from reclamation.

1. Introduction

The Yangtze Estuary, located at the junction of the Yellow Sea and the East China Sea, is one of the most prosperous estuaries in the world (Yu et al., 2015). Every year, approximately 4.8×10^8 tons of sediments is deposited in this estuary through river runoff (Dagg et al., 2004). The huge reserves of sediments tremendously boost the formation and development of island wetlands. The mature islands in this estuary mainly consist of Chongming Island, Hengsha Island, Changxing Island, and Jiuduansha Island. The intertidal wetland of the island is of great ecological importance in providing a living and breeding ground for many aquatic animals (Forde et al., 2015). Moreover, the island wetland can serve as an important stopover location for the migrating birds of eastern Asia and Australia (Ma et al., 2002). To protect the ecological security of migratory birds, the east shoal of Chongming Island was designated as a Ramsar Site of International Importance in 2002 (Gao and Zhang, 2006). Due to its vulnerability and sensitivity, the intertidal wetlands in the east shoal of Chongming Island were designated as a national nature reserve area to protect its ecological integrity (Xu and Zhao, 2005).

The Yangtze Estuary is located next to the city of Shanghai, the economic and financial center of China. Due to population explosion and the expansion of urban construction, economic development of Shanghai has been delayed as a result of limited land resources (Shi et al., 2013). To efficiently mitigate the tense situation of land supply, the intertidal wetlands in the islands of Yangtze Estuary have been enclosed and developed widely. According to a recent report, the area of intertidal wetlands within 0 m depth contour had reached around 360 km^2 in the main tidal flats of Yangtze Estuary during the past 20 years. However, the area had respectively accounted for 23% and 30% of a total land explosion in east shoal of Chongming Island and east shoal of Hengsha Island, both of where were heavily enclosed (Du et al., 2013). Moderate reclamation can bring substantial economic benefits. On the other hand, excessive exploitation may cause degradation and a reverse succession of ecological environment, which can further lead to a constantly weak trend in ecological service function of original wetland (Wang et al., 2014).

The damaged habitat can no longer support the normal development of biodiversity (Harley, 2011). Therefore, timely restoration of the habitat to the original appearance of the tidal flat is in high demand. The restoration technologies needed for diverse wetland types may vary according to the multiple human disturbances found in them (Ge et al., 2013). In the intertidal zone, the areas enclosed by reclamation projects are usually high- and middle-tidal habitats and thus a fraction of mudflat (usually low-tidal zone) may be reserved from unrecoverable damage. Hypothetically, the reserved wetland was no longer interfered by human activities; the self-restoration of habitats may theoretically occur in this region, as though it is the formation process of original tidal flat. Currently, no studies have explored the process of wetland self-restoration.

The macrobenthos are present in the benthic area of the wetland ecosystem. Due to limited mobility and high sensitivity, macrobenthic

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diversity is considered an ideal indicator for monitoring environmental changes (Zhou et al., 2012). In recent years, relevant researches in Yangtze Estuary mainly focused on the influence of invasive plant species on macrobenthic diversity (Chen et al., 2009; Wang et al., 2010b). Although some studies have been conducted on macrobenthic diversity in reclamation wetland, their primary focus has been the outcomes of reclamation (Lv et al., 2013; Ma et al., 2012). In this study, changes in macrobenthic diversity before and after wetland reclamation were compared. The primary objectives of this study were (1) to investigate the effects of reclamation on macrobenthic diversity in intertidal wetland, (2) to discuss the self-restoration of habitat and biodiversity in reserved natural tidal flats after reclamation, and (3) to explore the positive effects of nature reserve in resisting the degradation of macrobenthic community during the reclamation process.

2. Materials and methods

2.1. Study areas

In this study, two heavily enclosed island habitats were investigated including east shoal of Chongming Island and east shoal of Hengsha Island.

The east shoal of Chongming Island, located between 31°25′-31°38′ N and 121°50′-122°05′E, is the most mature intertidal wetland in Yangtze Estuary. There was a visible difference among the three tidal levels. The vegetation types of original wetland included *Phragmites australis*, *Spartina alterniflora*, *Scirpus mariqueter*, and *Scirpus triqueter*. The reclamation project was undertaken in the north of east shoal of Chongming Island and extended nearly to the whole area of high and middle tidal zones between 2013 and 2014. The reserved tidal flat is less than two kilometers wide at its maximum. There was virtually no salt marsh covering the mudflat, except for scattered *Scirpus mariqueter* community. The south of east shoal of Chongming Island was not affected by the reclamation project. The habitat characteristic in this region is relatively close to that of original wetland. The width of the tidal flat can reach five kilometers at its maximum, with stripped distribution of vegetation.

The east shoal of Hengsha Island (31°10′-31°21′N, 121°52′-122°20′ E) is located between two national nature reserves. At the end of last century, the east shoal of Hengsha Island was divided into northern and southern regions by the north dike, which was constructed during the deep water navigation channel project. There is a significant difference in habitat characteristic between these two parts. The southern region is composed primarily of mudflat and sparsely distributed *Scirpus mariqueter* community on the west tidal flat. No human disturbance was observed in southern habitat after reinforcing project of the north dike in 2010. The ecological environment of this region was in the process of becoming a habitat. The vegetated habitat in the west tidal zone showed a higher expansion rate than the non-vegetated habitat in the east area.

The northern region is characterized by the classic habitat feature of intertidal wetland in Yangtze Estuary. There is an obvious succession tendency in the distribution characteristics of salt marsh with changes in elevation. The reclamation project was conducted in the west region of northern habitat in 2012. The dikes of reclamation project constructed in 2012 enclosed the vegetated area of west intertidal zone. The east tidal flat retained the habitat characteristics of original wetland.

2.2. Field sampling and sample processing

Three different survey regions based on habitat features were investigated: protected region - east shoal of Chongming Island, normal region - northern part of east shoal of Hengsha Island, self-restored region- southern part of east shoal of Hengsha Island (Fig. 1A). Each investigation occurred at low-level spring tide in October 2011 and April 2012 (pre-reclamation) and October 2014 and April 2015 (post-reclamation). A total of six sampling sites were distributed across the three survey regions, including reclamation site (RP) and control site (CP) in protected region, reclamation site (RN) and control site (CN) in normal region, and vegetated site (VSR) and bald site (BSR) in self-restored region. Each sampling site was further divided into three sampling levels: high-tidal, middle-tidal, and low-tidal zone.

In the survey conducted from 2011 to 2012, high-tidal sampling level in RP, CP, CN, and RN was located in the habitat covered with *Phragmites australis* and *Spartina alterniflora*; middle-tidal sampling level was located in the habitat covered with *Scirpus mariqueter* and *Scirpus triqueter*; and low-tidal sampling level was located in a mudflat. In VSR and BSR, three tidal levels were equidistantly distributed on the mudflat based on elevation and width of tidal flat (Fig. 1B).

In the 2014 – 2015 survey, the tidal levels in RP and RN were redistributed based on the width of reserved mudflat. In VSR, the tidal flat had formed the initial framework of intertidal wetland in Yangtze Estuary. Hence, the three tidal levels in VSR were redistributed across different communities of salt marsh vegetation (Fig. 1C).

Each sampling level was precisely located with a handheld global positioning system. Four 0.25 m × 0.25 m quadrats were equally distributed around the sampling center to obtain quantitative data. All the macrobenthos including epifauna and infauna within the depth of 30 cm were sampled. Meanwhile, as many qualitative samples as possible were collected from the surrounding habitat. Only epifauna approximately within an area of 25.0m^2 from the sampling center were involved in the qualitative data collection. The macrobenthos were washed with a 1.0 mm aperture mesh and fixed with 75% alcohol. In the laboratory, all the animals were classified into their lowest taxonomic levels, and the quantitative samples were enumerated. The qualitative data were organized based on the presence or absence of species (including the species collected in quantitative samples).

At each sampling site, the environmental indicators including water temperature, water salinity, pH value, and dissolved oxygen were monitored in the field. The concentrations of nitrate (NO_3-N), phosphate (PO_4-P), and silicate (SiO_3-Si) were measured and converted according to the standard methods of American Public Health Association (APHA, AWWA, WPCF, 1998).

2.3. Statistical analysis

2.3.1. Diversity measures

Macrobenthic diversity was analyzed based on species, taxonomic, and phylogenetic measures using PRIMER 5.2 (Clarke and Warwick, 2001).

Several indices based on species richness and species evenness were calculated with quantitative data to explain the species diversity. The richness measures included the number of species (S), the abundance of assemblage (N), the Margalef's index (d), and the rarefaction method ($ES_{(100)}$). The evenness measures consisted of the Pielou's index (J'), the Simpson's index ($1\text{-}\lambda'$), and the Hill's number (N_∞). These two aspects were combined in the Shannon-Wiener diversity (H'), which provided a more accurate representation of species diversity.

Before estimating the taxonomic and phylogenetic diversity, 84 species recorded during 2011- 2015 investigation were compiled into a checklist of macrobenthos. Moreover, each specimen was systematically categorized into six taxonomic levels according to Linnaean's method to build a classification tree. The qualitative data based on the presence (recorded as 1) or absence (recorded as 0) of species were used to calculate the taxonomic distance of each pair of individuals in the classification tree. The taxonomic diversity was examined with average taxonomic distinctness (AvTD, denoted by Δ^+), total taxonomic distinctness (TTD, denoted by $S\Delta^+$), and variation in taxonomic distinctness (VarTD, denoted by Λ^+) based on the taxonomic distances. Also, two phylogenetic indices, including average phylogenetic diversity (AvPD, denoted by Φ^+) and total phylogenetic diversity (PD, denoted by $S\Phi^+$), were calculated based on the minimum total branch length in the phylogenetic tree.