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Different effects of reclamation methods on macrobenthos community structure in the Yangtze Estuary, China

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ABSTRACT

The effects of enclosed, semi-closed, and opened reclamation methods on the macrobenthos community structure were investigated. Compared with their paired controls, water salinity decreased sharply in the enclosed reclamation region with no apparent change in the opened reclamation region. Declining species and biodiversity was observed in the reclamation regions, but the extent of this declining trend was weaker in the semi-closed and opened reclamations than in the enclosed reclamation region. The ABC curve indicated that the enclosed reclamation was disturbed, whereas the semi-closed and opened reclamations were undisturbed. Taken together, these results suggest that reclamation may have a negative effect on the community and health status of macrobenthos in the intertidal wetlands of the Yangtze Estuary. Semi-closed and opened reclamation methods may mitigate the problem of a salinity decrease caused by enclosed reclamation, while also having a relatively weaker negative effect on community structure and wetland habitat.

1. Introduction

With rising urban development and the expansion of human populations, a shortage of land has become one of the most important factors for the development of coastal cities (Meng et al., 2017). Reclamation, the process of creating new land from a river, lake or coastal wetland through the construction an embankment, is considered one of the important and effective measures to resolve this land shortage. To address the emerging problems of population expansion and greater land use demand, many coastal countries, such as China (Meng et al., 2017; Wang et al., 2014), Japan (Ohkura, 2003; Suzuki, 2003), Netherlands (De Mulder et al., 1994; Hoeksema, 2007), and Singapore (Bo et al., 2005; Lu et al., 2002), have carried out many reclamation projects for cultivation or other uses. For example, a total area of 11,162.89 km^2 has been reclaimed between 1979 and 2014 in China alone (Meng et al., 2017). Reclamation can bring substantial economic benefits to humanity. However, coastal reclamation may cause adverse effects to the hydrological environment, such as heavy metal enrichment and littoral sea eutrophication (Chen and Jiao, 2008; Duan et al., 2016). Importantly, reclamation may cause loss of habitats and biodiversity, including saltmarshes and seagrass, which are among the most valuable ecosystems, harboring many species of invertebrates and vertebrates. Macrobenthos in particular are a critical component of estuarine ecosystems, where they play a significant role in maintaining key functions, such as the flow of energy and the cycling of matter in estuarine food webs (Bilyard, 1987; Kuipers et al., 1981). Due to the long life cycle, wide distribution, sedentary nature, high fecundity of these organisms, and their direct contact with sediments, the macrobenthic community structure is frequently used as an important indicator to monitor and assess changes in the marine environment, such as in the deterioration of water and sediment conditions (Borja et al., 2012; Pearson and Rosenberg, 1978; Wang et al., 2017; Wildsmith et al., 2011).

In recent years, many researchers have reported on the effects of enclosed reclamation on the macrobenthos, including studies of community structure (Lu et al., 2002; Lv et al., 2012; Ma et al., 2012; Naser, 2011; Obolewski and Glińska-Lewczuk, 2008), diversity (Lv et al., 2016; Yuan and Lu, 2001), functional groups (Lv et al., 2013), and coastal ecosystem health (Borja et al., 2009; Jin et al., 2016; Shen et al., 2016). Lv et al. (2013) found that enclosed reclamation changed the habitat characteristics, resulting in a simpler community structure and a lower community similarity index. Some studies suggest enclosed reclamation has caused water quality deterioration—such as littoral sea eutrophication and heavy metal contamination—in coastal waters and that the structure of the macrobenthic community would be severely affected by enclosed reclamation (Lv et al., 2016). Under this scenario,

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enclosed reclamation has already shown its shortcoming, semi-closed reclamation and opened reclamation has emerged as the times require. Through an array of sluice gates, natural saltwater can enter into the area of semi-closed reclamation. The opened reclamation approach to create new land slows down the tide through the accropode, but it does not cut off water exchange between the inside and outside of the embankment. Many marine studies, however, tend to focus on the overall effects upon macrobenthos from a single method of reclamation: that of enclosed reclamation. By contrast, a study that directly compares the effects of different reclamation methods on the macrobenthic community can provide a sounder objective knowledge base for decision makers. Yet to our best knowledge, such an analytical comparison of multiple reclamation methods is scarce in the literature.

To meet the increasing demand for new land by city and port expansions, or other purposes, large-scale sea reclamation has been carried out in the Shanghai municipality since the 1960s (Yu and Bin, 2006), with 649.99 km^2 reclaimed there between 1979 and 2014 (Meng et al., 2017). This area is mainly distributed near Hengsha Island, Chongming Island, and the east shoal of Nanhui (Lu and Jiang, 2013; Xu and Chen, 2011). Of notable interest are the different reclamation methods in these areas: enclosed reclamation on the east shoal of Hengsha Island; semi-closed reclamation on the east shoal of Chongming Island; opened reclamation on the east shoal of Nanhui. In this field study, we surveyed the macrobenthic communities in these three areas. Our primary objectives were (1) to compare the effects of the three different reclamation methods on key characteristics of the macrobenthic community; (2) to explain the influence of these reclamation methods upon ecological health status; and (3) to provide valuable baseline ecological information for the restoration of the Yangtze estuary.

2. Materials and methods

2.1. Site description

Three marine habitats were investigated: the east shoal of Hengsha Island (HS), the east shoal of Chongming Island (CM), and the east shoal of Nanhui (NH).

The HS (31°10′–31°21′N, 121°52′–122°20′E) lies east of the Yangtze estuary, and several reclamation projects have been carried out there. The sixth reclamation project was pursued in the northern region with the construction of an enclosed embankment. Since the reclamation area has not been affected by the tides, habitat changes have occurred: for example, the hardening of the reclamation substrate. The eastern regions of HS were not affected by reclamation.

The CM (31°25′–31°38′N; 121°50′–122°05′E) is the most comprehensive wetland in the Yangtze estuary. To control the alien species *Spartina alterniflora*, a reclamation project was carried out at CM, to its north, with the construction of the embankment completed by the end of 2013. This embankment has a sluice that connects both sides of the reclamation, to ensure that the saltwater of East China Sea can run off into the reclamation area via an array of sluice gates. The southern area of CM was not affected by this semi-closed reclamation. The habitat characteristics of the southern area remain relatively close to that of original wetland.

The NH (30°53′–31°06′N; 121°52′–121°58′E) is located at the junction of the Yangtze estuary and Hangzhou Bay, where it is divided into northern and southern reclamation areas (by the Dazhi River). In this study, the northern reclamation region was selected as the representative site of opened reclamation. Unlike HS and CM, for which hydrodynamic forces were obviously weakened, the tide still exerted its effect on NH. The main vegetation types of original wetland in this region were *Phragmites australis* and *Scirpus mariqueter*.

2.2. Sampling procedure

Based on their mode of reclamation, three different reclamation regions were designated in the Yangtze estuary for surveying: enclosed reclamation at HS, semi-closed reclamation at CM, and opened reclamation at NH (Fig. 1A).

To reduce the effects of reclamation time on the macrobenthos, field samples were collected during low tide intermittently in the second year since the embankment construction: namely, in 2013 for HS, in 2015 for CM, and in 2016 for NH. Collections were made in April (spring), July (summer), October (autumn) and December (winter). The sampling occurred, respectively, within each type of reclamation region at paired sites: enclosed reclamation (ER) and its control (ERC); semi-closed reclamation (SER) and its control (SEC); opened reclamation (OR) and its control (OC). In this way, macrobenthos were sampled at 20 sites locations in total across the three different reclamation regions (Fig. 1B, C).

Each sampling site was precisely located with a handheld global positioning system. At each selected location, four sediment samples were collected using a quadrats corer (25 cm × 25 cm) to a depth of 30 cm. In parallel, as many qualitative samples as possible were collected from the surrounding habitat. The macrobenthos were washed with a 1.0-mm aperture mesh and fixed with 75% alcohol. In the laboratory, the macrobenthos were classified into species or their lowest known taxonomic level, and all the quantitative samples were counted and weighed (wet weight) on a 0.01-g-precision electric balance. The qualitative data were organized based on the presence or absence of species (including the species collected in quantitative samples).

At each sampling site, several environmental variables—the water's temperature, salinity, pH, and dissolved oxygen—were measured three times in situ by using a HQ 40D portable multi-parameter water quality meter (Hach, Loveland, Colorado, USA).

2.3. Statistical analysis

2.3.1. Diversity measures

The macrobenthic species and taxonomic diversity measures were calculated by using PRIMER v5.2 (Plymouth Routines in Multivariate Ecological Research).

Species richness and species evenness were calculated from the quantitative empirical data only. Richness was expressed via three indices: the number of species (S), Margalef's index (d), and rarefaction ($ES_{(100)}$). Pielou's index (J'), Simpson's index ($1\text{-}\lambda'$), and the Hill's number (N_∞) were derived to express species evenness in the community. These two attributes of species diversity were combined in the Shannon-Wiener diversity index (H′) ($\log_2$), which provides a more comprehensive representation of species diversity.

Taxonomic diversity was measured based on a species checklist of the macrobenthos in the Yangtze estuary that covered the HS, CM, and NH. All macrobenthic data of the different species were aggregated to six taxonomic levels: species, genus, family, order, class, and phylum. Two taxonomic indices—the AvTD is the average taxonomic distinctness (denoted by Δ^+) whereas VarTD is the variation in taxonomic distinctness (denoted by Λ^+)—were calculated based on the presence or absence of species.

2.3.2. Analysis of the community structure

Hierarchical clustering (CLUSTER) and two-dimensional nonmetric multidimensional scaling (NMDS) were performed to describe the degree of similarity of the macrobenthic communities. The number of individuals was pooled to calculate the community similarity according to a Euclidean distance. All data were first transformed into their fourth-root form before the analysis was performed in SPSS v19.0. By comparing the CLUSTER and NMDS results, it is possible to better understand the differences between the macrobenthos communities among the sites.