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Macrobenthic community characteristics and ecological health of a constructed intertidal oyster reef in the Yangtze Estuary, China

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ABSTRACT

Development of substrate organisms (oysters, barnacles) and the health of a monitored oyster reef were investigated in the Yangtze Estuary. Very low salinity suppressed oyster survival. Nevertheless, middle- to high-salinity significantly increased the abundance and biomass of substrate organisms, and macrobenthos species and diversity. Long-term variation in substrate organisms was steady after a major fluctuation, yet the macrobenthic community structure lagged behind that of oysters. Overall, the oyster reef was in a healthy state. The M-AMBI results showed that its ecological status under high-salinity was better than medium-salinity conditions. Redundancy analysis indicated these results were associated with changes in water salinity and substrate factors. Taken together, our results suggest this constructed intertidal oyster reef has had a positive effect on the community and health status of macrobenthos in the Yangtze Estuary. Further, these ecological benefits increased going from medium- to high-salinity waters, but were generally absent under low salinity.

1. Introduction

Estuaries are among the most biologically productive and important environments on earth, delivering many services and benefits of great value to human society (Costanza et al., 1997). Due to geochemical processes governed by the mixing of freshwater and seawater, estuaries often trap sediment and organic material carried by rivers, which unfortunately may also include various contaminants and pollutants (Ridgway and Shimmield, 2002). Most estuaries are near human settlements and activities and are easily disturbed. Because of rapid population growth and uncontrolled development, many estuaries now face problems from anthropogenic pressure, which have led to more biodiversity losses and changes in the internal functioning of these ecosystems, as reflected in the modification of benefits they provide to human societies (Dassenakis et al., 1995; Liu et al., 2015; Lv et al., 2014; Wang et al., 2014).

The Yangtze Estuary, one of the largest estuaries in Asia, provides key services for local economic growth (Chen et al., 2017; Li et al., 2007). Over the past decades, however, the Yangtze estuary has experienced high levels of anthropogenic pressure, such as environment pollution, overfishing, and wetland reclamation (Liu et al., 2016; Liu et al., 2015; Meng et al., 2017; Wang et al., 2014). Consequently, the ecological health of this estuary has clearly deteriorated, as indicated by increasing nutrient loads, loss or extinctions of aquatic species, and decreased biodiversity of macrobenthos (Chai et al., 2009; Chen et al., 2012; Liu, 2017; Liu et al., 2018; Lv et al., 2016b). To mitigate this deteriorating trend and safeguard the threatened ecological environment, the Chinese government invested heavily in the construction of an artificial oyster reef system in the Yangtze estuary (Quan et al., 2009).

Oyster reefs are widely recognized as key marine habitats since they provide numerous economic and ecological benefits, including those of erosion control, biodiversity conservation, commercial fisheries, and water quality purification (Breitburg et al., 2000; Coen and Luckenbach, 2000; Meyer and Townsend, 2000; Nelson et al., 2004; Thomsen et al., 2007). Previous studies have demonstrated that the constructed intertidal oyster reef in the Yangtze Estuary was able to provide important ecosystem services (Quan et al., 2007), to support sustainable oyster populations, to generate significant habitat structure (Quan et al., 2009), and to maintain a higher average trophic level and more robust food web than found in an adjacent saltmarsh (Quan et al., 2012). Further, the total ecological service values of the oyster reef in the Yangtze Estuary can reach approximately ¥8.27 million RMB per year, while its filtration capacity can purify 7.31×10^6 t/year of

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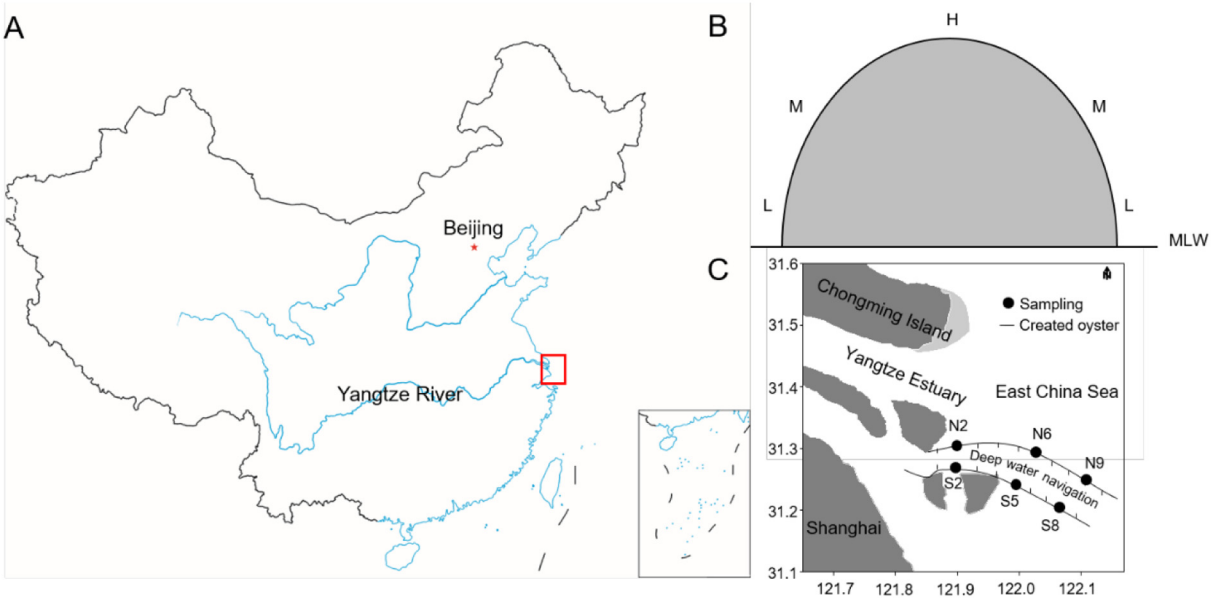

Fig. 1. Sampling sites of macrobenthos on the constructed intertidal oyster reef in the Yangtze Estuary, China.

sewage (Quan et al., 2007). Nonetheless, lacking effective management and protection measures, the ecological health, stability, and sustainability of the Yangtze Estuary's oyster reef habitats may face persistent risks, such as from oil spills, over-fishing of seedlings, and global environmental change (Lv et al., 2016a). For this reason, a follow-up health assessment of the reef's condition is crucial for informing and undertaking such restoration measures. Only by scientifically monitoring and evaluating the health of the constructed intertidal oyster reef in the Yangtze Estuary can we hope to prevent its degradation.

Some studies that evaluated the habitat restoration of oyster reefs focused solely on the abundance or biomass of oysters on the reefs (Powers et al., 2009; Tolley and Volety, 2005). However, doing so may overlook the other ecosystem services that oysters or other invertebrates may provide. Given that the exclusive assessments of oyster population alone may not reflect the oyster reef's full ecological functioning, more field studies are needed to determine both the oyster development and faunal utilization of restored reefs, and the relationship between the two (Meyer and Townsend, 2000; Quan et al., 2009). Macrobenthos in particular form a critical component of oyster reefs, where they play a vital role in maintaining ecosystem functions, such as the flow of energy and the cycling of matter in food webs (Bilyard, 1987; Fréchette and Bourget, 1985). Their abundance and wide distribution, long life cycle, sedentary nature, easy collection methods, and direct contact with sediments, have contributed to the adoption of macrobenthic features for monitoring and assessing changes in the marine environment, and ecosystem health (Borja et al., 2000; Borja et al., 2003; Liu et al., 2018; Lv et al., 2016a; Pearson and Rosenberg, 1978). As applied to constructed oyster reefs, however, most efforts have focused on their community structure of macrobenthos over just short period. Hence, the long-term characterization of community development of oyster reefs remains generally understudied (Coen and Luckenbach, 2000).

Research on oyster reefs in developed countries is mainly concerned with coastal protection, ecosystem services, and the removal of nutrients (Borsje et al., 2011; La Peyre et al., 2014). Investigations of the Yangtze Estuary oyster reef have reported on the abundance and diversity of sessile and motile epibenthic macrobenthos and nektons (Lv et al., 2016a; Quan et al., 2007; Quan et al., 2009; Quan et al., 2012). To date, however, a comprehensive assessment of the health condition of the macrobenthic communities of this oyster reef has not been undertaken. Therefore, the main objective of this study was to assess the ecological health of macrobenthos communities within the artificial Yangtze estuary oyster reef. For this assessment, we relied on established benthic indices—such as the ABC comparison, taxonomic diversity, the AZTI's Marine Biotic Index (AMBI), and the multivariate-AMBI (M-AMBI)—to translate community composition into a robust classification of ecological quality (Borja et al., 2000; de Almeida and Vivan, 2011; Muxika et al., 2007; Ranasinghe et al., 2009). Going further, the abundances of oysters and barnacles and the macrobenthic diversity data were integrated with the historical site-specific results documented by other authors over the past years. The present study's objectives were to (1) assess the ecological health of macrobenthos communities of the Yangtze Estuary oyster reef; (2) measure the variation in the macrobenthic communities over a large temporal scale (i.e., 14 years); (3) gauge and explain the influences of environmental factors on the ecological restoration of oyster reef.

2. Materials and methods

2.1. Study area description

The Yangtze River Estuary (29°30′N–32°00′N, 121°00′E–124°00′E) is the largest estuary in Asia and recognized as one of the most important ecotones in the world. This estuary's climate features an annual mean precipitation of 1124 cm and a mean temperature of 15.7 °C (Quan et al., 2009); it has four major inlets to the East China Sea divided by three alluvial islands: Chongming, Jiuduansha, and Hengsha.

At the end of the 20th century, two dikes (south dike: 48 km, north dike: 49.2 km) and nineteen groins (N1–N10 in north branch, S1–S9 in south branch, total length: 30 km) were constructed to dredge the Deep Water Navigation Channel. The dikes and groins form an intertidal concrete modular structure, and provide hard substratum (~260 ha) for oyster settlement and growth, as well as associated macrobenthos. The cross-section of these hydraulic structures appears roughly vaulting, standing 2.5 m above the mean low water (MLW) level during the spring tide (Fig. 1B). In April 2004, approximately 20 t of seed oysters (*Crassostrea ariakensis*), which were obtained from Xiangshan Bay, were transplanted to the artificial concrete modular reef (dikes and groins) to create an intertidal oyster reef.