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Assessment of the benthic ecological status in the adjacent waters of Yangtze River Estuary using marine biotic indices

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ABSTRACT

The adjacent waters of the Yangtze River Estuary are influenced by heavy anthropogenic activities. The benthic ecological status was assessed using the Shannon–Wiener diversity index, the AZTI Marine Biotic Index (AMBI), and the multivariate AMBI (M-AMBI) based on macrofaunal data collected in this area at 51 sites in June 2013 and June 2014. In total, 321 species of macrofauna were identified. Polychaetes were the most dominant, followed by mollusks and crustaceans. The AMBI results showed that 72.55% of the sites were under slight disturbance with a decreasing disturbance trend from inshore to offshore. M-AMBI showed that most of the sites were under lower disturbance level than those shown by AMBI. The Shannon–Wiener diversity index showed that only two sites, near the Yangtze River Estuary and the Zhoushan Islands, respectively, were under moderate status. Other sites were under good or high status, which is consistent with the M-AMBI results.

As the largest river on the west coast of the Pacific Ocean, the Yangtze River plays an important role in fishery, transportation, conservation, and depuration of pollutants. Owing to its large input of freshwater, the Yangtze River brings a great amount of fresh water, sand, nutrients, and pollutants into the East China Sea (Hua et al., 2014). In addition, the water is brackish in the Estuary and in its adjacent waters. Because of the strong influence of freshwater runoff, the Yangtze River Estuary and its adjacent waters have become the most intense zones for the exchange of materials and energy between the land and the sea, and complex physical, chemical, biological, and geological processes have taken place (Lane et al., 2007). The Yangtze River Estuary is the region with the most active economic development in China. Frequent human activities have caused the nitrogen and phosphorus contents in the water to be significantly higher than those in other sea areas. The area encompassing the Estuary and its adjacent waters has become a zone in which frequent harmful algal blooms (HAB) occur in China owing to the abundant nutrients, sufficient light, and suitable temperature (Zhou et al., 2001; Wang, 2002; Huang et al., 2003). HAB organisms in toxic HAB contain or secrete toxic substances, which may damage the ecosystems, fishery resources, mariculture, and human health. Moreover, the large proliferation of non-toxic HAB organisms can also lead to excessive oxygen consumption in the sea area, which affects the living environment of marine organisms and thus destroys the ecosystem structure of the sea area (Liu et al., 2011).

Macrofauna are important components of marine ecosystems, and they respond predictably to changes in water and sediments caused by natural and anthropogenic activities. For most benthic organisms, macrofauna have high biodiversity owing to the high diversity of their habitats (Liu et al., 2014a). The living environment of benthos is relatively stable. Most species of adults live in fixed places for a lifetime or only within a limited range of the substrate surface. The avoidance of benthic animals against adversity is relatively slow. They are sensitive and show profound reaction to disturbances in the benthic environment, which make them good indicators for reflecting local environmental conditions (Stull, 1995; Thrush and Dayton, 2002; Luo and Yang, 2009; Zhang, 2011). Because the activity of benthic animals is relatively weak, the species composition and density may change according to the direct influence of human activities. The changes in local environmental factors can be inferred on the basis of changes in the abundance and biomass of macrofauna (Cai, 2003; Liu et al., 2014a). Therefore, the environmental conditions indicated by biological characteristics have been widely studied (Wilding and Nickell, 2012; Lacoste et al., 2018).

Because the industrial and agricultural development in this region were rapid, the pollution caused to the marine environment gradually exceeded the self-purification ability of the ocean. The role of macrofauna in the benthic environment enables benthic organisms to be used for assessment of the environmental conditions (Tenore, 1970; Cai,

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2003; Moreno et al., 2008; Bonzini et al., 2008; Liu et al., 2014b). On the basis of species composition, temporal and spatial changes of the community, and the surrounding habitat disturbances of benthic organisms, a variety of benthic organism indices has been established such as the Shannon–Wiener diversity index, AZTI Marine Biotic Index (AMBI; Borja et al., 2000), multivariate AMBI (M-AMBI), Bentix Index (Simboura and Zenetos, 2002), Benthic Quality *Index* (BQI; Rosenberg et al., 2004), and Marine Pollution Index (MPI) (Cai, 2003) among others.

Shannon–Wiener diversity index has been used to evaluate environmental pollution status for long time (Cai et al., 2002). The AMBI method was proposed by Borja et al. (2000) at the Spanish Institute of Fisheries and Food Technology (AZTI-Tecnalia) on the basis of the biotic indices (BI) ecological model established by Glémarec and Hily (1981). It also led to the establishment of M-AMBI (Muxika et al., 2007). AMBI and M-AMBI are widely used in assessing the quality of benthic environment all over the world and they were also reported as good approaches to assess the benthic ecological quality in China seas (e.g., Cai et al., 2013; Li et al., 2017). Cai et al. (2013) assessed the benthic ecological status in Yangtze River Estuary using AMBI and M-AMBI. Lu et al. (2013) also assessed the benthic ecological status in coastal area near Yangtze River Estuary using AMBI and M-AMBI. However, these studies only focused on the areas located at the coastal or inshore waters of the Yangtze River Estuary. In this study, AMBI and M-AMBI methods combined with the Shannon–Wiener diversity index were used to assess the benthic ecological status of the adjacent waters of the Yangtze River Estuary, both including the inshore and offshore waters.

Samples for macrofauna and environmental factors were collected in the adjacent waters of the Yangtze River Estuary in June 2013 and June 2014 by the vessel *Runjiang I*. The collection range for the former year was 30.25°–32.6° N, 122°–124.5° E at 19 sites, and that for the latter was 27°–33° N, 121°–125° E. In total, 32 sites were sampled, 17 of which were sampled in both years (Fig. 1).

Two replicate samples were collected by a 0.1 m^2 box corer and were sieved with a 0.5 mm mesh sieve at each site. All animals were fixed in 5% buffered formalin solution and were identified in the

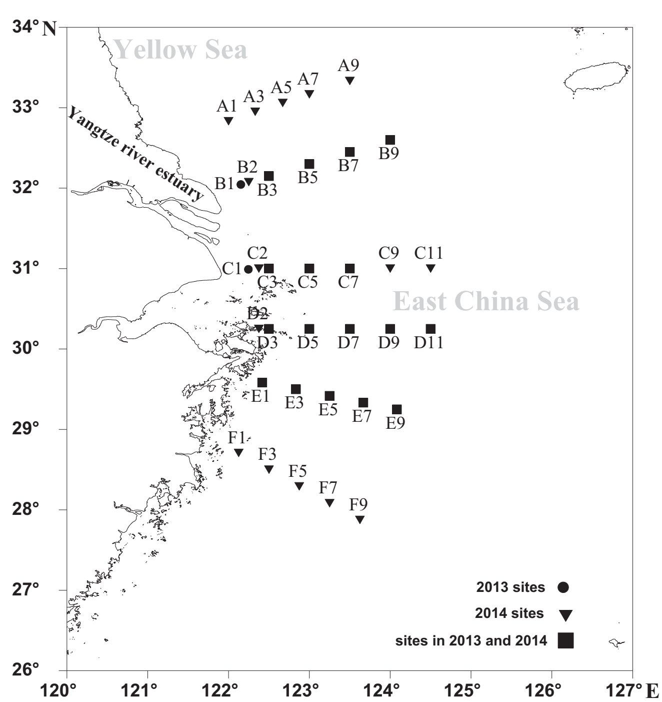

Fig. 1. Map of adjacent waters of the Yangtze River Estuary, indicating the sites of macrofauna sampling in June 2013 and June 2014.

laboratory. Samples for sediment characteristics were collected from surface sediments and were stored at −20 °C until analysis (Wang et al., 2017). The biological samples were stained with 1‰ Rose Bengal sodium salt dye 24 h prior to analysis. The macrofaunal biomass is expressed as wet weight gram per square meter; group specimens were not counted (Eleftheriou and McIntyre, 2005).

The sediment organic matter content was measured by using the potassium dichromate-sulfuric acid ($K_2Cr_2O_7$-H_2SO_4) oxidization method (Walkley and Black, 1934). The sediment grain size was measured by using a laser particle size analyzer (Master Sizer 3000; Liu et al., 2007). The seawater characteristics including temperature, salinity, and pH were measured by using a YSI 600XLM Multi-Parameter Water Quality Sonde (YSI Inc., Yellow Springs, Ohio, USA) *in situ* (Wang, 2001; Zhang, 2001). The chlorophyll *a* (Chl-a) and phaeophorbide (Pha) were measured by using a fluorophotometer. The ship's *Global Positioning System* (GPS) was used to determine the location of the sampling sites.

The sampling site distribution map, data statistical histogram, and pie chart were drawn by using Surfer 8.0 and Excel 2010. Pearson correlation analysis was conducted using SPSS22.0 statistics software to analyze the abundance, biomass, and environmental factors of macrofauna in the adjacent waters of the Yangtze River Estuary. The community structure was analyzed by using the clustering and BIOENV functions of the Primer 6.0 program. Data related to AMBI and M-AMBI were processed by AMBI software obtained from the AZTI Center website (http://www.azti.es).

The Shannon–Wiener diversity index can effectively reflect the temporal and spatial changes of benthic communities. The formula (Sun, 2001) is

$$H' = -\sum_{i=1}^{s} (P_i)(log_2 P_i), \tag{1}$$

where P_i is the proportion of the individuals of the *i* species in the sample. For example, if the total number of individuals in the sample is *N*, the number of *i* individuals is n_i; therefore, $P_i = n_i/N$. In addition, *s* is the number of benthic species collected. The H' value is equal to 0, where the absence of benthic organisms indicates serious pollution, 0–1 represents heavy pollution, 1–2 represents moderate pollution, 2–3 represents mild pollution, and values > 3 represent clean conditions (Cai et al., 2002).

Glémarec and Hily (1981) established the BI ecological model, which divides the health of benthic communities into eight levels representing eight environmental quality conditions of BI = 0, where the benthic community is normal, to BI = 7, where the benthic community is inanimate; this range represents no contamination to extreme pollution, respectively (Grall and Glemarec, 1997). On the basis of this index, AMBI was built by Borja et al. (2000). The grading and the corresponding benthic ecological quality status of AMBI are shown in Table 1 (Borja et al., 2000). This index is calculated as

$$\text{AMBI} = [(0 \times \text{EGI\%}) + (1.5 \times \text{EGII\%}) + (3 \times \text{EGIII\%}) + (4.5 \times \text{EGIV\%}) + (6 \times \text{EGV\%})]/100, \tag{2}$$

where EGn corresponds to the following groups: EG I is sensitive to

Table 1
Classification threshold levels for benthic ecological status based on the Shannon–Wiener diversity index, AMBI, and M-AMBI (adapted from Wang et al., 2017).

AMBI	M-AMBI	Shannon–Wiener diversity index	Ecological quality status
< 1.2	> 0.77	> 3	High
1.2–3.3	0.53–0.77	2–3	Good
3.3–5.0	0.38–0.53	1–2	Moderate
5.0–6.0	0.20–0.38	0–1	Poor
> 6.0	< 0.20	0	Bad