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Long-term variation of the macrobenthic community and its relationship with environmental factors in the Yangtze River estuary and its adjacent area

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ABSTRACT

Using data from four periods from 1959 to 2015, we report the long-term variation of the macrobenthic community in the Yangtze River estuary and its adjacent area. In total, 624 species were collected, and Polychaeta was the dominant group. Significant differences between the four periods were found. The CCA (canonical correspondence analysis) and RDA (redundancy analysis) results revealed that temperature, salinity, and depth significantly influenced the macrobenthic communities (89.6% of the species-environment relationship variance was explained by the first two axes of CCA and 94.3% was explained by RDA). The results of *K*-dominance curves (the elevation increased over time), ABC (abundance/biomass comparison) curves (the W value changed from 0.311 to 0.167 during 1959 to 2014–2015) and the Shannon-Wiener index (log base = 2; 2.29–5.03 in 1959, 2.86–4.55 in 2000–2001, 2.28–4.56 in 2011–2012, and 1.79–4.43 in 2014–2015) showed that the ecological status of the benthic study area was deteriorating.

The Yangtze River estuary is the largest estuary in the Asian region, located on the east side of Shanghai, China (Yang et al., 2011; Nie et al., 2015; Lv et al., 2016). Saltwater and freshwater mix here. The environment is complex and volatile because of strong tides and riverbed landforms (Shou et al., 2013).

The temporal and spatial variation of macrobenthic communities in marine ecosystems has always been the topic of many studies. Most research has found that macrobenthic communities all over the world change over large time scales. They are disturbed in varying degrees due to the comprehensive influence of climate change and human activities, and macrobenthic ecological environments have typically worsened over time (Blomqvist and Bonsdorff, 1986; Holland et al., 1987; Paiva, 2001; Ysebaert and Herman, 2002; A. Zhang et al., 2016). These studies could help us better understand the distribution patterns of marine macrobenthos and predict their changes in the future. Estuaries are in close proximity to human activities and easily disturbed, so it is important to regularly assess the benthic ecological status of estuaries and their adjacent areas (Aubry and Elliott, 2006). Macrobenthos are major groups of organisms living in the marine benthic environment. Most of them are relatively slow-moving, have a long life history strategy, are sensitive to environmental perturbations, and are easily collected (Peng et al., 2014). Due to these characteristics, macrobenthic organisms are effective ecological indicators for evaluating benthic environment health (Tong et al., 2013; Keeley et al., 2014), and relevant methods for assessing them have been developed. For example, a polychaete:amphipod ratio has been proposed to reflect the temporal change of soft-bottom communities (Gesteira and Dauvin, 2000). AMBI (AZTI's Marine Biotic Index) and M-AMBI (Multivariate AZTI Marine Biotic Index) have been used to assess the benthic ecological status of the stressed coastal waters of Yantai in the Yellow Sea (Li et al., 2013). Taxonomic and phylogenetic ecological indicators have been proved to be helpful tools for evaluating the benthic health of a typical sub-tropical semi-enclosed bay (Arbi et al., 2017). Environmental factors have been considered to play important roles in macrobenthic communities (Chainho et al., 2006; Schückel et al., 2015; Mattos and Almeida, 2016). Researchers have found that macrofaunal communities show spatial differences along a depth gradient (Dolbeth et al., 2007; Xu et al., 2016). Temperature and salinity can affect the metabolism, survival, and distribution of macrofauna (Shou et al., 2013; J.L. Zhang et al., 2016).

A previous study has reported the temporal variation of the macrofaunal community structure in the Yangtze River estuary by comparing the results obtained in historical surveys from literature with results obtained from two investigations conducted in the spring of

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2009 and 2010 (Liu et al., 2012). They concluded that the macrobenthic community changed greatly over time due to natural environmental variation and human disturbance. However, the results were based on literature (investigations carried out from 1959 to 2007) and field investigation data (obtained during 2009 and 2010). No direct comparison of the quantitative data has been performed because it is difficult to obtain the original data from historical surveys. The temporal and spatial variabilities of benthic macrofaunal communities in the Yangtze River estuary and adjacent area have also been reported (Shou et al., 2013), but studies on long-term changes are still lacking. The present study aimed to (1) measure the variation in the macrobenthic community over a large temporal scale, (2) investigate the relationships between macrofaunal communities and environmental factors, and (3) evaluate the benthic environmental health of the Yangtze River estuary and its adjacent area. To achieve these aims, we analysed the original survey data from 1959 to 2015 by means of a series of statistical methods.

A total of 72 sampling stations (28.35–33.02°N, 122–124.64°E) were investigated. Eight cruises were classified into four discrete periods for the analysis of temporal variation: 1959, 2000–2001, 2011–2012, and 2014–2015. The time of the cruise, the number of stations and the mesh size for each period are listed in Table 1. Sampling stations in different periods were labelled on the map (Fig. 1). Although the mesh size used in the 1959 cruise (1 mm) was different from the size used in other cruises (0.5 mm) (Table 1), the data are still useful for detecting temporal variation. Some researchers found an increase in the number of individuals collected when using the 0.5 mm mesh size compared to the 1 mm mesh size, especially for Polychaeta because of their body shape and the large numbers of juveniles (Bachelet, 1990; Schlacher and Wooldridge, 1996), but no significant differences were detected (Gage et al., 2002; Lampadariou et al., 2005; Li et al., 2005). Other researchers found that few additional species could be identified with the 0.5 mm mesh size compared to the 1.0 mm mesh size (Bishop and Hartley, 1986; Thompson et al., 2003).

Duplicate sediment samples were collected at each station with a modified 0.1 m^2 Gray-O'Hara box corer (0.1 m^2 "Ocean 50" corer for 1959). After that, all samples were passed through a 0.5 mm mesh sieve in the field (1 mm mesh size for 1959, Table 1), and the retained fraction was preserved in 75% ethanol (5% neutral formalin for 1959) for further analysis. In the laboratory, the samples were sorted after staining with rose bengal, then identified to the species level, counted and weighed. Environmental parameters, including bottom water temperature, bottom water salinity and depth were available for all eight cruises except for October 2012.

For each sample, Margalef's richness (d), Simpson index ($1\text{-}\lambda'$), Shannon-Wiener index (H', base = e), Pielou's evenness (J'), total abundance (ind./m^2) and the abundance of each taxonomic group (Polychaeta, Crustacea, Mollusca, Echinodermata and Others), total species number and the species number of each taxonomic group were calculated. Data from the same station in two different cruises were averaged for every period. Kruskal-Wallis tests were used to evaluate the difference in macrobenthic community parameters between periods. Species dominance (Y) for every period was calculated as:

$$Y = (n_i/N) \times f_i$$

where N is the total number of individuals, n_i is the number of individuals for the ith species, and f_i is the frequency of occurrence for the ith species. When $Y > 0.02$, the species is considered a dominant species (Xu and Chen, 1989).

Table 1
Number of stations and mesh size for each cruise in the Yangtze River estuary and its adjacent area from 1959 to 2015.

Period	Time of cruise	Number of stations	Mesh size (mm)
1959	Apr 1959 Oct 1959	27	1
2000–2001	Oct 2000 Mar 2001	12	0.5
2011–2012	Apr 2011 Oct 2012	17	0.5
2014–2015	Oct 2014 Apr 2015	16	0.5

Mar: March, Apr: April, Oct: October.

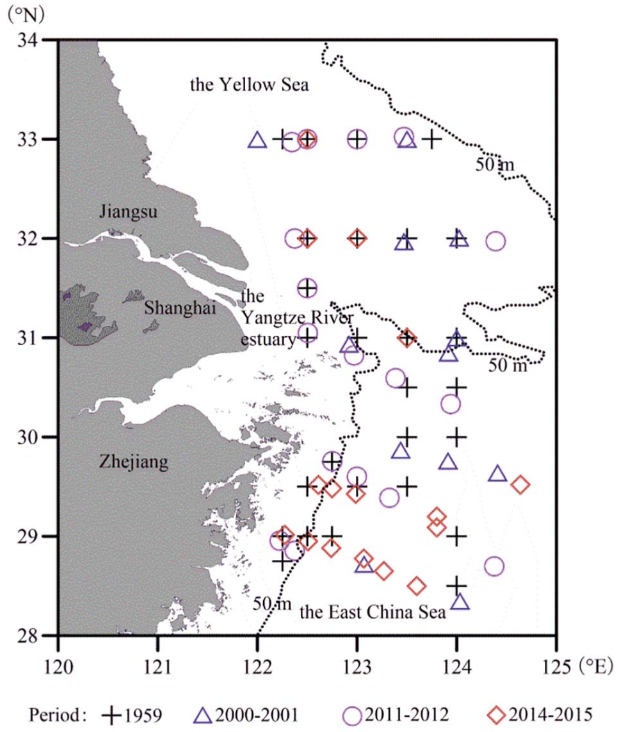

Fig. 1. Macrobenthic sampling stations from four periods and the 50 m isobath in the Yangtze River estuary and its adjacent area.

Temporal variation in the macrobenthic community structure was evaluated using cluster analysis (hierarchical agglomerative clustering with group-average linking) and PCO (principal coordinates) analysis (Borcard and Legendre, 2002; Fabi et al., 2009). Bray-Curtis similarity matrices based on the fourth root-transformed abundance data were constructed before the analyses (Clarke, 1993; Clarke and Warwick, 2001). Species with an occurrence frequency of < 5% were eliminated to minimize the effects of rare species (Almeida et al., 2008). A PERMANOVA (permutational multivariate analysis of variance) hypothesis test was applied to assess differences in the species composition among periods (Anderson et al., 2008). SIMPER (similarity percentage procedure) analysis was used to identify the species that contributed the most to the dissimilarities between the macrobenthic communities in different periods (Clarke, 1993; Clarke and Warwick, 2001).

CCA (canonical correspondence analysis) and RDA (redundancy analysis) were used to investigate the biological-environmental relationships (Feld and Hering, 2007). Before that, we relied on DCA (detrended correspondence analysis) to determine whether to use CCA or RDA. In DCA, if the maximum gradient length of the axes was > 4 SD, then CCA was more suitable; if the maximum gradient length of the axes was < 3 SD, then RDA was more suitable (Ter Braak and Smilauer, 2002). CCA was used to assess the correlations between the environmental factors (bottom water temperature, bottom water salinity and depth) and the discriminating species, because in preliminary DCA, the maximum gradient length of the axes was 4.699 SD. RDA was performed to analyse the relationships between the environmental parameters and diversity indexes, because in the DCA, the maximum gradient length of the axes was 1.410 SD.