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Species Composition and Diversity of Macrobenthos in the Intertidal Zone of Xiangshan Bay, China

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Abstract Xiangshan bay is a narrow semi-closed bay and situated on the northwestern coast of the East China Sea. Over past decades, it has become to a major bay with intensive human activities, dense urbanized area, and poor water quality. The aim of this paper was to reveal the ecological status through the elucidation of the species composition, abundance, biomass and diversity of macrobenthos in this bay. Six intertidal sections were surveyed from January 2007 to November 2008 quarterly. Sections TG, HD and XH are located in the three inner bays, sections QJ and WS are located near the thermal power plants, and section XX is located at the outer part of Xiangshan Bay. Great variations in macrobenthos community were indentified, and the species composition of the community in the present study showed the dominance in the order of molluscs (bivalves and gastropods), crustaceans and others, and only few Polychaeta were recorded. Only three dominant species, *Littorina brevicula*, *Ilyplax tansuiensis*, and *Cerithidea cingulata* were collected in all the sections, and a total of 19 dominant species were recorded only in one section. Two-way ANOVA analyses of abundance indicated that there were significant differences among sections or seasons. Shannon-Wiener diversity index (H') had its maximum (2.45) in section QJ, and minimum (1.76) in section TG. Multiple irregular k-dominance plots clearly showed that the study area was polluted and the macrobenthos community was under stress. We conclude that the macrobenthos of Xiangshan Bay have been disturbed by human activities, especially at the interior bay.

Key words macrobenthos; abundance; biomass; community structure; species diversity; intertidal zone

1 Introduction

Intertidal zone is crisscross zone with high biodiversity, floristic composition and complex community types between land ecosystem and marine ecosystem, and is one of the areas easily disturbed by human activities (Sheng and Shi, 2008). Among the marine biological entities, macrobenthos (body size <1 mm) is an important part of the intertidal zone and plays a significant role in the aquatic community considering its involvement in mineralization, mixing of sediments, flux of oxygen into sediments, and cycling of organic matter (Snelgrove, 1998). The macrobenthos community structure can change as a continuum on various spatial and temporal scales in relation to both natural and anthropogenic gradients (Pearson and Rosenberg, 1978), thus macrobenthos communities represent the best tool to investigate the ecological condition of an aquatic ecosystem (Sergy and Evans, 1975). Due to their reduced mobility and short life cycles, benthic communities are often used as indicators in biomonitoring studies (Gray and Elliot, 2010). The variance in community composition, abundance and diversity of benthic fauna can affect the function of the entire ecosystem (Bylyard, 1987). Moreover, macrobenthos distribution and composition vary considerably in response to perturbations, and the macrobenthos fauna is disturbed, impoverished and even generally dominated by stress- tolerant opportunistic species in areas of high level pollution (Estacio *et al*., 1997; Ingole *et al*., 2009). Therefore benthic monitoring programs collect several variables, such as taxonomic composition, relative abundance and biomass distribution among organisms, whose magnitude of change in time represents the main basis for assessing disturbance effects on the macrobenthos communities (Rosenberg, 1973). Limited benthic studies have been conducted in intertidal zone compared to shallow waters.

In recent decades, serious pollution has taken place along the coast of Xiangshan Bay, probably due to the rapid development of aquaculture, urbanization and industry (*e.g*., thermal power plant, reclamation and dockyard) in this region. As we all know, pollution due to various anthropogenic, industrial, and maritime discharges renders the environment hostile for native species and opens a window for the proliferation of opportunistic native and exotic species (Galil, 2000). Substantial atten-

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tion has been paid to identify the biota present in man-disturbed areas for proper management, from the marine bio-invasion risk perspective, and this strategic move needs to be preceded by a thorough and synergic study of the biological components of the ecosystem (Sumit *et al*., 2013). Without the baseline dataset on native biota, it is virtually impossible to imply management protocol stringently and identify alien species (Sumit *et al*., 2013).

Studies on macrobenthos along the intertidal region of Xiangshan Bay are limited till now, only Yang *et al*. (2004) studied the benthic macrofauna in the intertidal zone near the Zhejiang Ninghai Power Station and Liu *et al*. (2008) and Yang (2008) studied the marine macrofauna near Wushashan power plant and Qiangjiao power plant, respectively. Other studies in Xiangshan Bay include those of the macrobenthos community (Gao *et al*., 2003; Gu *et al*., 2010), faunal diversity (Gu *et al*., 2010), functional feeding group (You *et al*., 2011), and comparative studies on macrobenthos between aquacultured and non-aquacultured areas (Liao *et al*., 2010). But these study areas are all in shallow water environment, not in intertidal zone (Ning *et al*., 1999; Gao *et al*., 2005; Wang *et al*., 2006). In brief, few work has been done to elucidate the macrobenthos community structure of the intertidal zone of Xiangshan Bay on the west coast of the East China Sea. Neither have studies of benthic diversity been conducted around this Bay, information being limited to individual or confined areas of the shelf.

The main objective of the present study is to provide a description (abundance, biomass, diversity) of intertidal macrobenthos organisms and their spatial occurrence along the bay, and to investigate the disturbance of human activities, such as thermal power plant and urbanization, to the distribution of macrobenthos. With this approach, we analyzed the spatial occurrence of the macrobenthos along Xiangshan Bay using to the data 2007–2008.

2 Materials and Methods

2.1 Study Sites

Xiangshan Bay (29˚24´–29˚48´N, 121˚25´–122˚03´E) is a narrow semi-closed bay, including around 59 islands and 3 inner bays. The total length of this bay exceeds 60 km, while the average width is only from 3 km to 8 km. The intertidal area is about 171.5 km^2. Since past decades, it has become to a major bay with intensive human activities, dense urbanized area, and poor water quality. Extensive aquaculture, urban, and industrial development around the bay have caused substantial changes to the surrounding environment.

2.2 Sampling

Six intertidal sections were surveyed from January 2007 to November 2008 quarterly, and totally 432 samples were taken (triple samples were collected from each sations − 6 sections × 3 intertidal flats × 4 seasons × 2 years × 3). Section TG, HD and XH are located in the three inner bays, section QJ and WS are located near the thermal power plants, and the last section XX is located at the outer part of the bay (Fig.1).

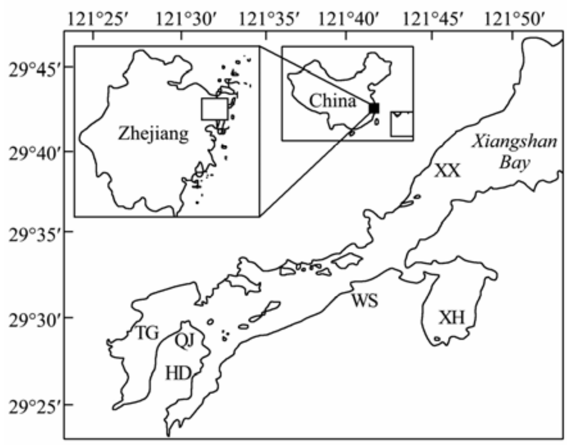

Fig.1 Sampling sections of the intertidal zone in the Xiangshan Bay, China. The first letter indicates the location of the sampling station. XX, Xianxiang; TG, Tiegang inner bay; QJ, Qiangjiao inner bay; HD, Huangdungang inner bay; WS, Wu shashan; XH, Xihugang inner bay.

Macrobenthos samples were collected in triplicate with stainless sieve (50 cm × 50 cm; 20 cm deep) and were in situ washed separately through 1.0 mm mesh size sieves. The retained materials were transferred to plastic bottles and preserved in 5% formalin in seawater containing Rose Bengal stain. Macrobenthos samples were labeled and transported to laboratory for further examination. Prior to identification, biomass (wet weight) was determined by an electronic balance (Mettler Toledo MS304S). Organisms were identified at the lowest possible taxonomic level using a microscope with the help of available taxonomic literature. All the organisms were counted with stereoscopic microscope and abundance was expressed by using the surface area of the sampling cores (0.25 m^2).

2.3 Data Analysis

We calculated species richness and four different measures of species diversity: Shannon-Wiener diversity index using $\log_2(H')$, Hurlbert index expressed with the estimated number of species per 100 individuals (ES_{100}), Margalef's species richness (d), and Pielou eveness (J'). Univariate and multivariate analysis were performed using the PRIMER software version 6 (Plymouth Routines in Multivariate Ecological Research) package (Clarke and Gorley, 2006; Clarke *et al*., 2008). The graphical tools like *k*-dominance curve and Ellipse plots and multivariate tools such as Bray-Curtis similarity based on square root transformed abundance were adopted. The hierarchical agglomerative clustering using group-average linking and multidimensional scaling (MDS) both based on macrobenthos abundance after square-root transformation were used.

Two-way ANOVA in SPSS 16.0 software package was used to indicate differences of abundance and diversity in different observation sections or seasons. The study area map was drawn with the help of SURFER 8.0. All the average data were represente with mean ± SD. The marks of classification and MDS plot represent section (First number), sampling year (Second number), and sampling month (Last two numbers), respectively.

3 Results

3.1 Abundance and Biomass

A total of 152 species macrobenthos were identified, of which molluscs and crustaceans were the most important groups. Molluscs dominated the macrobenthos (65 species) and contributed numerically up to 41% of the population. Crustaceans consisted of 52 species and contributed 33% of total infauna production. Meanwhile, 11 species were fishes, 6 species were polychaetes, 6 species were echinoderms, 6 species were coelenterates and 4 species belonged to other groups.

The abundance and biomass of the macrobenthos in every season in different sections were calculated, and information on the macrobenthos community structure at the six sections are summarized in Figs.2 and 3. The lowest abundance recorded in all the samples was from section XX in July 2007 (8.27 ± 1.30 ind m^{-2}), and the highest abundance recorded was from section HD in January 2007 (86.81 ± 39.71 ind m^{-2}). In particular, *Ruditapes philippinarum* was the most abundant bivalve at section TG and section HD, where it represented 68.52% and 61.35% of total abundance. Two-way ANOVA (Factors: section and season) analysis of abundance indicated that there were significant differences among sections (F = 14.82, P<0.01) or seasons (F = 4.99, P<0.01). The abundance for different sections and seasons also showed significant differences (F = 5.32, P<0.01) by the interactive analysis. In different sections, the abundance in section HD and TG was greater than that in section XH, and the latter was greater than that in section WS. The lowest abundance was in autumn, being lower than in other three seasons by analysis of Turkey HSD.

Two-way ANOVA analysis's result showed that there are no significant differences in biomass (F = 0.98, P= 0.420) among seasons, but the differences among sections are significant (F = 7.99, P<0.001). The biomass would be separated into three groups: the first for sections WS, XX and QJ, the second for sections TG and HD, the third for section XH. Among them, the lowest was from section WS (5.84 ± 1.46 g m^{-2}) and the highest was from section XH (14.22 ± 3.47 g m^{-2}). In contrast to abundance, no differences were detected for biomass among seasons, and the biomass of section XH with high abundance but lower than Section TG and HD. For evenness, the pattern was the same as Shannon-Wiener diversity; the lowest evenness was found at section TG and the highest was at section WS.

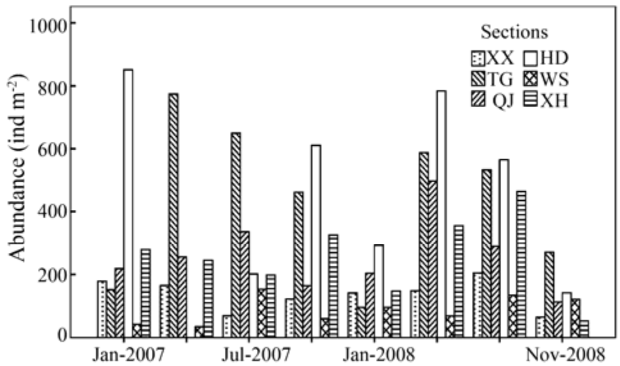

Fig.2 The macrobenthos abundance of Xiangshan Bay in different sections and seasons.

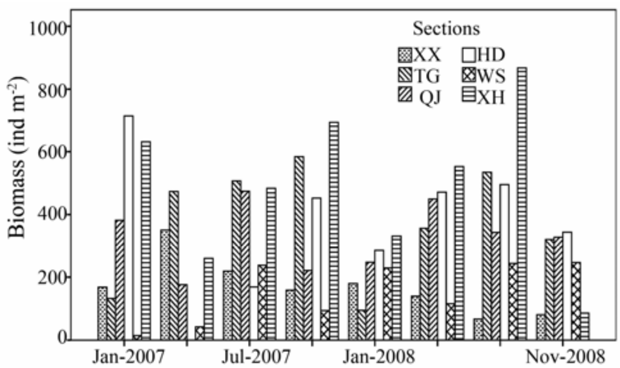

Fig.3 The macrobenthos biomass of Xiangshan Bay in different sections and seasons.

Table 1 Two-way ANOVA on macrobenthos community at six sections.

	Species number (S)	Abundance (N)	Margalef's species richness (D)	Pielou's eveness (J')	Hurlbert index (ES_{100})	Shannon-Wiener diversity H'(log_2)
Sections	P=0.00*	P=0.00**	P=0.79	P=0.00**	P=0.58	P=0.08
Seasons	P=0.04*	P=0.02*	P=0.34	P=0.19	P=0.38	P=0.47
Sections × seasons	P=0.00**	P=0.00**	P=0.65	P=0.00**	P=0.54	P=0.14

Notes: Significant differences (factors: section and season) on normalized measures per sample data.

3.2 Diversity

The recorded species numbers in the six sections varied from 8.7 ± 1.1 to 12.4 ± 1.6 with the average 10.77 ± 0.57. The Shannon-Wiener diversity index (H') of the six sections ranged from 1.76 ± 1.16 to 2.45 ± 0.18, with maximum in section QJ and minimum in section TG, while Shannon-Wiener diversity index (H') of different seasons varied from 2.10 ± 0.14 (Autumn) to 2.34 ± 0.15 (Winter). In section TG, *Ruditapes philippinarum* was the dominant species, which contributed 68.52% of abundance; in contrast, Shannon-Wiener diversity was lower than those in other sections with the largest number species. As to the seasons, the maximum value of 379 ± 81 ind m^{-2} was recorded in Spring and the minimum value of 215 ± 44 ind m^{-2} was recorded in Autumn. Significant differences of the macrobenthos abundance was found among the sections (P<0.01), which varied from 101 ± 18 to 533 ± 101. The Pielou's evenness (J') ranged from 0.57 ± 0.06 to 0.84 ± 0.03, while the former was in section TG and the latter in section WS. For other index, Margalef's species richness (d) ranged from 1.70±0.20 to 1.99±0.27, and Hurlbert index (estimated number of species per 100 individuals, ES_{100}) ranged from 8.51±1.05 to 10.17±1.16.

Two-way ANOVA analysis indicated that no significant differences among all sections were detected excepted for abundance and Pilou's evenness (J': both P<0.01), but significant differences among section × season were detected for all the community measures excepted for Margalef's species richness (d), Hurlbert index (ES_{100}), and Shannon-Wiener diversity (H'). All of them showed no significant seasonal differences (P>0.05).

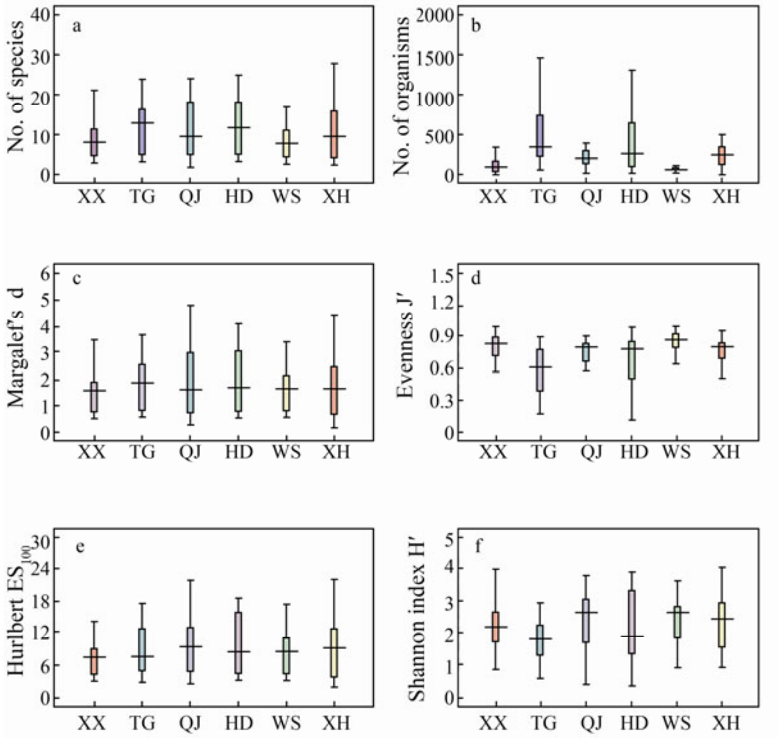

Fig.4 Univariate measures for macrobenthos infauna of Xiangshan Bay (section-wise). a, Number of species; b, abundance; c, Margalef's species richness; d, Pielou's evenness J'; e, Hurlbert index (the estimated number of species per 100 individuals, ES_{100}); f, Shannon-Wiener index H'. Data presented as mean (*lines*) ±SE (*boxes*) ±SD (*whiskers*).

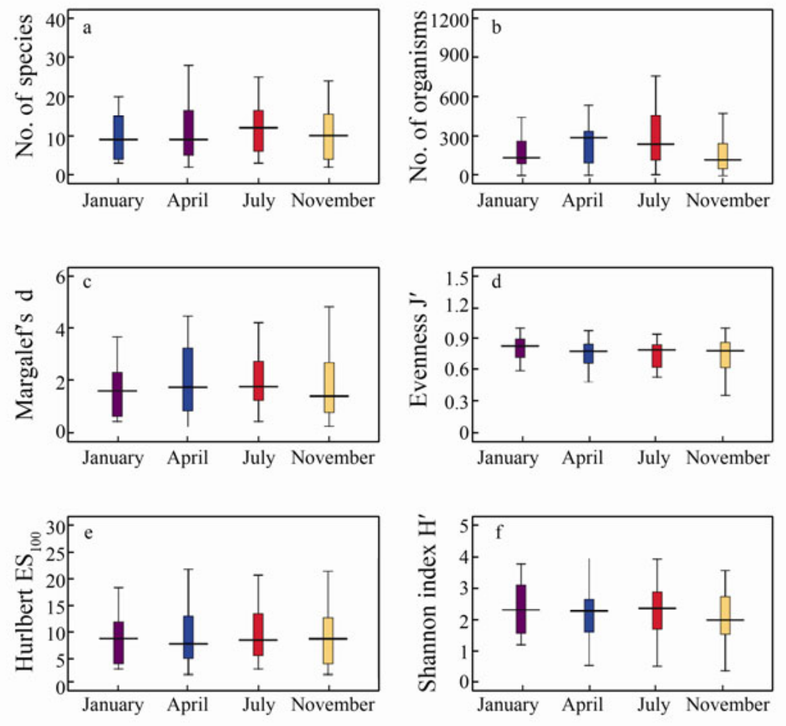

Fig.5 Univariate measures for macrobenthos infauna of Xiangshan Bay (season-wise). a, Number of species; b, abundance; c, Margalef's species richness; d, Pielou's evenness J'; e, Hurlbert index (the estimated number of species per 100 individuals, ES_{100}); f, Shannon-Wiener index H'. Data presented as mean (*lines*) ±SE(*boxes*) ±SD(*whiskers*).

3.3 Spatial Variation

The classification analyses (using Bray-Curtis similarity), followed by an ordination through MDS on macrobenhos abundance data (number m^{-2}) independently for infauna (152 species), were undertaken. Figs.6 and 7 display the results of hierarchical clustering and MDS ordination, respectively, based on species abundance data representing 6 sections during eight seasons (during 2007 to 2008). From the resulting dendrogram, all samples were classified into three groups: the first group included 7 samples which were form 4 sections (section XX, TG, WS and XH) and 3 seasons (three in autumn, three in winter, only one in summer), the second group included 13 samples which were form 6 sections mainly in spring and autumn, and the other samples were classified into

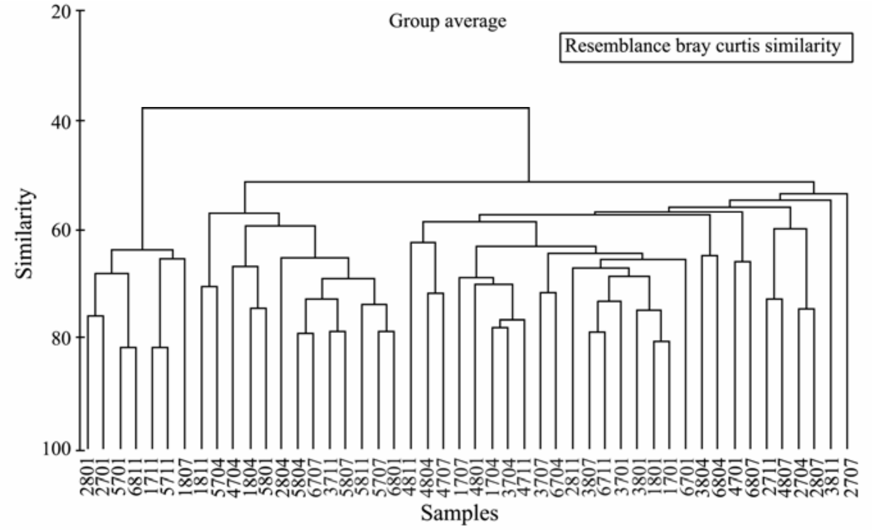

Fig.6 Dendrogram showing grouping of sections sampled during different seasons for macrobenthos. The four numbers designate four items: First number for section: 1, XX; 2, TG; 3, QJ; 4, HD; 5, WS; 6, XH. Second number for samplying year: 7, 2007; 8, 2008. The last two numbers for sampling month: 01, January; 04, April; 7, July; 4, November.

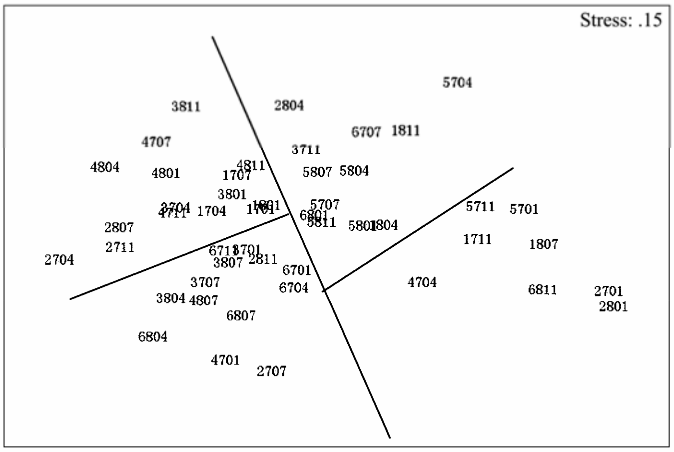

Fig.7 MDS plot for 48 stations sampled. The four numbers designate four items: First number for section: 1, XX; 2, TG; 3, QJ; 4, HD; 5, WS; 6, XH. Second number for samplying year: 7, 2007; 8, 2008. The last two numbers for sampling month: 01, January; 04, April; 7, July; 4, November.

the third group. In the MDS plot, it was found that all the samples of the first group were separated from other samples, which conforms to the dendogram. The other samples could be separated into three groups: one group mainly covered sections XX and HD, the second group mainly covered sections QJ, XH, and WS, and other few samples were separated into the third group.

3.4 *k*-Dominance Curve

Multiple *k*-dominance plots facilitated the discrimination of macrobenthos according to species-relative contribution to standard stock (Fig.8). When all the sections belonging to all the seasons were plotted together, the curves for section 3701 (section QJ, winter 2007) and section 2704 (section TG, spring 2007), are lying low and is S-shaped, indicating the highest diversity, whereas the curve for station 1807 is lying high, showing the lowest diversity. Although the curve of section 1707 (section XX, summer 2007) is lying low, it is disturbed also, for the curve is not absolutely S-shaped; furthermore, the section TG was disturbed for Spring (see the curves 2701 and 2801). When the *k*-dominance plot is plotted according to seasons (Fig.9), it does not show any difference between the seasons. The *k*-dominance plot was also plotted for the sections (Fig.10), and the curves for HD, WS and XH with the same S-shape are lying low, indicating highest diversity, whereas the curves for the sections QJ and TG have irregular shapes, showing that the lower diversity, is lying high (Fig.10).

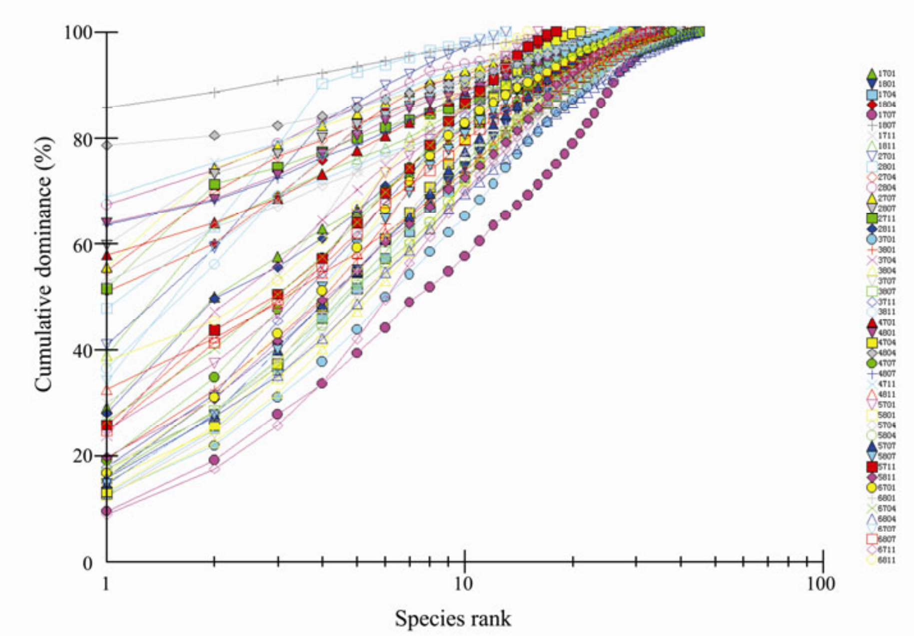

Fig.8 *k*-Dominance curves for all stations. The four numbers designate four items: First number for section: 1, XX; 2, TG; 3, QJ; 4, HD; 5, WS; 6, XH. Second number for samplying year: 7, 2007; 8, 2008. The last two numbers for sampling month: 01, January; 04, April; 7, July; 4, November.

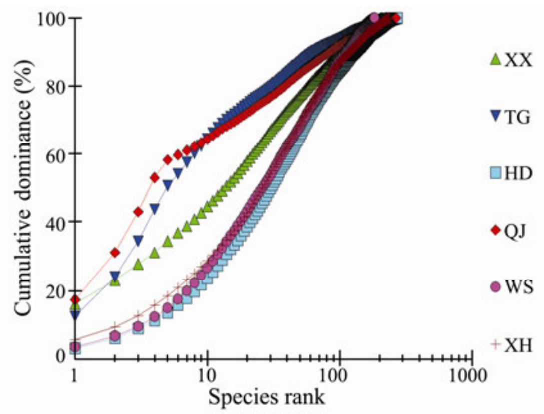

Fig.9 *k*-Dominance cures for species abundance data in different sections.

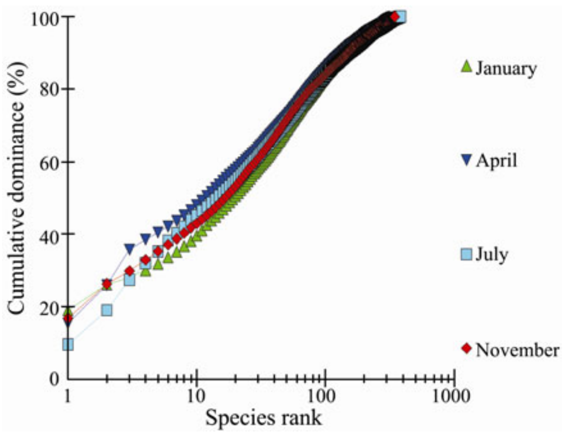

Fig.10 *k*-Dominance curves for species abundance data in relation to season.

4 Discussion

Comparison of the present dataset with earlier reported literature for this area shows some changes in the faunal composition and abundance. Earlier average macrobenthos abundance and biomass were 288.18±29.97 ind m^{-2} and 84.23±7.04 g m^{-2}, respectively, which have both declined considerably (Shao *et al*., 1996; Yang *et al*., 2008,). The declines of abundance and biomass are due to the changes of species composition surveyed in different periods.

Biotic structures can provide habitat for other species, which potentially enhances the bottom surface complexity and thus has implications on functioning (Pacheco *et al*., 2011); so the distribution of macrobenthos play key roles in biotic structures. In the present study, a great variability in the macrobenthos community have been discoveried, and species composition of macrobenthos shows the dominance in the order of molluscs (bivalves and gastropods), crustaceans and others (Figs.11 and 12), as observed earlier by Shao *et al*., (1986). This is especially so in sections TG, HD, and XH, the three inner bays of Xiangshan Bay, where the sediments are mainly muddy and form suitable habitats for buried Bivalve. Buried *Ruditapes philippinarum* with abundance of 294.58 ind m^{-2} in section TG and 264.33 ind m^{-2} in section HD was the dominant species, which contributed approximately 57.21% and 66.76% of total abundance, respectively. The reason of high abundance of *R. philippinarum* was that there were two seed reserves in these two inner bays. In section XH, though the Bivalve abundance was lower than that of Gastropod, their abundance reached 95.42 ind m^{-2} and the biomass reached 34.29 g m^{-2}. Buried *Muscuius senhousei* was the dominant species in this inner bay. In contrast, compared to other species, the abundance and biomass of bivalve were the lowest in section XX, section QJ, and section WS. The sediment of section XX was hard bottom and the sediment of section QJ or section WS were both gravels, which confirms our conclusion about different macrobenthos composition in Xiangshan Bay and the theory of species compositions determined by the sediment types.

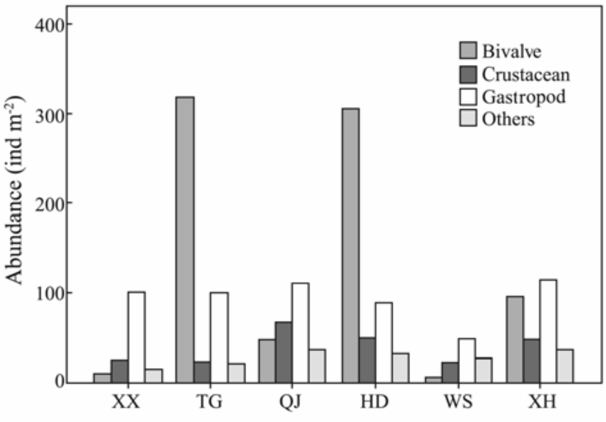

Fig.11 Composition of macrobenthos abundance in different sections.

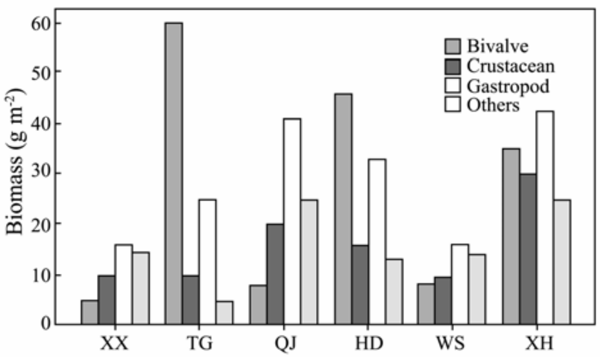

Fig.12 Composition of macrobenthos biomass in different sections.

It should be noted that the communities differentiated in the present study, as the macrobenthis compositions were affected by the environment factors (Sheng and Shi, 2002; Craeymeersch, 1991). Strong dominance by a few of these species was detected in sections, and the dominant species changed greatly in different sections. Only three species, *Littorina brevicula*, *Ilyplax tansuiensis* and *Cerithidea cingulata* were collected in all the sections. *L. brevicula* was a kind of Gastropod located at the high intertidal with hard bottom, especially rocky sediment. *I. tansuiensis*, and *C. cingulata* were located in muddy bottom. Similar to the results of Shao *et al*. (1990), only few Polychaeta were recorded in this survey. A total of 19 species, including *Patelloida pygmaea*, *Laternula marilina*, *Moerella iridescens*, *Macrophthalmus japonicus*, *Moerella culter* and *Haliplanella luciae*, were recorded only in one section, which represents a different community among the six sections. *Assiminea latericea*, *Ilyplax tansuiensis* and *Littorina brevicula* were the three dominant species of Section XX located at the outer part of Xiangshan Bay. *Ruditapes philippinarum*, *Ilyplax tansuiensis*, *Muscuius senhousei* and *Cerithidea cingulata* were the dominant species of the three inner bays (section TG, HD and XH). Compared to the early literature of Shao *et al*. (1996), the community of macrobenthos did not changed greatly, except that *Macoma praerupla*, *Assiminea brevicula*, *Theora fragilis* were not recorded, and *Muscuius senhousei*, *Nassarius* became the dominant species in this study. The dominant species of Section QJ was the same as that of section WS but differed from other sections. For example, *I. tansuiensis* and *C. cingulata* were the top two dominant species in sections QJ and WS. *M. iridescens* was the definite dominant species of Xiangshan Bay in the 1990's and recorded only in one section. This phenomenon is probably due to the decrease of artificial breeding of *Moerella iridescens* on the intertidal flat in recent decades. Tilman *et al*. (1997) showed that a strong linear relationship between functional and phylogenetic diversity pattern, and wider local taxonomic trees can support a wider range of species functions even in small spatial scales. However, a narrow range of species functions is maintained by certain species which are also present in the wider taxonomic trees. Furthermore, the results of this study confirms the hypothesis that some species are more important than others in ecosystem functioning.

Species diversity is a simple and useful measure of biological system. Sanders (1968) found a high level of agreement between species diversity and the nature of the environment and, hence, regarded the measure of species diversity as an ecologically powerful tool. Pearson and Rosenberg (1978) proposed that the use of diversity indices is advantageous for the description of faunas at different stages in the succession. Sanders (1968) postulated that the species diversity is mainly controlled by the fluctuations in the environment that lead to narrow diversity. In previous literatures the humpshaped relation between functional diversity and species abundance was revealed, which denotes that functional diversity increases when low and intermediate levels of species abundance are involved; however, when species abundance reaches its maximum values, functional diversity decreases. Furthermore, it is universally accepted that areas with lower diversity and richness indicate polluted or stressed conditions (Magurran, 1988). According to Wilhm and Dorris (1966), species diversity index (H') value >3.00 bit ind^{-1} indicates unpolluted conditions, 1.00 to 3.00 bit ind^{-1} indicates moderately polluted, and <1.00 bit ind^{-1} indicates heavily polluted condition of aquatic medium. The Shanonn-Wiener's index ranges from 1.62 to 2.79 with an average value 2.26, which declined significantly to this value from 3.23 in comparison with the survey of the 1990's (Shao *et al*., 1996), showing that the study area has been polluted and macrobenthos community is under stress due to natural or anthropogenic factors. For comparison, the Shanonn-Wiener's index is lower than that of Haitan Bay of Fujiang province (Lv *et al*., 2008), Jiaozhou bay of Shandong province (Li *et al*., 2006) and Gaoshaling of Tianjin City (Zhang *et al*., 2007), but higher than that of Hangzhou Bay of Zhejiang Province (Li *et al*., 2007) and Yangtze Estuary (An *et al*., 2007).

Table 2 The abundance and biomass of dominant species in different sections

Species	XX		TG		QJ		HD		WS		XH	
	Abundance (ind m^{-2})	Biomass (g m^{-2})	A	B	A	B	A	B	A	B	A	B
Patelloida pygmaea	2.33	0.06										
Nassarius semiplicatus	2.17	1.26			9.22	4.53	4.67	2.11	2.50	0.80	6.08	3.65
Laternula marilina											24.92	7.29
Sternaspis scutata							2.56	0.52	1.75	0.27		
Moerella iridescens					3.72	0.52						
Metaplax longipes	1.36	0.95			4.33	1.62	3.89	2.44	2.25	1.53	3.88	2.37
Diopatra amboinensis					5.28	2.22			1.33	0.99		
Nerita yoldii	9.11	1.68			3.00	1.07	4.69	1.48			3.54	2.31
Ilyplax tansuiensis	17.25	1.36	5.03	0.43	35.89	3.31	32.28	4.66	13.19	1.32	15.38	3.87
Moerella culter											4.25	0.64
Littorina brevicula	21.17	1.88	17.50	3.11	23.00	5.76	15.67	2.75	6.63	2.47	22.33	9.89
Assiminea latericea	27.33	0.93	7.00	0.29	6.17	0.56			6.08	0.68	12.92	0.57
Ruditapes philippinarum			294.58	41.67			264.33	25.73				
Ligia oceanica					4.50	1.87						
Corophium acherusicum			8.39	0.15								
Vignadula atrata											16.17	3.20
Nassarius succinctus					3.72	1.85			2.58	0.48	4.50	1.33
Gelasimus arouatus									1.22	0.65		
Protankyra bidenata					2.72	1.95						
Phasolosma esculenta											7.33	4.71
Scapharca subcrenata			6.22	9.62								
Chaetopterus variopedatus									1.33	1.38		
Retusa borneensis							4.25	0.54			3.92	0.37
Barbatia virescens	2.44	1.72										
Macrophthalmus japonicus											3.19	3.29
Hemigrapsus penicillatus											3.38	0.86
Notoacmea schrenckii	1.92	0.41										
Metopograpsus quadridentatus					4.17	3.87			1.25	0.89	4.21	8.40
Nassarius dealbatus	2.89	0.59	4.58	1.81	5.39	3.85	8.69	2.14			3.92	1.39
Muscuius senhousei					15.56	1.01	16.64	0.68			29.92	8.87
Lumbriconeris heteropoda									1.00	0.40		
Sinonovacula constricta					16.78	1.47						
Saccostrea cucullata					3.89	2.39	6.25	12.49	1.67	4.84	2.58	5.08
Corophium sinensis					10.06	0.49			5.39	0.23	7.92	0.24
Littorinopsis intermedia	4.50	0.69	7.33	1.45	16.17	3.70	8.63	2.74			12.33	4.23
Cerithidea cingulata	3.69	1.88	14.00	4.39	31.58	13.94	28.64	13.65	10.56	4.32	17.25	9.23
Nassarius variciferus	2.81	0.81	3.58	1.60	8.33	2.80			5.06	1.36	6.33	3.02
Haliplanella luciae									2.00	2.68		

Power and production plants are often built on sea coasts; more than one third of power plants in the United States are situated near the sea, and daily water intake by these plants has reached billions of liters since the 1970s (Young, 1971). Two thermal power plants are situated in Xiangshan Bay. The fouling of cooling systems at thermal power plants has been thoroughly investigated in China. The cooling systems of these plants take water from the benthic zone and mix it with coastal waters, usually in a 5 m layer of the pelagic zone. Cooling system biotopes are characterized by an absence of light and rapid water currents, thus excluding certain groups of foulers but favoring others (barnacles, hydroids, and mussels). In addition, the rapid water flow prevents the larval settlement of many motile animals that require a developed sessile fouling biotope as substrate. Water flow therefore defines the composition and quantitative characteristics of fouling communities on anthropogenic substrates (Sergy and Evans, 1975). Before the construction of thermal power plant, Yang *et al*. (2004) surveyed the abundance and biomass near Section QJ to be 839 ind m^{-2} and 1753.92 g m^{-2}, respectively, but they declined to 259.69 ind m^{-2} and 81.87 g m^{-2} in this study. On one hand, these changes might be due to the different sampling sections in the two studies. The sections surveyed in 2002 have been occupied by the power plant and we likely missed some species and their contribution to the functioning that could be obtained by enhancing the spatial replication. On the other hand, the changes may mainly be due to the deteriorating environmental conditions in the thermal power plant over the years, for a total of 80 $m^3 s^{-1}$ heat water have been discharged to the environment (You and Jiao, 2011). Meanwhile, coastal waters of Xiangshan Bay received industrial discharges up to 544 million ton and domestic wastes of around 1.29 billion ton per year (Huang, 2008). Furthermore, during the last decades, growing population and industries around Xiangshan Bay increased alarmingly the sewage discharge. The results of our study proves the conclusion of Liu's (2008), which showed that the abundance and biomass obviously declined and the dominant species was markedly changed after the field run of power station. The pollution produced by thermal power plant, urbanization and industrial waste have obviously affected the marine biological environment. The recovery of disturbed macrobenthos community is slow and complicated. Oshurkov *et al*. (1994) found that the fouling organisms form the so-called 'physically controlled' communities, which are common in intertidal zones and estuaries and developed for 1–3 years and regain their original state relatively easily after stresses.

5 Conclusions

The present study provided information on the diversity and community structure of macrobenthos in Xiangshan Bay and showed the changes in abundance and community structure over the years. Species composition of the macrobenthos showed the dominance in the order of molluscs (bivalves and gastropods), crustaceans and others. Macrobenthos species density declined considerably in the last two decades, and the low benthic diversity index in all the observation sections indicated that the study area was under stresses. The multiple *k*-dominance plots showed that the curves for the sections HD, WS and XH with the same S-shape were lying low, indicating highest diversity, whereas the curves for the sections QJ and TG with irregular shape, show indicating the lower diversity, were lying high. The results of our study showed that the abundance and biomass obviously declined and the dominant species markedly changed after the field run of thermal power stations, for the pollution produced by power plants, urbanization and industrial wasted had affected the marine biological environment inevitably.

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