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Summertime community structure of intertidal macrobenthos in Changdao Archipelago, Shandong Province, China*

WANG Xiaochen (王晓晨)[†], LI Xinzheng (李新正)[††, **], LI Baoquan (李宝泉)[††], WANG Hongfa (王洪法)[††]

[†] *College of Marine Life Sciences, Ocean University of China, Qingdao 266003, China*

[††] *Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071, China*

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Abstract The community structure of intertidal macrobenthos in Changdao Archipelago (north of Shandong Peninsula, between Bohai Bay and the northern Yellow Sea) was examined based on samples collected from 14 stations in five transects in June 2007. Three stations corresponding to high, medium and low tidal areas were set up for each transect. A total of 68 macrobenthic species were found in the research region, most of which belonged to Mollusca and Crustacea. The average abundance and biomass of the macrobenthos was 1 383 ind./m^2 and 372.41 g/m^2, respectively. The use of an arbitrary similarity level of 20% resulted in identification of five groups among the 14 stations in the research region. There were remarkable differences in the biomass, abundance and Shannon-Wiener diversity index of the different sediments. Specifically, the order of biomass was rocky shores > gravel > mud-sand > coarse sand > stiff mud, while the order of abundance was rocky shores > coarse sand > mud-sand > gravel > stiff mud, and that of the diversity index was mud-sand > gravel > stiff mud > rocky shores > coarse sand. The above results revealed that the sediment type was the most important factor affecting the structure of the macrobenthic community of the intertidal zone.

Keyword: macrobenthos; community structure; biodiversity; Changdao Archipelago; sediment

1 INTRODUCTION

Intertidal zones are important linkages between land and oceans that are always characterized by a complex environment and fragile ecosystem. It is therefore essential to monitor and assess the ecological impact of increasing human activities on these important areas. Macrobenthos are primary consumers in intertidal zones. As such, they play an indispensable role in the intertidal ecosystems by maintaining the local ecological balance. The importance of macrobenthic communities in the ecological processes that occur in coastal areas has been well established (e.g., Dolbeth et al., 2003; Ge et al., 2005). Furthermore, macrobenthos can also be used as an indicator of ecosystem health (DelValls et al., 1998; Cai et al., 2003).

Changdao Archipelago (37°53′–38°23′N and 120°36′–120°56′E) consists of 32 small islands located at the mouth of the Bohai Bay in the North Yellow Sea, between the Shandong and Liaodong Peninsulas. The macrobenthic communities in this area are influenced by strong environmental disturbances due to the region's exposure to strong ocean currents and monsoons. Recently, increases of human activities such as the aquaculture have resulted in the macrobenthos of the islands being exposed to many new ecological factors (Zhuang et al., 2001), such as the increasing concentration of the organic matter in the sediment. Many descriptive and experimental studies have been conducted on the intertidal habitats in this area and adjacent areas, especially in the rocky intertidal zones (Zhuang et al., 2003a, b). However, no multivariate analyses or comparisons of existing data describing the macrobenthic community structure of different sediments in the region have been conducted to date.

To elucidate the relationships between the intertidal macrobenthic community structure and the abiotic environmental factors in the Changdao Archipelago, we analyzed the ecological characteristics of the

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* Supported by Shandong 908 Project for Islands Investigation, and the Knowledge Innovation Program of Chinese Academy of Sciences (No. 072715)

** Corresponding author: lixzh@ms.qdio.ac.cn community and the abiotic environmental factors of sediment in the intertidal zones of five representative islands. The ecological characters included biodiversity indices, species composition, biomass and abundance. Each of the islands evaluated in this study had different intertidal substrata. For instance, the substratum in Daqin Is. is stiff mud, while that of Tuoji Is. is coarse sand, that of Miaodao Is. is mud-sand, that of Nanhuangcheng Is. is gravel, and the substratum of Nanchangshan Is. is composed of rocky shores. The results reported here may provide baseline information for use in future studies of the intertidal benthic ecology and resource development and conservation.

2 MATERIAL AND METHODS

All field work was conducted in June 2007 (Fig. 1). One transect line perpendicular to the coastline was set up for each island according to the sedimentary and environmental conditions of the island. Three stations were set up for each transect, with a station located at the high, medium and low tidal zone respectively. The locations of the sampling stations are shown in Table 1.

Samples used for quantitative analysis were collected from a 50×50 cm sampling square at each station (two replicates per station). During sampling, individual epifauna were collected first, after which all of the sediment within the square was removed to a depth of 30 cm. The sediment samples were then washed through a sieve with a 0.5 mm mesh to collect the infauna. All samples were preserved in 75% alcohol.

Table 1 The locations of the 15 sampling stations in the five islands of Changdao Archipelago evaluated in this study

Island	Tidal zone	Station	Latitude (°N)	Longitude (°E)
Daqin Is.	high	D1	38º18.154′	120º48.371′
	medium	D2	38º18.154′	120º48.373′
	low	D3	38º18.152′	120º48.374′
Tuoji Is.	high	T1	38º10.195′	120º45.141′
	medium	T2	38º14.220′	117º56.451′
	low	T3	38º21.058′	120º54.119′
Miaodao Is.	high	M1	37º55.977′	120º40.609′
	medium	M2	37º55.961′	120º40.597′
	low	M3	37º55.950′	120º40.583′
Nanhuangcheng Is.	high	N1	38º21.062′	120º54.125′
	medium	N2	38º21.057′	120º54.125′
	low	N3	38º21.058′	120º54.119′
Nanchangshan Is.	high	C1	37º55.326′	120º45.589′
	medium	C2	37º55.340′	120º45.586′
	low	C3	37º55.332′	120º45.607′

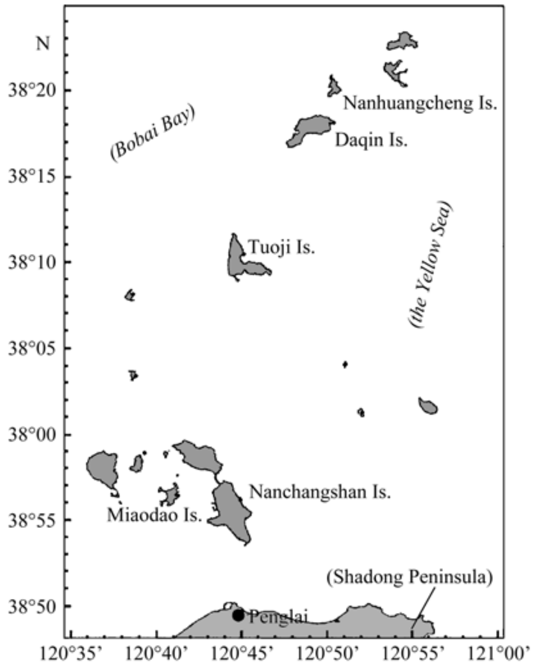

Fig.1 Locations of five islands evaluated in the Changdao Archipelago

The living organisms in the macrobenthic samples were identified to the species level in the laboratory by taxonomists, after which the samples were counted and weighed (wet mass).

In the data process, station with no macrobenthos distributing was excluded from the analysis.

Multivariate analysis was conducted using the PRIMER software package (version 5) (Clarke et al., 2001). Briefly, the data were fourth root transformed, after which the Bray-Curtis similarities were calculated. Ordination (non-metric multidimensional scaling-MDS) and classification (using group average linking) of samples were distinguished based on the resultant dendrogram and MDS plot. The total biomass (*B*), abundance (*A*), number of species (*s*), Shannon-Wiener diversity index (*H'*) (Shannon et al., 1949), Margalef (1968) richness index (*d*), and Pielou (1975) evenness index (*J*) were obtained. The biodiversity indices were calculated using the following formulae:

$$H' = -\sum_{i=1}^{s} P_i \log_2 P_i$$

$$d = (s-1)/\log_2 N$$

$$J = H'/\log_2 s$$

where s is the species number at each station; N is the total number of individuals at each station; P_i is the proportion of the abundance of the species i in the total abundance at each station (N_i/N).

Multidimensional scaling (MDS) was used to analyze the macrobenthic community characteristics. Clustering was conducted using the hierarchical agglomerative method employing the group average linking of Bray-Curtis similarities, after the fourth transformation of the species abundance data. Following MDS analysis, ANOSIM (a non-parametric procedure applied to the rank similarity matrix underlying the ordination of quadrats) was used to determine if significant differences existed between samples. Finally, the species making the greatest contribution to the division of sites into the identified clusters were determined using the similarity percentages program (SIMPER).

3 RESULTS

3.1 Species composition

A total of 68 species were collected, including 32 species of Mollusca (47.1% of the total), 19 Crustacea (27.9%), 14 Polychaeta (20.6%) and 3 other species (1 Hemichordate: *Glossobalanus polybranchioporus*; 2 Coelenterata) (Table 2). The average number of species was 9 among the 14 remaining stations. In addition, the minimum number of species was 3 at St. D3 and St. T2. The maximum number of species was 16 at St. M3 (Fig. 2).

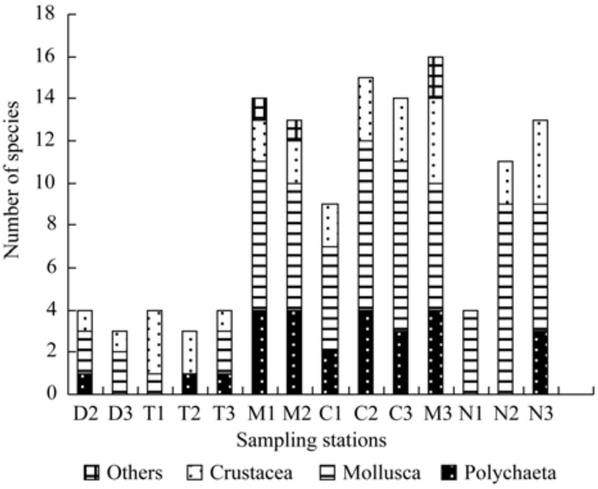

Fig.2 Species compositions of macrobenthos at the sampling stations

The species composition was quite different among the 14 sampling stations. Most of the species occurred in less than five stations, and there were only three species found in more than six stations (*Littorina brevicula*, nine stations; *Hemigrapsus penicillatus*, eight stations; *Mytilus galloprovincialis*, seven stations). Mollusca was the most dominant group, comprising more than 50% of the total species collected from six stations (100% at St. N1, 82% at St. N2, 67% at St. D3, 57% at St. C3, 56% at St. C1, 53% at St. C2: 53%). *Littorina brevicula* was the most dominant species of mollusk, being found at all above six stations. Crustaceans accounted for more than 50% of the total species at two stations (75% at St. T1, 67% at St. T2).

3.2 Abundance and biomass

The macrobenthic abundances of the sampling stations are shown in Figure 3. The average abundance was 1 383 ind./m^2. However, the abundance was quite different among stations, ranging from 12 ind./m^2 at St. D2 to 6 848 ind./m^2 at St. C2. Two stations had abundances lower than 100 ind./m^2 (St. D2, 12 ind./m^2; St. D3, 26 ind./m^2). Crustaceans and mollusks were the primary groups contributing to the abundance of the macrobenthos, with average abundances of 769 ind./m^2 and 506 ind./m^2, respectively. In addition, the abundance of mollusks was greater than 50% of the total macrobenthic abundance at five stations (St. N1, 170 ind./m^2, 100%; St. C1, 3548 ind./ m^2, 99%; St. N2, 472 ind./m^2, 96%; St. D2, 8 ind./m^2, 67%; St. C3, 484 ind./m^2, 64%). The abundance of crustaceans was greater than 50% of the total macrobenthic abundance at six stations (St. T1, 232 ind./m^2, 99%; St. T2, 3 528 ind./m^2, 99%; St. T3, 608 ind./m^2, 82%; St. D3, 20 ind./m^2, 77%; St. C2, 5 024 ind./m^2, 73%; St. N3, 568 ind./m^2, 67%). Two stations had abundances of polychaetes greater than 50% of the total macrobenthic abundances (St. M2, 800 ind./m^2, 83%, St. M1, 154 ind./m^2, 56%).

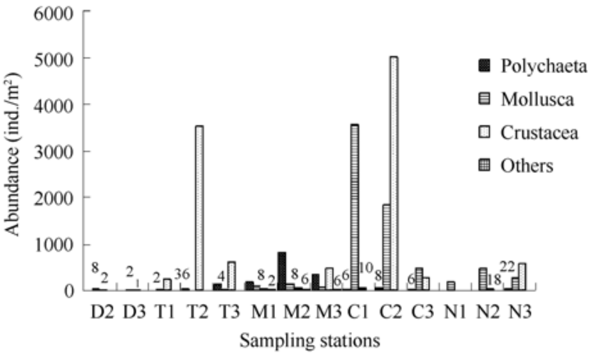

Fig.3 Compositions of the macrobenthic abundances at the 14 sampling stations

In cases in which the abundance of the four groups is less than 50, the numbers are written

Fig. 4 shows the compositions of the macrobenthic biomasses from the 14 sampling stations. The average biomass was 372.41 g/m^2, with the minimum

Table 2 Macrobenthic species recorded in the five islands of the Changdao Archipelago evaluated in this study summer (June 2007)

	Species	Stations													
		D2	D3	T1	T2	T3	M1	M2	M3	C1	C2	C3	N1	N2	N3
Coelenterata	*Anthopleura* sp.							+	+						
	Actiniaria						+								
Polychaeta	*Ceratonereis erythraeensis* Fauvel						++	+++	+++						
	Cirratulus cirratus (Müller)														++
	Cirriformia sp1.						++	++	++		+				
	Cirriformia tentaculata (Moutagu)						++	+++	++						
	Nereis multignatha Imajima and Hartman				++	+++									
	Nereis sp.									+					
	Nereis sp2.											+			
	Perinereis aibuhitensis Grube									+					
	Perinereis cultrifera Grube										+	+			
	Perinereis nuntia (Savigny)						++	+							
	Typosyllis adamantens Kurilensis and Chlefovitsh										+	+			+
	Nereidae	+													+
	Onuphidae								+						
	Phyllodocidae										+				
Mollusca	*Acanthochiton dissimilis* Taki and Taki											++			
	Acmaea sp.										++	++			
	Batillaria cumingi (Crosse)						++	++	+						
	Cellana toreuma (Reeve)									++					
	Ceratostoma sp.											+			+
	Collisella heroldi (Dunker)										+		++	+++	
	Collisella kolarovai (Grabar and King)									+					
	Collisella langfordi (Habe)										+				
	Crassostrea cf. gigas (Thunberg)													+	++
	Crassostrea sp.										+++	++			
	Littorina brevicula (Philippi)	+	+				++			++++	++++	++	++	+++	++
	Macoma incongrua (Martens)						+	++	++						
	Mitrella bella (Reeve)						+								
	Moerella iridescens (Benson)							+							
	Monodonta labio (Linné)													++	
	Musculus senhausia (Benson)								+						
	Mytilus galloprovincialis Lamarck			+		+				+	+++	++		+	++
	Nassarius festivus Powys	+					+	+	+						
	Nassarius hiradoensis (Pilsbry)							+							

To be continued

Continued

	Species	Stations													
		D2	D3	T1	T2	T3	M1	M2	M3	C1	C2	C3	N1	N2	N3
Mollusca	*Nassarius semiplicata* (A. Adams)		+											+	
	Neverita didyma (Roding)						+								
	Nodilittorina exigua (Dunker)												++		
	Notoacmea schrenckii (Lischke)									++			++	++	++
	Paramormula sp.								+						
	Patelloida pygmaea (Dunker)											++			
	Patelloida sp.										++				
	Puncturella sp.											+			
	Ruditapes philippinarum (Adams and Reeve)						++	++	++						
	Semelangutus sp.					+									
	Thais clavigera Kuster													+	+
	Trophonopsis sp.													+	
	bivalve (larva)										+++				
Crustacea	*Amphithoe* sp.								++						
	Chthamalus challengeri Hoek										++++	+++			+++
	Cirolana harfordi japonica Thielemann														+++
	Excirolana chiltonii Richardson			+++					+++						
	Gaetice depressus (de Haan)									+					
	Gammaropsis sp.			+											
	Grandidierella japonica Stephense							+							
	Hemigrapsus penicillatus (de Haan)						+	+	+						
	Hemigrapsus sinensis Rathbun										++	+			
	Hemigrapsus sp.									+				++	+
	Hyale grandicornis (Kroyer)										+				
	Hyale sp.				++++	+++									
	Ligia exotica (Roux)													+	
	Melita koreana Stephensen		++												
	Parhyale plumulosa (Stimpson)														+
	Pinnotheres sinensis Shen											+			
	Sinoediceros homopalmulus Shen			+					+						
	Aegidae				+										
	Gammaridae	+					+								
Hemichordate	*Glossobalanus polybranchioporus* (Tchang and Liang)								+						

+ indicates the species occur at that stations (+: abundance<10; ++: 10<abundance<100; +++: 100<abundance<1000; ++++: abundance>1000) of 1.06 g/m^2 being recorded at St. D3 and the maximum of 1 795.78 g/m^2 being observed at St. N3. Five stations had biomasses lower than 20 g/m^2 (St. D3, 1.06 g/m^2; St. D2, 1.10 g/m^2; St. T1, 4.93 g/m^2; St. T3, 7.58 g/m^2; St. T2, 12.59 g/m^2). Mollusks were the dominant group in the macrobenthic communities, with an average biomass of 336.65 g/ m^2. Only three stations had a biomass of mollusks less than 50% of the total macrobenthic biomass (St. T3, 2%; St. T1, 1%; St. T2, 0). Two stations had crustacean biomasses greater than 50% of the total macrobenthic biomasses (St. T1, 99%; St. T3, 62%). The polychaete biomass was greater than 50% of the total macrobenthic biomass at only one station (St. T2, 56%).

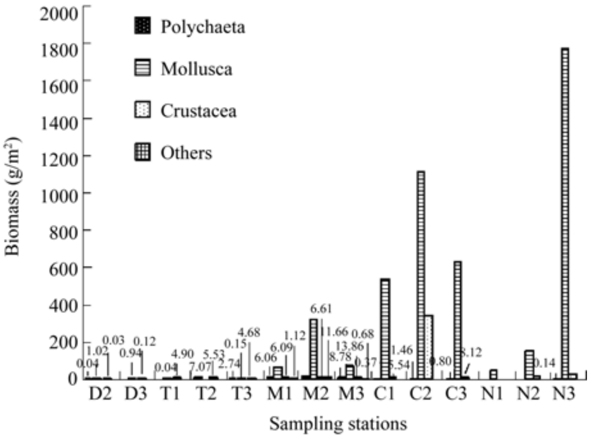

Fig.4 Compositions of the macrobenthic biomasses at the 14 sampling stations

In cases in which the biomass of the four groups is less than 20, the numbers are written

3.3 Biodiversity

The biodiversity indices are shown in Fig. 5.

The Margalef richness indices of the macrobenthos at the 14 sampling stations ranged from 2.316 to 0.245, with an average value of 1.275. Three high richness indices were recorded from Sts. M1 (2.316), M3 (2.216) and C3 (1.963). The lowest richness indices were recorded at the three stations on Tuoji Is. (St. T2, 0.245; St. T3, 0.454; St. T1, 0.550).

The Pielou evenness indices of the macrobenthos ranged from 0.959 to 0.056, with an average value of 0.505. The three highest values were recorded from St. D2 (0.959), St. N1 (0.865) and St. M1 (0.842). The three lowest values were recorded from St. T2 (0.056), St. C1 (0.062) and St. T1 (0.106).

The Shannon-Wiener diversity indices of the macrobenthos ranged from 3.207 to 0.213, with an average value of 1.503. Two stations had diversity indices lower than 0.2 (St. T2, 0.088; St. C1, 0.195), while five stations had values higher than 2.0 (St. M1, 3.207; St. C3, 2.469; St. N3, 2.340; St. M2, 2.123; St. M3, 2.007).

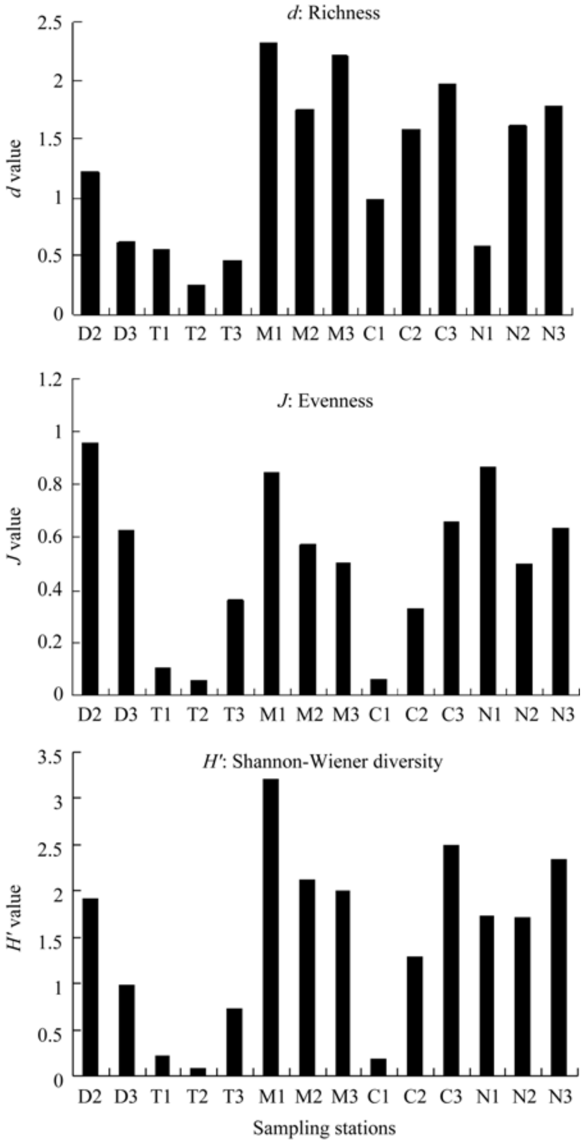

Fig.5 Diversity of the macrobenthic communities at the 14 sampling stations

3.4 Similarity of community structure

The Bray-Curtis similarities and MDS ordinations of 14 sampling stations are shown in Figs. 7 and 8. Based on the species abundances, the CLUSTER and MDS ordinations enabled the 14 sampling stations from the five islands to be classified into five groups with distinct spatial differences: the first group (Cluster I) included the three stations located at Miaodao Is.; the second group (Cluster II) consisted of only station T1 located in the high tidal zone of Tuoji Is.; the third group (Cluster Ⅲ) included the three stations located in Nanchangshan Is. and the three stations at Nanhuangcheng Is.; the fourth group

(Cluster IV) included the two stations located in the median and low tidal zones of Daqin Is.; the fifth group (Cluster V) consisted of the two stations located in the median and low tidal zones of Tuoji Is.

The similarity and distinctive assemblages were identified by multi-dimensional scaling ordination plots (MDS) of the macrobenthos. A stress <0.1 corresponded to a good ordination with no real prospect of a misleading interpretation. The five assemblages were compared using the ANOSIM (analysis of similarities) test. The results revealed significant differences both globally and among the pairwise tests (global *R*=0.970, *P* (significance level%)=0.1% <0.05, permutations = 999 random from a large number).

SIMPER analysis revealed that the five groups included quite different macrobenthic species. In the first group, the polychaetes, *Ceratonereis erythraeensis* and *Cirriformia tentaculata*, the mollusks, *Ruditapes philippinarum* and *Macoma incongrua* and the crustacean, *Hyale* sp., were the dominant species. The average coefficient of the species similarity within this group was 58.53%. The second group contained only the crustacean, *Gaetice depressus*. In the third group, the mollusks *Littorina brevicula*, *Notoacmea schrenckii* and *Mytilus galloprovincialis* were the dominant species and the average coefficient of the species similarity was 30.46%. In the fourth group, the mollusk, *Littorina brevicula*, was the dominant species, with an average coefficient of species similarity of 23.96%. In the fifth group, the crustacean, *Hyale* sp., and the polychaete, *Nereis multignatha*, were the dominant species, with an average coefficient of species similarity of 67.13%. When all 14 stations were evaluated, the mollusks, *Littorina brevicula* and *Mytilus galloprovincialis* were the dominant species, with an average coefficient of species similarity of 11.80%.

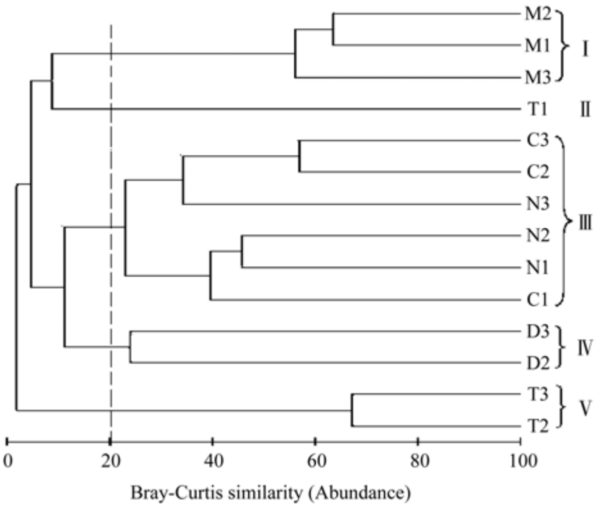

Fig.6 Hierarchical agglomerative clustering of macrobenthic communities from the 14 sampling stations based on fourth root transformed abundance data of 68 species, using group-average linking of Bray-Curtis similarity

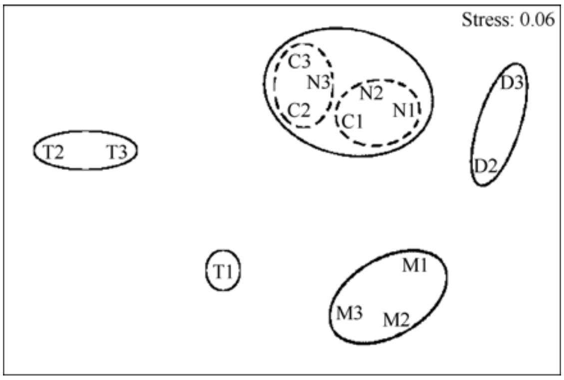

Fig.7 MDS ordination of the 14 stations based on fourth root transformed abundance data of 68 species

4 DISCUSSION

The species composition, total biomass, abundance and biodiversity varied greatly among the 14 stations on the five islands in Changdao Archipelago evaluated in this study, especially in the bottom sediment of sand and rock.

4.1 Relationships between species composition, abundance and biomass and sediments

In the present study, species composition was found to be closely related to the different types of sediment. The lowest species numbers were observed at stations that contained stiff mud sediment and low concentrations of organic material and oxygen, such as D2 and D3. Indeed, these stations contained only a few mollusks with wide adaptability such as *Littorina brevicula* and *Nassarius* sp.. Conversely, relatively high species numbers and similar compositions were observed at stations that contained hard sediment (gravel and rocky), such as N1, N2, N3, C1, C2, and C3. Specifically, eight common species were observed at these stations, the polychaete, *Typosyllis adamantens*, the crustaceans, *Chthamalus challengeri* and *Hemigrapsus* sp., and the mollusks, *Cellana toreuma*, *Collisella heroldi*, *Littorina brevicula*, *Mytilus galloprovincialis* and *Notoacmea schrenckii*. Finally, the mud-sand mixed type (Miaodao Is. substrata contained more species than the homogenized sediment (Tuoji Is.), especially with regards to mollusks and polychaetes.

The abundance and biomass of macrobenthos in different sedimentary intertidal zones are shown in table 3. Remarkable differences in the biomass and abundance of the five intertidal zones was observed. Specifically, the biomass occurred in following order: rocky shores > gravel > mud-sand > coarse sand > stiff mud. Moreover, the abundance was as follows rocky shores > coarse sand > mud-sand > gravel > stiff mud. Several studies have described the influence of the sedimentary environment on macrobenthos in the intertidal zone and suggested that the biomass and density of the rock stratum were both higher than that of sand stratum (Liao et al., 2007; Shou et al., 2007). Our findings that the rocky shores had the highest biomass and abundance support the results of these previously conducted studies which results from some dominant species with specific adaptabilities to the habitats. In the present study, stratal types with higher abundance were populated by several species, including the mollusks, *Chthamalus challengeri* and *Littorina brevicula* (1 751 ind./m^2 and 996 ind./m^2 in the rocky section, respectively). Mollusca, which was the most important group contributing to the macrobenthic biomass, was dominant in rocky sedimentary intertidal zones, which demonstrates that the hard stratum had a higher biomass value than the sandy or muddy stratum.

4.2 Relationships between biodiversity and environmental factors

Several investigations have been conducted to compare the biodiversity of different types of sediment. In a survey of the distribution of macrobenthos of the intertidal zone, the mud-sand stratum was found to have a higher biodiversity index value than the rocky stratum on Qushan Island (Shou et al., 2007), while the rocky stratum was found to have a higher value than the sandy stratum in Shengsi Archipelago (Liao et al., 2007). Zhuang et al. (2003b) found that the community diversity was generally higher in the gravel intertidal community than the rocky intertidal community. Our results supported the results of these studies. In the present study, the Shannon-Wiener diversity indices differed significantly among the different types of sediment (mud-sand > gravel > stiff mud > rocky shores > coarse sand). The results of numerous studies of the effects of habitat structure on macrobenthic species have indicated that increased complexity and heterogeneity clearly enhance the diversity of macrobenthos (McGuinness et al., 1986; Bourget et al., 1994; Guichard et al., 1998). It is likely that complex, heterogeneous habitats could provide the macrobenthos with a more preferable environment for settling, breeding, and preying, as well as better shelter and richer food resources than other types of substrates, which would result in a higher biodiversity than simple, homogenous habitats. Although habitat diversity (i.e., heterogeneity) is usually the primary factor affecting species biodiversity, the relationship between these factors can be complicated by several parameters including habitat quality and the specialized requirements of some species for special habitats.

4.3 Relationships between community structure and sediment

Junoy et al. (1990), Bazairi et al. (2003) and Li et al. (2006) demonstrated that sediment was an important factor in the distribution of macrobenthic assemblages in intertidal zones. Relationships between the macrobenthic community structure and sediment were also evident in the area evaluated in the present study. Based on the cluster and MDS analyses, there were five groups defined at the arbitrary similarity level of 20% among the communities at the 14 stations evaluated in the present study. These results corresponded well to the effects of the sediments on the macrobenthic community. The grouping of communities of stations located in Nanhuangcheng Is. and Nanchangshan Is. likely occurred due to the presence of similar hard sediments (gravel and rock) at these stations, which indicate that fauna from the two habitats display similar species compositions and similar limitations in their distribution. In addition, the species distributions at stations with coarse and mud-sand sediments were distinct from those of stations with hard sediments.

4.4 Suggestions

Zhuang et al. (2001) suggested that the variation in community compositions and structures in the intertidal zones of Yantai littoral regions primarily

Table 3 Biomass and abundance of macrobenthos in different sedimentary intertidal zones.

Sections types	Stiff mud	Coarse sand	Mud-sand	Rocky shores	Gravel
Biomass (g/m^2)	1.08±0.02	8.37±3.89	179.33±153.86	879.65±498.54	669.84±976.93
Abundance (ind./m^2)	19±10	1515±1793	703±375	3721±3051	503±339

resulted from eutrophication caused by human disturbances associated with tourism, inshore aquacultures and urban pollution. In the present study, a first class national conserved animal species, *Glossobalanus polybranchioporus* (Tchang and Liang), was collected from the intertidal zone of Miaodao Is. Restriction of this organism environment and the destruction of its habitat by pollution have endangered this species in the islands. In comparison with the intertidal zone of Jiaozhou Bay (Wang et al., 2006; Zhang et al., 2007), the species composition and distribution of Miaodao Is. was similar to that of intertidal zones that have been severely affected by human activities. Therefore, protective measures such as controlling pollution sources near sandy beaches, establishing natural reserve zones and exploiting temperately should be taken.

However, no single environmental factor could account for the distribution of species in a habitat, and several biotic and abiotic factors interact to determine the pattern of species distribution (Cusson et al., 1997; Takada, 1999). In addition to the type of sediment, temperature, rainfall and photoperiod also affect the macrobenthic community structure (Gilda et al., 2006). McArdle et al. (1992) found that variations in tidal swash could also lead to changes in the distribution of macrofauna. Thus, to fully understand the original formation and subsequent succession of the macrobenthic communities in the intertidal zones of the islands in Changdao Archipelago, more field work during different seasons and evaluation of a greater variety of abiotic and biotic factors is necessary.∂

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References

Bazairi H, Bayed A, Glemarec M, Hily C. 2003. Spatial organisation of macrozoobenthic communities in response to environmental factors in a coastal lagoon of the NW African coast (Merja Zerga, Morocco). *Oceanologica Acta*, **26**: 457-471.

Bourget E, DeGuise J, Daigle G. 1994. Scales of substratum heterogeneity, structural complexity, and early establishment of a marine epibenthic community. *Journal of Experimental Marine Biology and Ecology*, **181**: 31-51.

Cai L Z, Tam N F Y, Wong T W Y, Ma L, Gao Y, Wong Y S. 2003. Using benthic macrofauna to assess environmental quality of four intertidal mudflats in Hong Kong and Shenzhen coast. *Acta Oceanologica Sinica*, **22**(2): 309-319.

Clarke K R, Gorley R N. 2001. Primer V5: User Manual/Tutorial. Plymouth. PRIMER-E.

Cusson M, Bourget E. 1997. Influence of topographic heterogeneity and spatial scales on the structure of the neighbouring intertidal endobenthic macrofaunal community. *Marine Ecology Progress Series*, **150**: 181-193.

DelValls T A, Conradi M, Garcia-Adiego E, Forja J M, Gómez-Parra A. 1998. Analysis of macrobenthic community structure in relation to different environmental sources of contamination in two littoral ecosystems from the Gulf of Cádiz (SW Spain). *Hydrobiologia*, **385**: 59-70.

Dolbeth M, Pardal M A, Lillebo A I, Azeiteiro U, Marques J C. 2003. Short- and long-term effects of eutrophication on the secondary production of an intertidal macrobenthic community. *Marine Biology*, **143**(6): 1 229-1 238.

Ge B M, Bao Y X, Zheng X. 2005. Macrobenthic community ecology of a tidal flat in different habitats and creeks dyked in different years at Lingkun Island. *Acta Ecologica Sinica*, **25**(3): 446-453. (in Chinese)

Gilda S, José L C, Pedro R A, Maria J C. 2006. Structure and dynamics of a benthic invertebrate community in an intertidal area of the Tagus estuary, western Portugal: a six year data series. *Hydrobiologia*, **555**(1): 115-128.

Guichard F, Bourget E. 1998. Topographic heterogeneity, hydrodynamics, and benthic community structure: a scale-dependent cascade. *Marine Ecology Progress Series*, **171**: 59-70.

Junoy J, Vietiez J M. 1990. Macrozoobenthic community structure in the Ria de Foz, an intertidal estuary (Galicia, Northwest Spain). *Marine Biology*, **107**(2): 329-339.

Li X Z, Li B Q, Wang H F, Wang J B, Zhang B L. 2006. Macrobenthic community of intertidal zone of Jiaozhou Bay. *Acta Zoologica Sinica*, **52**(3): 612-618. (in Chinese)

Liao Y B, Zeng J N, Chen Q Z, Gao A G, Shou L, Xu X Q. 2007. Macrobenthos community patterns in the intertidal zone of the Shengsi archipelago in spring and autumn. *Acta Zoologica Sinica*, **53**(6): 1000-1010. (in Chinese)

Margalef R. 1968. Perspective in Ecological Theory. University of Chicago Press. 111p.

McArdle S B, McLachlan A. 1992. Sand beach ecology: swash features relevant to the macrofauna. *Journal Coastal Research*, **8**(2): 398-407.

McGuinness K A, Underwood A J. 1986. Habitat structure and the nature of communities on intertidal boulders. *Journal of Experimental Marine Biology and Ecology*, **104**: 97-123.

Pielou E C. 1975. Ecological Diversity. Wiley-Inters, New York. 163p.

Shannon C E, Wiener W. 1949. The Mathematical Theory of Communication. University of Illinois, Urbana. 117p.

Shou L, Gao A G, Zeng J N, Chen Q Z, Liao Y B, Xu X Q. 2007. The influence of the sediment environment on distribution of macrobenthos of the intertidal zone in Qushan Island. *Chinese Journal of Zoology*, **42**(3): 79-83. (in Chinese)

Takada Y. 1999. Influence of shade and number of boulder layers on mobile organisms on a warm temperate boulder shore. *Marine Ecology Progress Series*, **189**: 171-179.

Wang H F, Li B Q, Zhang B L, Shuai L M, Li X Z. 2006. The ecological research of the macrobenthic community in intertidal zone of Hongshiya, Jiaozhou Bay. *Marine Science*, **30**(9): 52-57. (in Chinese)

Zhang B L, Wang H F, Li B Q, Wang Y Q, Wang J B, Li X Z. 2007. The ecology of the macrobenthic community in the intertidal zone of Xindao, Jiaozhou Bay. *Marine Science*, **31**(1): 60-64. (in Chinese)

Zhuang S H, Wang K M, Chen L X. 2001. Study on invertebrate communities in rocky intertidal zones influenced by human activities. *Journal of Oceanography of Huanghai & Bohai Seas*, **19**(3): 54-64.

Zhuang S H, Chen L X, Sun L. 2003a. Seasonal variation pattern of benthic algal community structure in rocky intertidal zone of Nanchangshan Island. *Advances in Marine Science*, **21**(2): 194-202. (in Chinese)

Zhuang S H, Chen L X, Wang Z Q. 2003b. Diversity patterns in intertidal communities of three southern islands of Changshan archipelago. *Chinese Journal of Applied Ecology*, **14**(5): 747-752. (in Chinese)