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The relationship between soft-bottom macrobenthic communities and environmental variables off Ningjin, eastern Shandong Peninsula

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Abstract
Macrobenthic infauna and associated environmental factors influencing the benthic community in the eastern coastal region of Shandong Peninsula were analyzed in four seasonal surveys from January 2007 to October 2007 (30 stations in winter, 20 stations in other three seasons), in order to understand the community structure and the factors unfluencing the benthic distribution. PRIMER 6.0 and SPSS 15.0 software packages were adopted to analyze the environmental and macrobenthic data. The results show that there were 260 macrobenthic species in total collected from the research region. The composition of species is: Polychaeta (94 species), Crustacea (75), Mollusca (56) and Echinoderm (12), among which, only 23 species were common species in the cruises of every season. The dominant species varied from season to season; however, the polychaete species *Paralacydonia paradoxa* Fauvel and Echinoderm species *Amphioplus japonicus* (Matsumoto) were always present year-round. The abundance and biomass of the macrobenthos in the research region were variable from season to season. The results of CLUSTER and MDS analysis show that the similarities of macrobenthic structures between the stations were low; most of the similarities were at about 30% of similarity value, only two stations were up to 70%. In accordance with the similarity values of the macrobenthic structures, we divided the 20 stations into five groups by arbitrary similarity level of 30%. The ABC curve indicates that the marcofauna communities in the research region had not been disturbed massively, except two stations, SB1 and SB3. Ecologically, benthos were controlled by a combination of factors such as salinity, phytoplankton, zooplankton, SiO_3-Si and temperature, and no single factor could be considered as an ecological master factor.

Key words: benthos, community structure, biodiversity, the Huanghai (Yellow) Sea, Shandong Peninsula

1 Introduction

The Huanghai (Yellow) Sea is one of the most important marine fishery areas in China seas. Since the 1980s, the marine aquaculture along the coast of the peninsula has been developing quickly. The cultural breeds include prawns, bivalves, crabs, sea cucumbers, sea algae such as kelp. The human activities such as the aquaculture have been impacting the environments of the coastal areas of the Shandong Peninsula. The rushing development of fishery and the increasingly intensive human activities in the above region have worsened the marine ecosystem in recent years (Wang et al., 2004). Macrobenthos is considered to be one of the most important components in marine ecosystems, and it cannot help but follow the same trend of fate (Sun and Dong, 1986; Liu and Li, 2002) in the Huanghai Sea. The research water area is located on the coastal region off Ningjin, east of the Shandong Peninsula, near the Shidao Bay and Sanggou Bay, which are the ones of the most important sea areas for aquaculture of Mollusca scallop and sea belt *Thallus laminariae* in Shandong Province, China. Besides, Shidao Bay is also a very important port for

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commercial and fishery boats, large and small.

Macrobenthos in marine sediment play a very important role in ecosystem processes such as nutrient cycling, pollutant metabolism, dispersion and burial, and in secondary production (Snelgrove, 1998). Structure of benthic community is frequently used in pollution effect monitoring programmes (Jayaraj et al., 2007).

In this paper we report the results of an analysis of macrobenthos off Ningjin, Shandong Province using the data from four seasonal surveys carried out from January 2007 to October 2007. Our aim is to understand the present conditions of the marine benthic ecosystem in the east coast of the Shandong Peninsula, to research on the relationship between macrobenthic communities and environmental variables, and to provide the basic data for the evaluation of the impact from the human activities on the marine ecosystem of the region, we have studied the macrobenthos in the coastal water off Ningjin, east coast of the Shandong Peninsula.

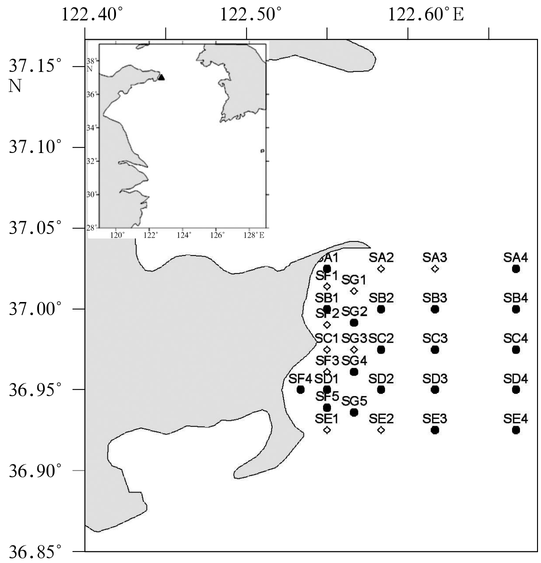

Fig.1. Study area and locations of sampling stations off Ningjin (● 20 ordinary sampling stations; ◇ 10 extended sampling stations).

Table 1. Localities of the sampling stations off Ningjin with the depth, sediment type and concentrations of organic matter (%)

Station	Depth	Sediment	OM	Winter			Spring			Summer			Autumn		
			(%)	*d*	*J′*	*H′*	*d*	*J′*	*H′*	*d*	*J′*	*H′*	*d*	*J′*	*H′*
SA1*	8	clay	0.69	4.2	1.0	2.9	4.2	1.0	2.8	4.4	1.0	2.9	–	–	–
SA2	14	sandy clay	–	–	–	–	–		–	– 2.3	0.9	2.1	–	–	–
SA3*	22	gravel	–	–	–	–	–	–	–	2.0	0.9	1.9	6.5	0.8	1.7
SA4*	33	silt	0.59	2.8	1.0	2.3	4.3	1.0	2.8	4.0	1.0	2.7	8.6	0.9	2.6
SB1*	10	silt	0.48	3.6	1.0	2.6	4.1	1.0	2.8	3.6	1.0	2.7	7.5	0.8	2.3
SB2*	18	sandy clay	0.58	5.2	1.0	3.1	2.5	1.0	2.2	4.8	1.0	2.9	3.7	0.5	1.0
SB3	24	clayey sand	0.76	2.7	0.8	–	–	–	2.1	3.2	0.9	2.4	6.8	0.9	2.3
SB4*	35	fine sand	0.6	4.6	1.0	2.9	3.2	1.0	2.5	4.1	1.0	2.8	7.2	1.0	2.3
SC1*	7	silt	–	–	–	–	1.1	1	1.1	2.9	0.9	2.3	1.8	0.4	0.7
SC2*	22	sandy clay	0.53	3.5	1.0	2.6	2.7	0.9	2.2	2.6	0.8	2.0	4.4	0.9	1.8
SC3*	23	sandy clay	0.73	1.9	0.9	1.8	3.5	1.0	2.6	1.7	0.9	1.6	7.0	0.8	2.1
SC4*	38	silt	0.51	4.7	1.0	2.9	5.9	0.9	3.1	3.6	1.0	2.6	6.3	0.8	2.2
SD1	9	sandy clay	0.4	4.0	1.0	2.7	–	–	–	3.6	1.0	2.6	8.9	0.9	2.4
SD2*	24	silt	0.79	3.6	1.0	2.6	1.8	1.0	1.8	2.9	1.0	2.4	5.0	0.8	1.7
SD3	29	sandy clay	0.72	3.0	0.9	2.4	–	–	–	1.2	1.0	1.3	–	0.8	0.6
SD4*	38	silt	0.58	4.8	1.0	2.9	4.6	1.0	2.9	–	–	–	8.0	0.9	2.6
SE1*	10	gravel	–	–	–	–	4.7	1.0	2.9	3.6	1.0	2.7	–	–	–
SE3*	37	clayey sand	0.75	3.8	1.0	2.6	4.2	1.0	2.8	0.6	1.0	0.7	6.9	0.9	2.4
SE4*	38	silt	0.59	4.1	1.0	2.8	4.2	0.9	2.8	1.4	1.0	1.4	10.4	0.9	2.9
SF1	9	–	–	–	–	–	–	–	–	3.1	1.0	2.5	–	–	–
SF2	9	–	–	–	–	–	–	–	–	3.5	1.0	2.6	8.8	0.9	2.4
SF3	7	–	–	–	–	–	–	–	–	2.3	1.0	2.1	–	–	–
SF4*	7	sandy clay	–	1.9	1.0	1.8	3.4	0.9	2.6	3.8	1.0	2.7	6.6	0.9	2.3
SF5	13	sandy clay	0.61	6.9	1.0	3.4	–	–	–	–	–	–	–	–	–
SG1*	11	muddy sand	–	–	–	–	5.3	1.0	3.1	5.0	1.0	3.0	9.0	0.9	2.3
SG2	11	sandy clay	0.44	4.9	1.0	3.0	–	–	–	4.3	1.0	2.9	–	–	–
SG3*	9	silty clay	–	–	–	–	–	–	–	3.5	1.0	2.6	–	–	–
SG4*	11	sandy clay	0.55	3.3	1.0	2.5	5.3	0.9	3.0	4.5	1.0	3.0	8.8	0.9	2.3
SG5*	19	sandy clay	0.9	3.2	1.0	2.5	5.2	1.0	3.0	–	–	–	–	–	–
	average		0.6	3.8	1.0	2.6	3.9	1.0	2.6	3.2	1.0	2.4	7.0	0.8	2.0

Notes: * represents 20 sampling stations explored on spring, summer and autumn; – missing values; OM organic matter; *d* Margalef richness index; *J′* Evenness index; and *H′* Shannon-Wiener index.

2 Materials and methods

2.1 *Sampling stations and research cruises*

Thirty sampling stations were set up in the coastal water off Ningjin, east coast of the Shandong Peninsula, the south of the Huanghai Sea, within the area of 36.85°–37.15°N, 122.40°–122.65°E (Fig. 1, Table 1). We cruised in the region once in every season, from January 2007 to October 2007: January 2007 in winter, April 2007 in spring, July 2007 in summer, and October 2007 in autumn.

2.2 *Sampling methods and procedure*

Bottom water quality parameters and sediment samples were collected at 30 stations in the depth range of 7–38 m. All samples were collected and treated in accordance with the *Chinese National Oceanography Census Regulation Methods* (edited by State Quality and Technical Supervision Administration, China, 1992). Sediment samples were collected using a modified 0.1 m^2 Gray-O' Hara box-corer along five transects. The sediment samples were washed though a 0.5 mm mesh sieve and then fixed and preserved in 80% (volume fraction) ethanol. All organisms were identified to the level when they were possible to be counted and weighted using 0.001 g precision electric balance in our laboratory to get the basic data.

2.3 *Environmental factors*

The bio- and abio- environmental factors were obtained in situ, which including water depth, temperature, salinity, sediment concentrations of heavy metals (Zn, Cd, Pb, Cu, Hg, As, Cr), nutrients (NH_4-N, NO_2-N, NO_3-N, TN, SiO_3-Si, PO_4-P, TP), TOC, pH, TA, dissolved oxygen (hereafter referred to as DO), COD, SS, Chlorophyll a, phytoplankton, zooplankton. Among these, water depth, temperature and salinity were measured by CTD (made by Alec Electronics, mode: AAQ1183-IF); Cu, Pb, Zn, Cd, and Cr concentrations by flame atomic adsorption spectrometer (PE–4100ZL); Hg and As concentrations in the extracts by AF Spectrophotometer (AF–610A); oil concentrations in the water column by Fluorescence Spectrophotometer (FL-4500); DO concentrations in the water column by the method of iodimetry; organic matter in the sediment by the analyzer PE-4100ZL (USA), Y38S(Franch) and AF-610A(China); COD concentrations in the water column by the basic potassium permanganate method; phytoplankton obtained by phytoplankton net (mesh size 70 μm), and the zooplankton by zooplankton net (mesh size 70 μm).

2.4 *Statistical analysis*

Software of Plymouth routines in multivariate ecological research (PRIMER 6.0) and SPSS 15.0 were used for the statistical analysis. The biological properties include the total biomass (B), the abundance (A), the number of species (S), the Shannon-Wiener diversity index (H'), the Margalef richness index (d), and the dominant index (Y). The dominant index of species was calculated by the following formulae:

$$Y = (n_i/N) \times f_i. \tag{1}$$

Where, N is the total abundance of all the stations; n_i is the abundance of the species i of all the stations; f_i is the occurring frequency of the species i of all the stations.

Macrobenthic community was analyzed by PRIMER 6.0 software packages, with the functions of CLUSTER, MDS, SIMPER, Abundance/Biomass curve (ABC), DIVERSE, BIOENV and BVSTEP (Spearman); in the statistical analysis, the unit of biomass is g/m^2, abundance ind./m^2.

In order to reduce the disturbance of the opportunistic species in the analysis of the biological properties of the macrobenthos, those species with their abundance proportions less than 1% in the whole abundance from the study region were deleted from the species of analysis, unless the species had more than 3% abundance proportion at any station of all the 26 stations.

3 Results

3.1 *Analysis of environmental factors*

Tables 1 and 2 show the summarized results for the contaminant data and physical characteristics of the sediments and bottom water.

The results of Principal Component Analysis (PCA) of environmental factors show that for all the sampling stations, the joined input of the first seven components (Components 1 and 7) accounted for 75.111% (Cumulative%) of the explained variance. Component 1 (15.975% of the total explained variance) was associated with a combination of variables changing from sampling station to sampling station. At all stations, such set of variables mainly corresponded to a gradient of changing NH_4-N, Cd, and pH; Component 2 (14.340% of the total explained variance) was associated with the Cr, Cu, silt sediment and bottom organic matter; Component 3 (11.916% of the total explained variance) was associated with the NH_4-N, PO_4-P, Cr, Hg, sand and silt sediment; Component 4 (10.684% of the total explained variance) was associated with the NH_4-N, NO_3-N,TP, TOC, and bottom organic matter; Component 5 (8.701% of the total explained variance) was associated with the NO_3-N, SiO_3-Si, PO_4-P; Component 6 (6.904% of the total explained variance) was associated with the NH_4-N, NO_2-N, NO_3-N, PO_4-P, TP, Pb, Zn, Cd, TA and clay sediment; Component 7 (6.592% of the total explained variance) was associated with the TN and pH.

Table 2. Concentrations of sedimental heavy metals and nutritive salts in bottom water off Ningjin in winter

Station	Cr/ mg·kg^{-1}	Cu/ mg·kg^{-1}	Pb/ mg·kg^{-1}	Zn/ mg·kg^{-1}	Cd/ mg·kg^{-1}	Hg/ mg·kg^{-1}	As/ mg·kg^{-1}	NH_4-N/ μmol·dm^{-3}	NO_2-N/ μmol·dm^{-3}	NO_3-N/ μmol·dm^{-3}	SiO_3-Si/ μmol·dm^{-3}	PO_4-P/ μmol·dm^{-3}	TP/ μmol·dm^{-3}	TN/ μmol·dm^{-3}
SA1	55.6	13.5	49.8	65.8	0.038	0.022	7.2	1.84	0.08	10.37	5.73	0.5	0.667	31.45
SA2	–	–	–	–	–	–	–	1.33	0.07	7.72	4.55	0.492	0.815	35.28
SA3	–	–	–	–	–	–	–	1.47	0.04	11.15	4.45	0.492	1.729	36.78
SA4	48.7	12.4	43.4	64.3	0.065	0.001	2.5	0.86	0.08	11.63	15.85	0.516	1.087	35.28
SB1	46.8	9.8	36.6	60.4	0.071	0.021	5.9	1.26	0.1	10.42	4.61	0.426	0.79	76.11
SB2	48.5	12.0	44.5	77.1	0.039	0.001	6.7	1.34	0.09	9.62	3.83	0.418	0.741	40.58
SB3	51.5	16.8	21.2	94.8	0.058	0.016	8.8	1.2	0.08	11.59	5.69	0.541	1.976	35.71
SB4	49.4	12.5	50.9	75.9	0.066	0.003	6.3	0.78	0.17	11.9	4.45	0.475	1.087	34.43
SC1	–	–	–	–	–	–	–	1.66	0.04	9.45	3.89	0.303	1.531	28.45
SC2	46.6	12.4	35.6	87.8	0.062	0.012	5.2	1.2	0.05	10.06	5.73	0.385	1.803	34.41
SC3	56.2	16.4	51.4	91.7	0.064	0.009	7.4	0.73	0.06	12.92	5.24	0.442	1.877	50.05
SC4	40.8	9.7	20.2	52.6	0.072	0.044	7.1	0.95	0.03	8.7	7.64	0.467	1.408	37.2
SD1	42.5	9.5	15.8	64.8	0.077	0.061	7.4	1.54	0.04	10.96	4.47	0.459	1.037	30.85
SD2	59.9	16.4	54.3	222.1	0.063	0.001	3.2	0.84	0.06	10.42	3.02	0.262	1.333	44.02
SD3	60.9	18.3	46.2	104.9	0.077	0.007	7.7	1.23	0.02	12.92	3.95	0.328	1.605	34.86
SD4	46.2	11.4	17.0	61.8	0.087	0.022	7.9	1.37	0.05	8.24	7.55	0.483	0.79	36.07
SE1	–	–	–	–	–	–	–	2.26	0.07	10.16	4.68	0.516	0.691	28.58
SE2	–	–	–	–	–	–	–	1.61	0.092	11.21	7.09	0.39	1.432	32.15
SE3	54.2	16.9	24.1	110.2	0.072	0.022	10.1	1.23	0.04	12.34	4.88	0.361	1.235	33.86
SE4	49.1	13.3	23.6	60.2	0.123	0.041	6.8	1.07	0.03	8.73	6.25	0.426	1.012	49.27
SF1	–	–	–	–	–	–	–	3.46	0.08	11.17	5.77	0.402	0.716	30.67
SF2	–	–	–	–	–	–	–	1.41	0.1	8.31	4.33	0.393	0.593	28.58
SF3	–	–	–	–	–	–	–	1.13	0.08	10.47	4.84	0.508	0.691	32.22
SF4	51.1	1.5	25.2	43.2	0.042	0.264	7.0	0.86	0.04	10.2	5.07	0.492	0.691	30.91
SF5	47.9	13.0	47.5	67.6	0.026	0.003	5.3	1.89	0.07	8.97	2.55	0.451	0.741	28.86
SG1	–	–	–	–	–	–	–	1.31	0.09	10.42	6.35	0.467	0.988	33.86
SG2	45.5	9.7	49.5	64.1	0.043	0.009	5.8	1.57	0.05	10.11	3.41	0.336	0.988	30.98
SG3	–	–	–	–	–	–	–	1.15	0.06	9.45	3.7	0.303	0.741	29.61
SG4	40.7	12.7	40.4	82.0	0.063	0.005	5.8	1.44	0.07	8.68	2.81	0.524	0.543	37.56
SG5	60.7	18.1	51.2	89.5	0.048	0.016	7.9	1.52	0.05	9.84	3.17	0.426	0.741	30.5

Notes: –represents missing values.

3.2 *Species composition*

In total, 260 species of macrobenthos were found by the recent research. Polychaeta represented the best taxon with 94 species (occupying 36.2% of all the species), followed by Crustacea with 75 species (28.8%), Mollusca with 56 (21.5%) and Echinodermata with 12 (4.62%) and other groups with 23 (8.85%). The total species number of each of the four cruises was different: 104 species in the winter cruise, 99 in spring, 115 in summer and 82 in autumn. Only 23 species were shared by the four cruises (Table 3).

Of all four cruises, with one cruise in every season, ten species were identified as dominant species in the study area in accordance with their dominant values (Y >0.02). Although the dominant species were different among the four seasons, the polychaete species *Paralacydonia paradoxa* Fauvel and Echinoderm species *Amphioplus japonicus* (Matsumoto) were always dominant year-round (Table 4).

3.3 *Abundance and biomass*

The distribution of macrobenthic abundances of the four seasonal cruises from the study region was patchy and no obvious trend was observed (Fig. 2, left). The all-year average abundance was 219.6 ind./m^2, with the variation in four seasons. Generally, total biomass was highest in winter, (268.10±166.74) ind./m^2, following by spring (238.89±120.74) ind./m^2, summer (205.37±121.37) ind./m^2, and lowest in autumn (166.19±85.13) ind./m^2 (Table 3).

Biomass also show similar pattern (Fig. 2, right). The all-year average biomass was (9.58±2.56) g/m^2, of which the highest value was presented in spring, (13.22±28.42) g/m^2, followed by summer (10.47±19.75) g/m^2, autumn (8.3±12.44) g/m^2, and lowest in winter (6.33±6.68) g/m^2 (Table 3).

Table 3. Species numbers, dominanat groups, average biomasses and average abundances from sea area off Ningjin

Cruise	Winter	Spring	Summer	Autumn
Species number	110	99	115	82
Dominant group	Polychaeta	Polychaeta	Crustacea (34.78%),	Polychaeta
(ratio in all samples)	(50.0%)	(45.45%)	Polychaeta (32.17%)	(43.9%)
Average biomass/g·m^{-2}	6.33±6.68	13.22±28.42	10.47±19.75	8.3±12.44
Average abundance/ind.·m^{-2}	268.10±166.74	238.89±120.74	205.37±121.37	166.19±85.13

Table 4. The dominant species and their dominant values (Y) in four seasons from sea area off Ningjin

Species	Y			
	Winter	Spring	Summer	Autumn
Paralacydonia paradoxa Fauvel	0.088	0.098	0.048	0.072
Sternaspis scutata (Ranzani)	0.057	0.076	0.022	–
Amphioplus japonicus (Matsumoto)	0.046	0.031	0.030	0.028
Ampelisca cyclops Walker	0.025	0.033	–	–
Cirrophorus furcatus (Hatman)	0.023	0.022	0.026	–
Moerella jedoensis (Lischke)	–	0.047	–	–
Ampelisca miharaensis Nagata	–	0.024	–	–
Theora lubrica Gould	–	–	0.031	–
Moerella iridescens (Benson)	–	–	0.021	0.060
Heteromastus filiforms (Claparede)	–	–	–	0.029

Notes: – represents missing values, not the dominant species at the season.

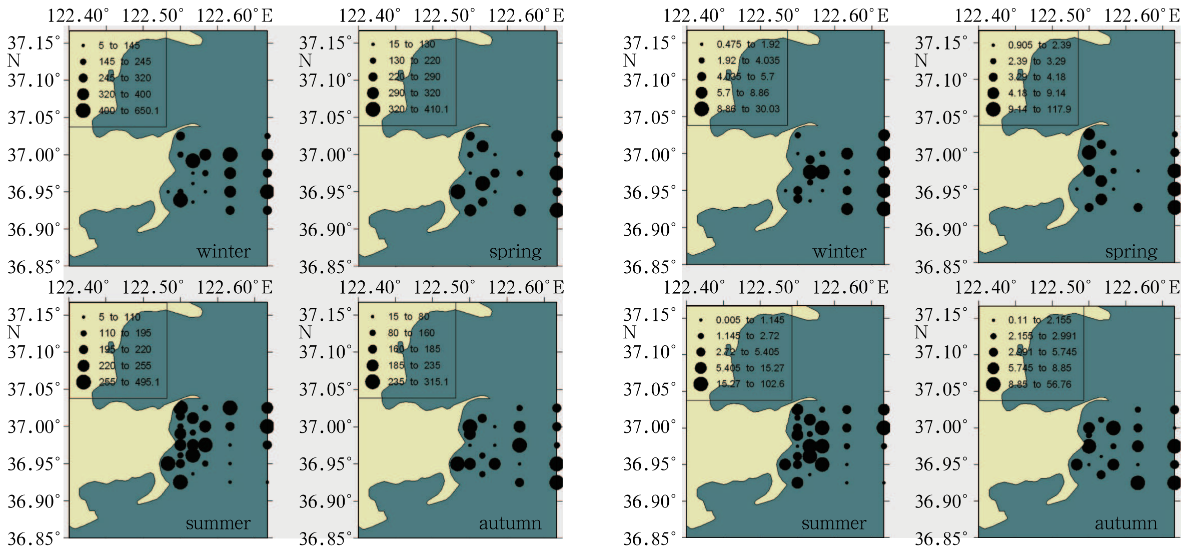

Fig.2. Distributions of the abundances (left) (ind./m^2) and biomass (right) (g/m^2) of macrobenthos from sea area off Ningjin.

3.4 *Biodiversity*

Table 1 shows the three biodiversity indices of the macrobenthos at all stations in four seasons. The results of One- Way ANOVA shows that there are significant difference among four seasons in Margalef richness index d (F=27.661, Sig.=0.000), Evenness index J' (F=15.821, Sig.=0.000) and Shannon-Wiener index H' (F=4.925, Sig.=0.003).

3.5 *Community structure*

We made the cluster analysis of the macrobenthos from the study region based on the species and their abundances in the winter cruise. The results (Fig. 3) imply that the similarity of macrobenthic structures among the stations were low, mostly in 40%–60% of similarity value, and the highest value was about 70%, which occurred in stations SC4-SB4. In accordance with the similarity values of the macrobenthic structures, the 20 ordinary stations were divided into five groups at arbitrary similarity level of 30%: Group I–two stations included, SE3, SC3, and the similarity values of the two stations was close to 50%; Group II–only one station, SA1, separated from other 19 stations, the similarity value was less than 30%; Group III–nine stations included, in which, the similarity value of the stations, SC4–SB4, was about 70%, then grouped with SD4, the similarity value was over 50%, and SD3-SB3 also had an over 60% high similarity value; Groups IV–six stations included, the similarity value was over 40%; Group V–only two stations included, SG4-SF4, was absolutely different in the macrobenthic structure from the other four groups, and the similarity value was lower than 17%. The MDS plots (Fig. 4) show the similar results.

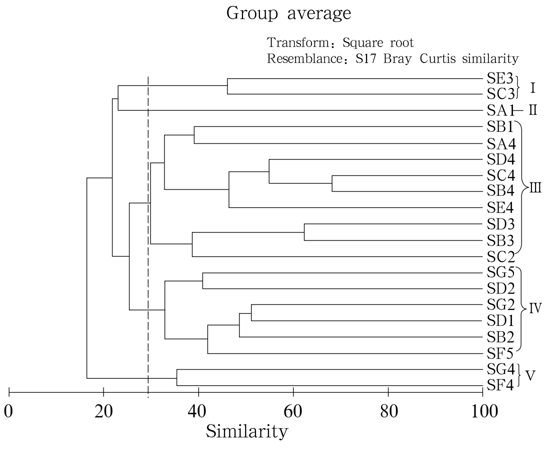

Fig.3. Dendrogram of the similarity of macrobenthic structures from sea area off Ningjin, (Using the group-average linking on *Bray-Curtis species similarities* calculated on the square root transformations of abundance data).

Further analysis using SIMPER reveals that different macrobenthic species compositions among the 20 stations were responsible to the results of the cluster analysis. In Group III, the average coefficient of the species similarity was 36.01%. The polychaetes *Paralacydonia paradoxa* Fauvel and *Sternaspis scutata* (Ranzani) were the two dominant species; their contributions of the similarity value were 24.03% and 22.06% respectively. The other species with the contributions of the similarity value over 5% were *Amphioplus japonicus* (Matsumoto) (9.58%), *Ampelisca cyclops* Walker (9.41%) and *Notomastus latericeus* Sars (5.25%). In Group IV, the average coefficient of the species similarity value was 38.56%, with three species' contribution of the similarity value over 10%, namely *Glycinde gurjanovae* Uschakov and Wu (12.21%), *Cirrophorus furcatus* (Hatman) (11.70%) and *Paralacydonia paradoxa* Fauvel (10.94); and the other three species, *Sthenolepis japonica* (McIntosh) (9.14%), *Moerella jedoensis* (Lischke) (6.91), *Ampelisca cyclops* Walker (5.74), with the contributions of the similarity value over 5%.

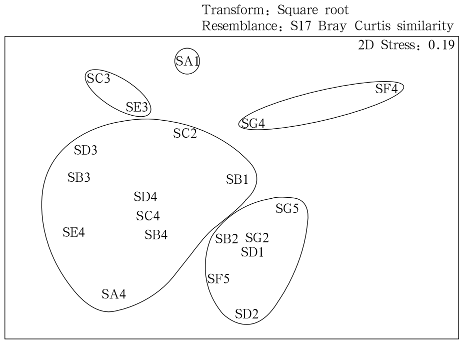

Fig.4. Two-dimensional MDS of the similarity matrix from sea area off Ningjin (Using the group-average linking on *Bray-Curtis species similarities* calculated on the square root transformations of abundance data).

3.6 *Abundance/Biomass curve (ABC)*

The Abundance/Biomass curve (ABC) can be used to determine the levels of disturbance (Pollution-induced or otherwise) on the benthic macrofauna communities (Clarke and Warwick, 2001). In order to inspect the "disturbed" situation from the human activities to the macrobenthos in the study area, we analyzed the Abundance/Biomass Comparisons (ABCs) of the macrobenthos in the ten stations based on the data of the winter cruise (January 2007). The ten stations were selected by five transects according to the locations of the sampling stations, namely, SA1-SA4; SB1-SB3; SC2-SC4; SD1-SD3; SG5-SE4. Polychaeta was the dominant group for all ten stations. Figure 5 shows the analytic results. The eight stations exhibit what Warwick (1986) would define as the "undisturbed" condition with the biomass curve above the numbers curve of its entire length, indicating that the marcofaunal communities of these eight stations had not been disturbed distinctly; while stations, SB1 and SB3, with the abundance curve cross with the biomass curve, as the "disturbed", had been disturbed.

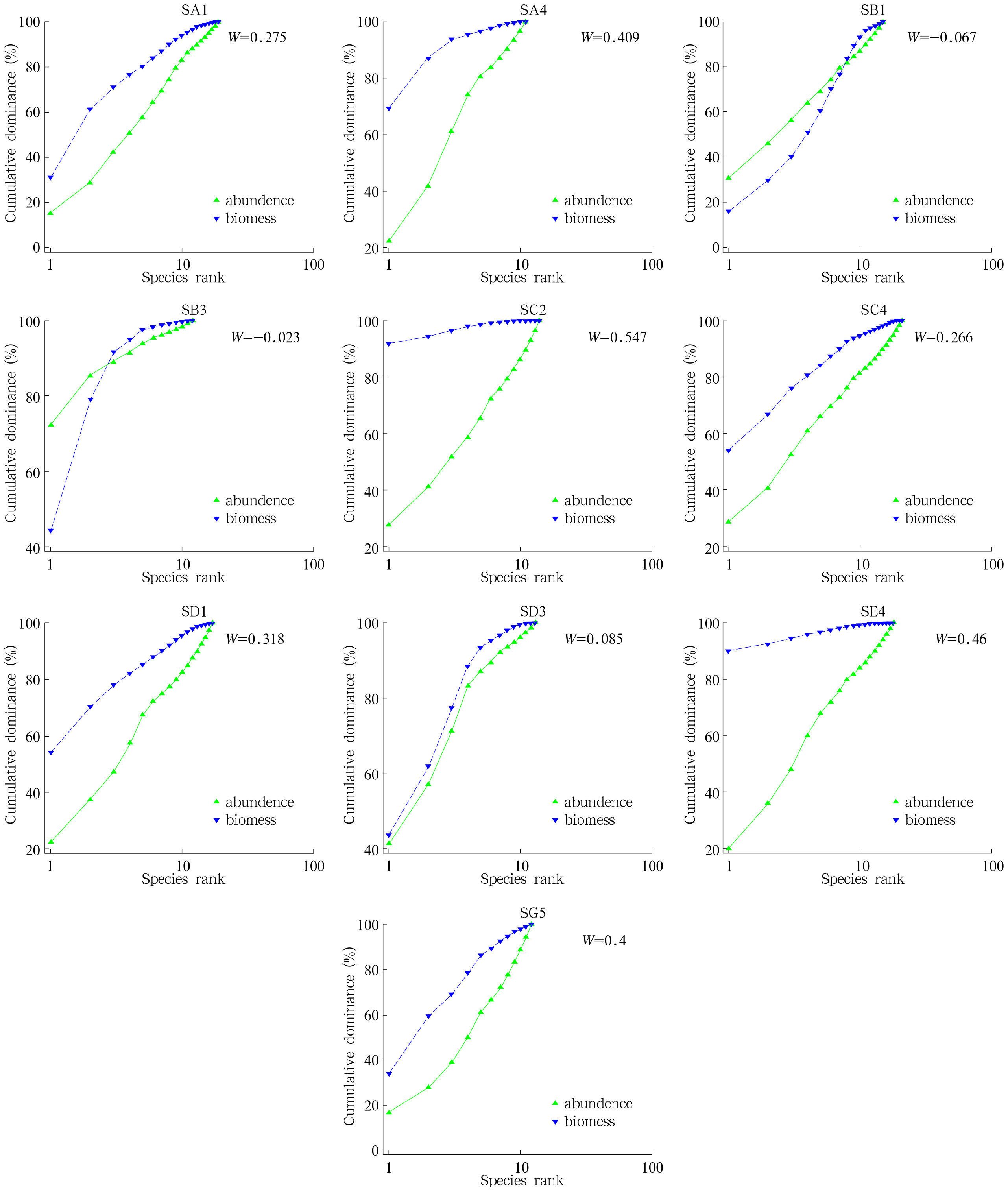

Fig.5. ABC plots of macrobenthos of eight stations in the winter cruise from sea area off Ningjin.

3.7 *Relationships of marcobenthos with environmental factors*

We analyzed the correlative coefficients (Spearman) between 28 bio- and abiological environmental factors and the community structure of the macrobenthos using the software SPSS 15.0 based on the data of the winter cruise (December 2006). The factors included water depth, bottom water temperature and salinity, size of sediment grain, heavy metal concentration of sediment (Zn, Cd, Pb, Cu, Hg, As, Cr), bottom organic matter, bottom oil, resolvable solid, nutrients (NH_4-N, NO_2-N, NO_3-N, TN, SiO_3-Si, PO_4-P, TP), TOC, pH, TA, DO, COD, SS, Bottom Ch-a, phytoplankton, zooplankton in bottom water.

The results show that the concentrations of salinity (r=0.837), phytoplankton (r=0.607), zooplankton (–0.616) and SiO_3-Si (r=–0.621) and temperature (r=–0.768) were the significant factors correlating with the macrobenthic community structure, and the relationships between the factors were obvious (P <0.01); the concentration of NO_3-N (r=–0.456), water depth (r=–0.489) , TP (r=–0.527) also had obvious relationship with the community structure of macrobenthos (P <0.05), as for the other 20 factors, but little were correlated (Table 5).

Table 5. Correlation coefficients (Spearman) between main environmental factors and community structure of macrobenthos from sea area off Ningjin

Environmental factor	Correlation coefficient (r) value	P (significances) value (2-tailed)
Salinity	0.837**	0.000
Phytoplankton	0.607**	0.005
Zooplankton	–0.616**	0.004
SiO_3-Si	–0.621**	0.003
Temperature	–0.768**	0.000
NO_3-N	–0.456*	0.043
Depth	–0.489*	0.029
TP	–0.527*	0.017
NH_4-N	0.292	0.212

Notes: * represents correlation is significant at the 0.05 level (2-tailed) and ** correlation is significant at the 0.01 level (2-tailed).

The MDS plots (Fig. 6) of the similarity matrix of the environmental factors coincided largely with the MDS plots of the 20 stations, which again imply that the environmental factors affected the community structure of macrobenthos.

The result of PCA on the above environmental factors, defined after clustering analyses of macrobenthos, also coincides with the MDS-ordination (Fig. 7).

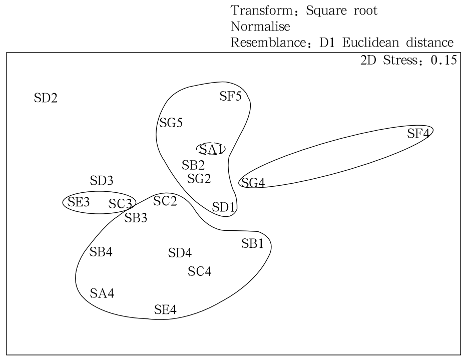

Fig.6. Two-dimensional MDS of the similarity matrix of the environmental factors from sea area off Ningjin (Using the group-average linking on *Eucidean distance* calculated on the square root transformations and normalize of factors data).

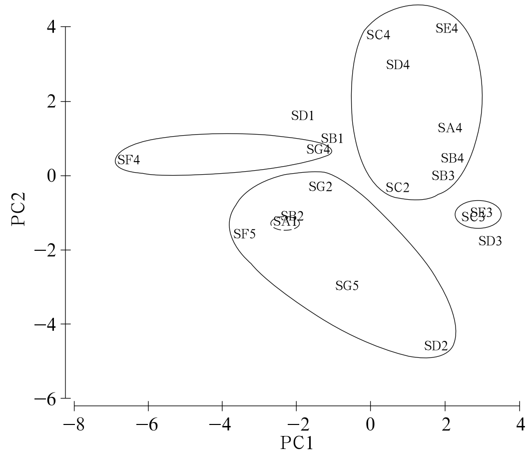

Fig.7. Two-dimensional PCA ordination of the environmental variables (transformed and normalized), for the sampling stations.

The result of the BVSTEP (Spearman) analysis shows that the combination of concentrations of Zn, Sand% and temperature would impact mainly the community structure of macrobenthos in winter (r=0.548).

4 Discussion

4.1 *Comparison with adjacent regions*

The marine macrobenthic communities were described in both ecosystems that are subjected to different sources and levels of contamination (Delvalls et al., 1998). Because the relationship between macrobenthic communities and environmental variables is so complicated, the parameters of macrobenthos from the different sites of the Huanghai Sea Ningjin were different, and our results also was different from other adjacent regions in the Huanghai Sea (Table 6), resulting from different environmental factors and human's activities in the above water areas.

Table 6. Characteristics macrobenthos from sea area off Ningjin and adjacent regions in the Huanghai Sea

Region	Investigated time	Average biomass/ $g\cdot m^{-2}$	Average abundance/ $ind.\cdot m^{-2}$	Species number	Reference cited
Off Ningjin	2006–2007	9.58	219.6	260	present research
Off Rushan	2006–2007	39.8	257.3	236	Li et al. (2009)
Northern HuanghaiSea	1997–1998	106.1	511.0	107	Hu et al. (2000)
Southern Huanghai Sea	1997–1998	13.36	129.4	136	Hu et al. (2000)
Eastern Huanghai Sea	2001–2002	30.3	156.8	272	Liu and Li (2003) (spring & autumn)
Huanghai Sea	1997–2000	37.17	250	414 (in total)	Tang (2006)

4.2 *Community structure*

The results of CLUSTER and MDS analysis show that the structures of the macrobenthic commnitites in the 20 to 30 stations are very different, presented with low value of similarity among them, due to the variable habitats in the local region. In some uniform habitats or homogeneity region, the structures of the macrobenthic communities are very similar, but the value of Bray-Curtis similarity is very high, over 80%, which is very different from our recent study (Li et al., 2007).

4.3 *Abundance/biomass comparison*

DelValls et al. (1998) concluded that abundance/biomass comparison (ABC) plots classified the macrobenthic communities into different classes mainly related to organic contamination. However, this analysis did not reflect the alteration due to the inorganic sources of contamination. In our recent study, The ABC plots of all eight stations exhibit the "undisturbed" condition, which implies that the macrobenthos did not suffer from the organic contamination. The result also coincides with the relatively low values of the organic matter concentrations in the sediment at the eight stations. Yet at the other two stations, SB1 and SB3, they exhibit the "disturbed" condition, implying that the macrofaunal communities of these two stations were suffered from some kind of disturbance. Based on the analysis of PCA of the whole environmental factors and three biodiversity index at Stas SB1 and SB3, it is hardly to separate the two stations from other stations. Due to the complicated nature of the ecosystem, maybe the macrobenthos at Stas SB1 and SB3 suffered from human's activities, because the two stations were aquaculture zones for Mollusca scallop and sea belt. Unfortunately, our recent study could not find the unquestionable sources or reasons of this disturbance, which would need further study.

4.4 *Relationships of macrobenthos with environmental factors*

Coastal marine benthic communities are threatened by pollution and coastal development. Often pollution will also cause changes in community composition with drastic reduction in diversity (Snelgrove, 1998). Several studies also prove that anthropogenic activities and environmental factors would influence the spatial and temporal distributions of macrofaunal abundance and biomass (Drake and Mrias, 1997; Magni et al., 2005, 2006; DelValls et al., 1998). Magni et al., (2005) also concluded that an excess of sedimentary organic matter may strongly affect the composition, structure and distribution of macrofaunal communities of a lagoon. Ellingsen (2002) studied macrobenthic infauna in relation to environmental variability in Norway and found that the best correlative variable combination included depth, median grain size and silt–clay content. Nevertheless, physical disturbance and chemical contamination in sediment may have higher effects on macrobenthic infauna than sediment characteristics in coastal waters (Lu, 2005). Han et al. (2004) studied the macrobenthic community structure in the eastern and central Bohai Sea and reported that "water depth and nitrate concentration in the bottom water, followed by microfauna abundance, had the closest relationships with the macrobenthic community". Jayaraj et al. (2007) studied the macrobenthos and associated environmental factors in the northwest Indian shelf, and thought that "benthos were controlled by a combination of factors such as temperature, salinity, dissolved oxygen, sand and organic matter and no single factor could be considered as an ecological master factor". Our recent study showed that the salinity, phytoplankton, zooplankton, SiO_3-Si and temperature in the research region were the most important factors impacting the community structure of macrobenthos and without "one master factor" controlling the macrobenthos community. The combination of factors of concentrations of Zn, Sand and temperature would impact mainly the community structure of macrobenthos. The result of PCA on environmental factors coincides with the MDS-ordination also show that environmental factors affect the community structure of macrobenthos. Our results are different from that of the above mentioned, which may be due to the different environmental factors in the two water regions.

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