Macrobenthic Assemblages across a Gradient of Seagrass Habitat in Swan Lake, China

Qingxi HAN[1]*, Qinggong HAN[1], Junyong ZHENG[1] and Qiuying HAN[2]

*[1]School of Marine Sciences, Ningbo University, Ningbo,
Zhejiang Province 315211, PR China.
[2]Hainan Tropical Ocean University, Sanya, Hainan, 572022, PR China.*

Abstract

The composition and structure of macrobenthic communities based on biological traits in relation to seagrass presence was studied in Swan Lake, northern Yellow Sea, China. The research consisted of seasonal monitoring of communities cross a gradient of distance to a seagrass meadow. The most dominant biological traits observed in the macrobenthic communities were the carnivores (concerning the feeding guilds), the free-living organisms (concerning the living habits) and moderately mobile species (in terms of mobility). The increase of sand content in substrate probably can result in the decrease of abundance of macrobenthos and feeding guilds. It was shown that the presence of seagrass meadows in the direct vicinity had significant effects on the biological traits based community structure. Although there was no clear-cut linear distribution pattern along the distance gradient from the seagrass meadow, the community structure at 5-10 meters distance from the seagrass meadow was quite different from other sites adjacent to seagrass meadow (0-1 m). It can be concluded that the effects of seagrass meadow on macrofauna were confined to 5-10 meters in Swan Lake.

Keywords: macrobenthos; feeding guild; community structure; seagrass meadow; Swan Lake

---

* Corresponding Author

1. INTRODUCTION

The macrobenthic organisms usually have a long generation time and limited locomotion ability, which allows them to reflect the combined environmental changes over a long period of time caused by natural or anthropogenic perturbations in the marine environment [1-6]. Therefore, macrobenthic assemblages have been employed in environmental monitoring for a long time, and the attributes of macrobenthic community structure are commonly considered in these studies [7-10]. Although the assessment of patterns in the structure of marine benthic assemblages has been proven effective for the detection of various disturbances, macrobenthic communities are extremely complex, comprising large quantities of taxa and species [11-12]. The identification of these animals usually requires a high degree of taxonomic expertise and many specialized taxonomists [13-14]. To avoid unnecessary and time-consuming hard work in both field sampling and lab identification, the feeding guild was proposed and has proven effective and authentic in the detection of anthropogenic or natural perturbations.

Guilds were defined as sets of organisms that act or exploit environmental resources in a similar manner, regardless of their phylogenetic relationships [15-20]. Feeding guilds have proven valuable in interpreting the basic ecological functioning or rationale behind various taxa or species and are crucial in furthering our understanding of benthic processes, such as commensalism, the role of the benthos and the community energy flux [16, 21-24]. Usually, coastal environments and ecosystems are sensitive to external stress, and even small disturbances introduced naturally or artificially can result in rapid deterioration of the system. Swan Lake represents a typical example of such a vulnerable coastal ecosystem.

Swan Lake, also called Yuehu Lagoon, is a lagoon-inlet located in the southern part of Rongcheng Bay, Shandong Peninsula, China. This small saltwater lagoon, famous as the winter habitat of the swan *Cygnus cygnus*, covers an area of 4.8 square kilometers [25]. Swan Lake has been subjected to intensive exploitation, such as the aquaculture of shrimps, crabs, bivalves and sea cucumbers. Moreover, this lagoon has also been affected by human activities and the irrational utilization of resources, such as tourism, harbor construction and sewage discharge [26]. Therefore, many scientific researchers in China have tried to propose measures to restore the ecological quality of Swan Lake. However, studies on macrobenthic assemblages remain unavailable in this area. To understand the composition and distribution of macrobenthic communities in Swan Lake, we conducted this field investigation of the intertidal macrobenthos from August 2011 to June 2012. This study also addressed the composition of the macrobenthos in relation to the distribution of environmental factors and distance gradient from seagrass communities to provide referential baselines for future

research and management. Therefore, the analyses of macrobenthic communities could provide accurate and useful information on the local benthic environmental and ecological quality.

2. MATERIALS AND METHODS

Swan Lake is a lagoon-inlet located in Rongcheng City, northern Yellow Sea (37°21′N, 122°34′E), connected with Rongcheng Bay by a small waterway. This small saltwater lagoon covers an area of 4.8 square kilometers [25], and the water depth is shallow, less than 1.5 meters in most parts during ebb tide and no more than 2 meters at flood tide. There are several seasonal rivulets that flow into this small-scale lagoon-tidal system. Seaweed (*Sargassum* spp.) and seagrass are the most common aquatic plants during the spring and summer, and *Chladophora* may bloom during the spring and summer. Because over 3,000 whooper swans (*Cygnus cygnus* (Linnaeus, 1758)) pass by, with seagrass (*Zostera marina*), wheat (*Triticum aestivum*), kelp (*Laminaria japonica*) and seagrass (*Zostera japonica*) as their food every winter, the lagoon is named Swan Lake, and it has been designated a National Wildlife Reserve [26], and undergoing development for aquaculture and tourism for many years [27-28]. Well-preserved seagrass meadows were found in this coastal lagoon, including *Zostera japonica* and *Zostera marina*. The Japanese seagrass *Z. japonica* inhabits the shallow water or intertidal area of this lake, usually found in the eastern coast where we sampled the macrobenthos. This invasive species is normally considered to produce net loss of provisions for native seagrass but can colonize and effectively displace formally productive shellfish growing grounds [29].

All field works were conducted from August 2011 to June 2012 quarterly (Fig. 1). Transection lines perpendicular to the coastline were established on the east coast of the lagoon. Four sites were deployed on each line along a distance gradient from the seagrass meadow, with one site in seagrass meadow as control group and other 3 sites away from the seagrass meadow 1, 5 and 10 meters, respectively. The locations of the sampling sites are shown in Figure 1. Macrobenthic samples were collected from a 50×50×30 cm sampling square at each site (three replicates per site) and washed *in situ* through a 0.5 mm mesh screen. The animal samples were preserved in 95% ethyl alcohol. The macrobenthos were sorted using a stereo- and binocular microscope after staining with Rose Bengal, identified to the species level, quantified and weighed. Extra samples were collected to analyze the characteristics of the grain size. The grain size was measured using a Mastersizer 2000 Laser Particle Sizer (Malvern Instruments Limited, UK), and the detailed grain sizes were denoted by the terms sand (64 μm-2000 μm), coarse silt (16 μm-64 μm), fine silt (4 μm-16 μm) and clay (<4 μm) [30].

The abundance data were normalized (ind. m^{-2}) and univariate and multivariate statistical analyses were carried out. PRIMER (Plymouth routines in multivariate ecological research, version 6.0) and PASW Statistics (version 18.0) were used for the statistical analyses. The abundance data were square root transformed to reduce the contribution of prevalent taxa and increase the importance of less abundant species before all subsequent analyses. The resemblance matrices were also needed before further analysis, with Bray-Curtis for abundance and biomass data and Euclidean distance for environmental data. Non-metric multidimensional scaling (MDS) and hierarchical cluster analysis (Cluster) were performed to analyze the community structure. Analysis of similarities (ANOSIM) was conducted to test statistically for a significant difference between two or more groups of samples. Similarity percentages (SIMPER) were used to examine which variable contributes the most to the within-group similarities at every site. The Seriation test was also performed to analyze the community structure. Pearson's correlation coefficients (Spearman) between environmental factors and the feeding guilds of the macrobenthos and macrobenthic indices [e.g. the number of species (*S*), abundance (*N*), the Shannon-Wiener diversity index (*H'*, calculated using base-10 logarithms), the Margalef richness index (*d*) and Pielou's evenness index (*J'*)] were calculated using the PRIMER 6.0 ecological software package.
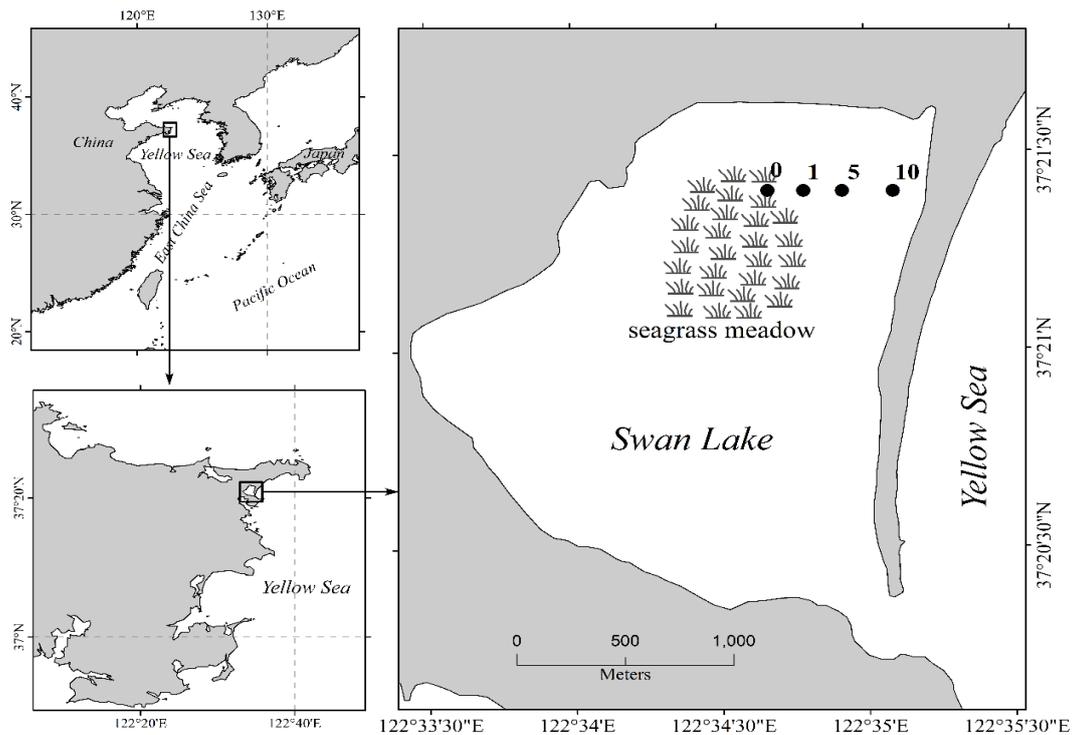
Fig. 1 Sample locations in Swan Lake, Shandong Peninsula, from 2011 to 2012.

3. RESULTS

3.1 Profile of the local macrobenthic community and its ecological status

In this study, a total of 69 species belonging to 60 genera and 42 families were identified among the 1961 specimens collected, whose total biomass was 4801.25 g. The abundance of macrobenthos varied from 4 to 576 ind./m^2. As the most abundant and speciose macrobenthic taxon in this area, polychaetes comprised 56.52% of the total species and 58.00% of the total individuals. The most speciose families were Spionidae (5 species), Syllidae (4 species) and Lumbrineridae (4 species), whereas the most abundant families included Veneridae, Maldanidae, Lumbrineridae and Cirratulidae, accounting for 18.92%, 14.63%, 10.79% and 8.18% of the total abundance, respectively. The family Veneridae were also the most important contributor to the biomass, constituting 93.29% of the total biomass, of which *Ruditapes philippinarum* was the most important contributor, and other members of this family were negligible in terms of biomass. The mollusc *R. philippinarum* and the polychaete *Euclymene lombricoides* were the two most abundant and prevalent species, comprising 18.67% and 9.21% of the total abundance across all sampling sites, respectively.

3.2 Changes in feeding guilds

The 69 total macrobenthic species were classified into 5 feeding modes (subsurface deposit feeder or burrower, carnivore, filter feeder, herbivore and surface deposit feeder) and 18 submodes (BDF, BDT, BMF, CMF, CMB, CMT, FDA, FDF, FMF, FSA, FST, HDF, HMA, HMB, HMF, SDF, SDT and SMF) (Table 1). Carnivores were the leading feeding guild in the study area in terms of species number (39.13% of the total species), followed by surface deposit feeders (27.54%), burrowers (13.05%), suspension feeders (11.60%) and herbivores (8.70%). Herbivores were the least common, represented by only 6 species across all seasons and transects. Across all sampling seasons and transects, burrowers and carnivores were found to be the most dominant (26.22% and 29.63%, respectively) over other feeding guilds in terms of abundance, viz., filter feeders (23.46%), surface deposit feeders (17.50%) and herbivores (3.22%).

Table 1 Feeding guilds of polychaetes found in this study *

Macrophagous modes	Motile	Discretely motile	Sessile
Burrowers			
Free-living	BMF	BDF	
Tubiculous		BDT	
Carnivores			
Free-living	CMF		
Burrow-dwelling	CMB		
Tubiculous	CMT		
Filter feeders			
Free-living	FMF	FDF	
Attached		FDA	FSA
Tubiculous			FST
Herbivores			
Free-living	HMF	HDF	
Attached	HMA		
Burrow-dwelling	HMB		
Surface deposit feeders			
Free-living	SMF	SDF	
Tubiculous		SDT	

* Modified following Fauchald and Jumars (1979), Pagliosa (2005), Macdonald et al. (2010) and Jumars et al. (2015).

The three-letter codes represent feeding type, locomotion pattern, and living habit, respectively. For the first letter, B: subsurface deposit feeder (burrower); C: carnivore; F: filter feeder; H: herbivore; S: surface deposit feeder. For the second letter, D: discretely motile; M: motile; S: sessile. For the third letter, A: attached (to hard substrate, requiring just one point of attachment, e.g., solitary ascidians or calcareous sponges); B: burrow-dwelling (sedentary, living in burrow); F: free-living (may live on surface or actively burrow); T: tubiculous.

With respect to living habit, free-living (F) is the foremost predominant living habit in terms of both abundance and diversity, accounting for 65.83% of the total individuals and 65.17% of the total species, followed by tubiculous (21.93% and 24.64%), burrow-dwelling (8.36% and 5.80%), and attached (3.88% and 4.35%). Discretely motile was the most common motility pattern in terms of abundance, accounting for 62.21% of the total individuals, compared to 37.68% for motile and 0.1% for sessile,

whereas motile was the most speciose group, accounting for 57.97% of the total species, compared with discretely motile (39.13%) and sessile (2.90%).

Among all 18 feeding guilds (Table 2), CMF and SDT were the most speciose taxa, constituting approximately 34.79% and 17.40% of the total species across all sampling season and transects, respectively. However, the feeding guilds CMF (21.67%), FDF (20.30%) and BDT (14.58%) were found to be more common than the other feeding submodes in terms of abundance, e.g., SDF (9.38%), CMB (7.90%), SDT (7.24%), BDF (7.19%), BMF (4.44%), FDA (2.65%, with the only species *Musculus senhousei*), HMA (1.17%, with the only species *Patelloida pygmaea*), SMF (0.87%), HDF (0.87%), HMF(0.71%), HMB (0.71%), FMF (0.41, with the only species *Apseudes* sp.), FST (0.05%, with the only species *Serpula vermicularis*), FSA (0.05%, with the only species *Alectryonella plicatula*) and CMT (0.05%, with the only species *Marphysa sanguinea*). The bivalve *Ruditapes philippinarum* , polychaete *Euclymene lombricoides*, Crustacea *Paraphoxus* sp., polychaete *Lumbrineris latreilli* and *Capitella* sp. were the most important contributors of abundance in terms of dominant feeding submodes (FDF, BDT, CMB, CMF and BDF), accounting for 91.71%, 62.94%, 99.36%, 35.06% and 99.29% of the total abundance of their corresponding guilds, respectively.

Table 2 The composition of feeding guilds of the macrobenthic community in Swan Lake in 2011-2012.

Feeding guild*	Description	The most abundant species
BDF	Discretely motile free-living burrower	*Capitella* sp.
BDT	motile free-living burrower	*Euclymene lombricoides* (Quatrefages, 1866)
BMF	Motile free-living burrower	*Haploscoloplos elongatus* (Johnson, 1901)
CMB	motile burrow-dwelling carnivore	*Paraphoxus* sp.

CMF	Mobile free-living carnivore	*Lumbrineris latreilli* Audouin et Edwards,1834
CMT	Tentaculate sessile carnivore	*Marphysa sanguinea* (Montagu, 1815)
FDA	Discretely motile filter feeder	*Musculus senhousei* (Benson, 1842)
FDF	Motile filter feeder	*Ruditapes philippinarum* (Adams & Reeve, 1850)
FMF	Motile free-living filter feeder	*Apseudes* sp.
FSA	Sessile attached filter feeder	*Alectryonella plicatula* (Gmelin, 1791)
FST	Sessile tubiculous filter feeder	*Serpula vermicularis* linnaeus,1767
HDF	Discretely motile free-living herbivore	*Grandidierella japonica* Stephensen, 1938
HMA	Motile attached herbivore	*Patelloida pygmaea* (Dunker，　1860)
HMB	Motile burrow-dwelling herbivore	*Ampithoe lacertosa* Bate, 1858
HMF	Motile free-living herbivore	*Stenotis oxytropis* (Pilsbry,1895)
SDF	Discretely motile free-living surface deposit feeder	*Chaetozone setosa* Malmgren, 1867
SDT	discretely motile tubiculous surface deposit feeder	*Aonides oxycephala* (Sars, 1862)
SMF	Motile free-living surface deposit feeder	*Calliostoma koma* (Shikama & Habe, 1965)

*: The feeding guild codes are the same as in Table 1, consisting of three capital letters that, in order, identify feeding type, locomotion pattern and living habit.

3.3 Relationship between macrobenthic feeding guilds and grain size of substratum

Spearman rank correlation was performed to analyze the relationships between the macrobenthic feeding submodes and the grain size, including clay (<4 µm), fine silt (4 µm-16 µm), coarse silt (16 µm-64 µm), silt (4 µm-64 µm) and sand (64 µm-2000 µm). The results indicated that some of the feeding submodes were sensitive to grain size, including diet (e.g. burrowers and filter feeders), motility pattern (discretely motile) and living habit (free-living and tubiculous), whereas the other feeding submodes appeared to show no relationship to grain size (Table 3). The results also revealed that the content of fine particle size (<64 µm) were positively correlated to the abundance of feeding modes, whilst content of sand (64 µm-2000 µm) was negatively correlated to the abundance of feeding modes. Furthermore, the increase of sand content in substrate probably can result in the decrease of abundance of macrobenthos and feeding guilds.

**Table 3 The correlation matrix of Pearson correlation between grain size and feeding modes.**

	Feeding modes	Clay	Fine silt	Coarse silt	Silt	Sand
Diet	Burrower	**0.752****	**0.714****	**0.707****	**0.713****	**-0.722****
	Carnivore	0.362	0.443	0.431	0.437	-0.425
	Filter feeder	0.559	**0.612***	**0.577***	**0.592***	**-0.588***
	Herbivore	0.472	0.479	0.446	0.459	-0.463
	Surface deposit feeder	0.225	0.318	0.291	0.302	-0.289
Motility	Discretely motile	**0.717****	**0.743****	**0.723****	**0.733****	**-0.733****
	Motile	0.362	0.431	0.408	0.418	-0.410
	Sessile	0.154	0.146	0.105	0.120	-0.126
Living habit	Attached	0.107	0.211	0.159	0.177	-0.165
	Burrow-dwelling	0.170	0.245	0.199	0.215	-0.208
	Free-living	**0.578***	**0.640***	**0.623***	**0.632***	**-0.625***
	Tubiculous	**0.685***	**0.649***	**0.644***	**0.649***	**-0.657***

Statistically significant values are in bold
** Significant at 99% confidence level, * Significant at 95% confidence level.

3.4 Comparison of feeding guilds along the distance gradient
The hierarchical CLUSTER and MDS ordination with the abundance of individuals showed that the sampling sites appeared to cluster into four groups at a 48% similarity level (Fig. 2), and the ANOSIM analysis confirmed this result ($R=0.842$, $P<0.01$). February and December were significantly different from June and August, and no discernable spatial distribution was revealed along the distance gradient from the seagrass meadow.
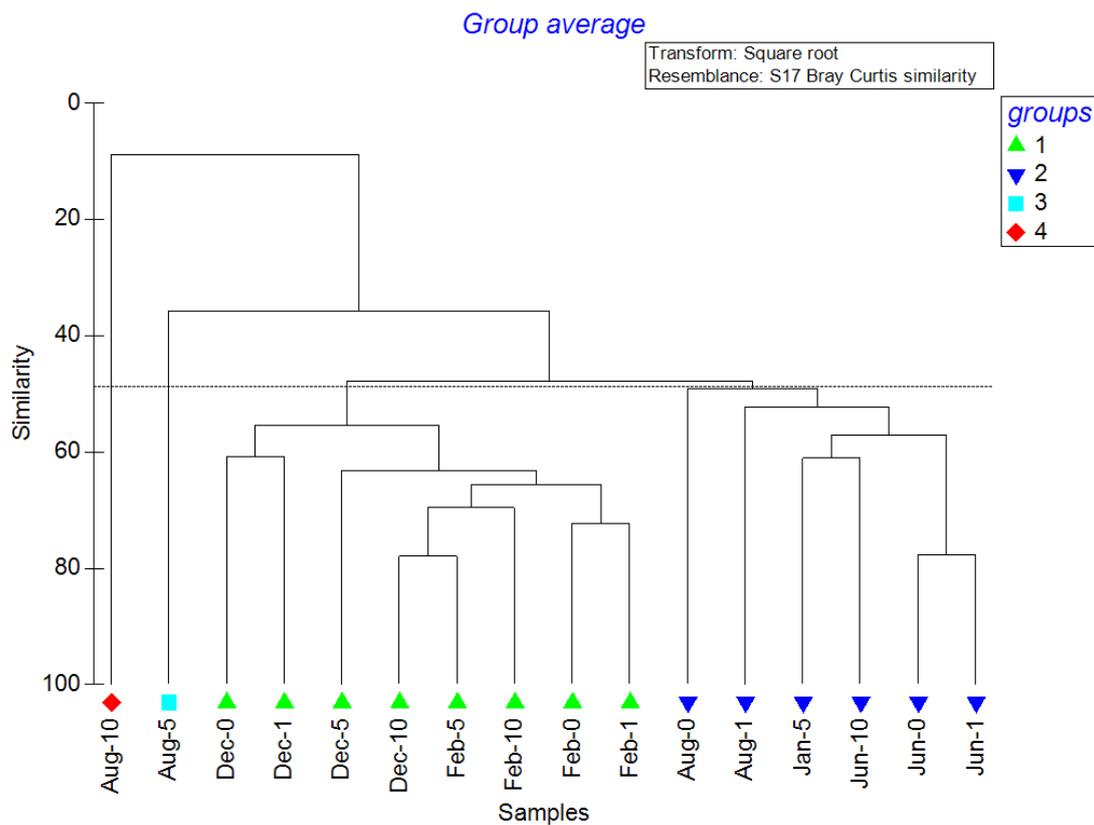
Fig. 2 Dendrogram of hierarchical clustering using group-average linking across all sampling transects.

The Seriation test is highly sensitive to changes in community composition and structure, and consistently, significant Seriation results could indicate the possible effects of seagrass meadow on the macrobenthic communities. Therefore, a Seriation test was performed along the distance transects from the seagrass meadow to look for an ongoing pattern of seriation. However, no discernible ecological patterns were detected along the distance gradient from the seagrass meadow. The Index of Multivariate Seriation (IMS) varied from 0.123 to 0.926 (Table 4), and the

relationship between community structure and distance gradient was highly non-monotonic ($P>0.05$). Across all transect, the major dissimilarity in the pairwise comparison among all sampling months agreed well with the results of the MDS and CLUSTER analyses.

Table 4 Index of Multivariate Seriation (IMS) along the three transects for all sampling months in Swan Lake*

	Transect 1	Transect 2	Transect 3
February	0.432(34.4%)	0.37(35.8%)	0.185(32.5%)
June	0.123(41.1%)	0.926(8.5%)	0.247(40.7%)
August	0.557(17.1%)	0.772(8.4%)	--
December	0.617(18.3%)	0.278(42.2%)	0.432(26.8%)

*Figures in parentheses are the % significance levels in a permutation test for the absence of seriation.

Two-way pairwise analysis of similarities (ANOSIM) was performed to test the significance of temporal and spatial variation (Table 5),

Table 5 Two-way ANOSIM pairwise test between different sampling months (right) across all sampling gradients and gradients (left) across all sampling seasons using PRIMER 6.0.

Gradients	R Statistic	Significance level	Seasons	R statistic	Significance level
0 m-1 m	0.141	10.7%	Win-Spr	0.537	0.2%**
0 m-5 m	0.418	1.6%*	Win-Sum	0.632	0.2%**
0 m-10 m	0.596	0.4%**	Win-Aut	0.269	1.4%*
1 m-5 m	0.124	17.5%	Spr-Sum	0.496	0.3%**
1 m-10 m	0.539	0.1%**	Spr-Aut	0.62	0.1%**
5 m-10 m	0.371	0.1%**	Sum-Aut	0.534	0.1%**

and the results indicated highly significant temporal ($R=0.48$, $P<0.01$) and significant spatial variations ($R=0.339$, $P<0.01$). Across all sampling gradients without exception, the feeding guilds showed noteworthy differences. Similarly, the feeding guilds also demonstrated significant differences along the sampling gradients away from the seagrass bed, including the sampling site 10 meters away from the seagrass meadow with other sampling sites. To verify the randomness of the sampling transects, both results showed no differences by one-way ANOSIM ($R=-0.041$, $P>0.05$) or two-way ANOSIM across all sampling seasons ($R=-0.041$, $P>0.05$). With the further Similarity percentages (SIMPER) analysis, the average dissimilarities of 10 m and 0 m, 1 m, and 5 m, were 48.13, 43.25% and 36.85% respectively, which were higher than other

dissimilar percentages, and the main contributors were CMF, FDF, BDT SDF, CMB, BDF and SDT (Table 6). The major contributors, such as BDT, FDF, CMF and SDT, were also the most abundant feeding guilds. However, the results of single factor ANOVA showed that samples of 10 m from the seagrass meadow were significantly different from the samples adjacent to seagrass meadow (0-1 m), such as BDF, BDT, SDF and SDT (Fig. 3).
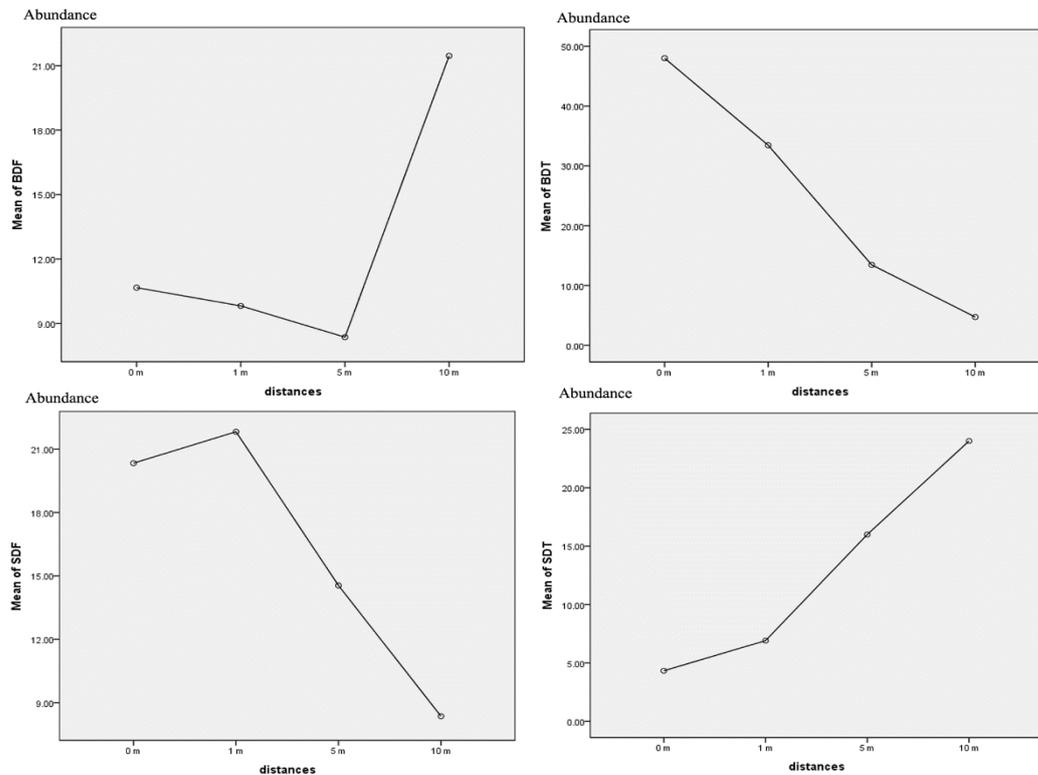
Fig. 3 Line chart of abundance of four selected feeding guilds across all sampling seasons

4. DISCUSSION

The macrobenthic community of the Swan Lake demonstrated a diverse range of invertebrate taxa dominated by polychaetes, accounting for 58% of the total individuals. The mollusc *Ruditapes philippinarum* and polychaete *Euclymene lombricoides* were the most abundant species, constituting 42.68% and 11.33% of the total individuals. The abundant mollusc *R. philippinarum* (defined as FDF) is widely distributed from the South China Sea and the Philippines to the Yellow Sea and Japan and is also cultured in some intertidal areas and shallow bays in northern China, with an annual output of 100, 000 tons [31], including Swan Lake. The blooming of seaweed (*Sargassum* spp.) and seagrass might be responsible for the dominance of this filter feeder due to providing large amounts of organic debris, especially during spring and

summer [26]. Therefore, it is understandable that this species might be the most important contributor to the total abundance and biomass in this area. The polychaete *E. lombricoides* (defined as BDT) is a cosmopolitan species inhabiting the Pacific, Atlantic and Indian Oceans and is one of the most important components of the intertidal and coastal soft bottom communities [32].

As the most important components of the intertidal marine ecosystem, macrobenthic organisms play an indispensable mediating role in the food web. Humans are always modifying both the identities and numbers of species in ecosystems [33], and the application of feeding guilds will improve the accuracy of stability and prediction despite spatial and temporal variations [34]. The feeding guild is based on analyses of ecological traits instead of simple taxonomic identification, which simplifies the intra- and inter-species relationships and thus reduces the complexity of ecosystem analysis [35]. These fauna show more sensitive and comprehensive responses to environmental changes, and therefore feeding guilds could provide a scientific basis for speculation on population stress or ecological quality [36]. Any tiny change in an ecosystem, especially damage to ecological function, can be reflected by the type and composition of feeding guilds [33]. The feeding guild has thus far been applied to analyze the macrobenthic structure. When analyzed by feeding modes, burrowers and carnivores were found to be the most important, whereas herbivores were the least relevant despite the abundant available seaweed (*Sargassum* spp.) and seagrass. In Swan Lake, the excessive food supply leads to limited locomotion abilities (discrete motility), and the frequency of the free-living living habit results from the sufficient food supply and various refuges. When feeding guilds were adopted to analyze the ongoing patterns of the macrobenthic communities subject to nearby seagrass meadows, we found significant temporal and spatial variations. The feeding guilds during winter and autumn were significantly different from the ones during summer and spring, most likely due to the blooming seaweed (*Sargassum* spp.) and seagrass, which can provide sufficient food to local macrobenthic invertebrates.

The composition of feeding guilds can be affected by many environmental factors, such as elevation (Roth and Wilson, 1998), substratum type [37-38], hydrodynamics impact [38-39], oxygen [39], salinity [40], primary productivity [41], external nutrient supplementation [41], food availability and quality [42] and vegetation conditions [43]. However, we should pay close attention to certain species that can switch their feeding behavior in response to flow and food flux conditions [9, 44], as seen for spionid worms, such as *Prionospio* spp. [45], and for the amphipod *Siphonoecetes* sp. [46-47]. Nevertheless, most polychaetes seemed to adopt a single feeding behavior in a relatively stabilized substrate and benthic community [18].

Various multivariate statistical methods were adopted to verify the effects of seagrass meadow and grain size, including the CLUSTER, MDS, SIMPER, ANOVA and Seriation tests. These methods are highly sensitive to changes in the macrobenthic community. There was no clear-cut linear distribution pattern along the distance gradient from the seagrass meadow, because various feeding guilds responded differently to the presence of seagrass meadow. However, feeding guilds near the seagrass meadow (less than 1 meter away) were significantly different from the feeding guilds distant from seagrass meadow areas (5-10 meters away). Generally, the community structure of the macrofauna is very similar in uniform habitats or homogenous regions, and our analyses revealed that the effects of seagrass meadow on macrofauna were confined to about 5-10 meters. The seagrass meadow can provided a complex three-dimensional habitat for marine organisms and modify the surrounding environment, e.g. organic matter content and substrate compactness. The presence of seagrass meadow can also slow down the current velocity and facilitate the feeding of filter feeders for suspended organic particles and microorganisms. This can be testified by the predominant biomass of filter feeder (*Ruditapes philippinarum*) in Swan Lake.

5. ACKNOWLEDGMENTS

REFERENCES

[1]　Weisberg S B, Schaffner L C, Ranasinghe J A, *et al*. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. Estuaries, 1997, 20(1): 149.158.

[2]　Borja Á, Franco J, Pérez V. A Marine Biotic Index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Marine Pollution Bulletin, 2000, 40(12): 1100.1114.

[3]　Simboura N, Zenetos A. Benthic indicators to use in ecological quality classification of Mediterranean soft bottom marine ecosystems, including a new biotic index. Mediterranean Marine Science, 2002, 3(2): 77.111.

[4] Belan T A. Marine environmental quality assessment using polychaete taxocene characteristics in Vancouver Harbour. Marine Environmental Research, 2003, 57(1-2): 89.101.

[5] Dauvin J C, Ruellet T. Polychaete/Amphipod ratio revisited. Marine Pollution Bulletin, 2007, 55(1-6): 215.224.

[6] Weise A M, Cromey C J, Callier M D, *et al*. Shellfish-Depomod: Modelling the biodeposition from suspended shellfish aquaculture and assessing benthic effects. Aquaculture, 2009, 288(3-4): 239.253.

[7] Pearson T H, Rosenberg R. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanographic Marine Biology: Annual Review, 1978, 16: 229.311.

[8] Shin P K S, Huang Z G, Wu R S S. An updated baseline of subtropical macrobenthic communities in Hong Kong. Marine Pollution Bulletin, 2004, 49(1-2): 128.135.

[9] Gaudêncio M J, Cabral H N. Trophic structure of macrobenthos in the Tagus estuary and adjacent coastal shelf. Hydrobiologia, 2007, 587: 241.251.

[10] Han Q X, Wang Y Q, Zhang Y, *et al*. Effects of intensive scallop mariculture on macrobenthic assemblages in Sishili Bay, the northern Yellow Sea of China. Hydrobiologia, 2013, 718(1): 1.15.

[11] Elias R, Palacios J R, Rivero M S, *et al*. Short-term responses to sewage discharge and storms of subtidal sand-bottom macrozoobenthic assemblages off Mar del Plata City, Argentina (SW Atlantic). Journal of Sea Research, 2005, 53: 231.242.

[12] de-la-Ossa-Carretero J A, Del-Pilar-Ruso Y, Giménez-Casalduero F, *et al*. Assessing reliable indicators to sewage pollution in coastal soft-bottom communities. Environmental Monitoring and Assessment, 2012, 184(4): 2133.2149.

[13] Olsgard F, Somerfield P J, Carr M R. Relationship between taxonomic resolution, macrobenthic community patterns and disturbance. Marine Ecology Progress Series, 1998, 172: 25.36.

[14] Terlizzi A, Anderson M J, Fraschetti S, *et al*. Scales of spatial variation in Mediterranean subtidal sessile assemblages at different depths. Marine Ecology Progress Series, 2003, 332: 25.39.

[15] Root R B. The niche exploitation pattern of the blue-gray gnatcatcher. Ecological Monographs, 1967, 37: 317.350.

[16] Fauchald K, Jumars P A. The diet of worms: A study of polychaete feeding guilds. Oceanographic Marine Biology: Annual Review, 1979, 17: 193.284.

[17] Macdonald T A, Burd B J, Macdonald V I, *et al*. Taxonomic and Feeding Guild Classification for the Marine Benthic Macroinvertebrates of the Strait of

Georgia, British Columbia. Canadian Technical Report of Fisheries and Aquatic Sciences, 2010, 2874: 1.63.

[18] Manokaran S, Khan S A, Lyla S, *et al*. Feeding guild composition of shelf macrobenthic polychaetes of southeast coast of India. Tropical Zoology, 2013, 26(3): 120.139.

[19] Jumars P A, Dorgan K M, Lindsay S M. Diet of Worms Emended: An update of Polychaete Feeding guilds. Annual Review of Marine Science, 2015, 7: 497.520.

[20] Pagliosa P R. Another diet of worms: the applicability of polychaete feeding guilds as a useful conceptual framework and biological variable. Marine Ecology, 2005, 26: 246.254.

[21] Warwick R M.. The level of taxonomic discrimination required to detect pollution effects on marine benthic communities. Marine Pollution Bulletin, 1988, 19: 259.268.

[22] Pearson T H. Functional group ecology in soft-sediment marine benthos: the role of bioturbation. Oceanographic Marine Biology: Annual Review, 2001, 39: 233.267.

[23] Gray J S, Elliott M. Ecology of Marine Sediments: From Science to Management. 2nd edition. USA: Oxford University Press. 2009.

[24] Chaudhuri A, Mukherjee S, Homechaudhuri S. Food partitioning among carnivores within feeding guild structure of fishes inhabiting a mudflat ecosystem of Indian Sundarbans. Aquatic Ecology, 2014, 48: 35.51.

[25] Zhang X M, Zhou Y, Wang F, *et al*. Ecological characteristics of *Zostera japonica* population in Swan Lake of Rongcheng，Shandong Province of China. Chinese Journal of Applied Ecology, 2013, 24(7): 2033.2039. (in Chinese)

[26] Gao S. On the restoration and improvement of deteriorated coastal environments, with special reference to Yuehu lagoon, Shandong Peninsular, China: World Sci-Tech Research and development, 1998, 20(4): 123.126. (in Chinese)

[27] Dong C L, Qi X L, Liu J. Food habits of Whooper Swan in winter at the Tian'ehu of Rongcheng. Chinese Journal of Zoology, 2007, 42(6): 53.56 (in Chinese).

[28] Yang Y L, Yin X C, Mu X Y, *et al*. Environmental Geochemistry of Swan Lake Inlet, Rongcheng Bay, the Yellow Sea of China. Chinese Journal of Geochemistry, 2001, 20(2): 152.160.

[29] Fisher P F, Bradley T, Patten K. Invasion of Japanese seagrass, *Zostera japonica* in the Pacific Northwest: A Preliminary Analysis of Recognized Impacts, Ecological Functions, and Risks. Unpublished report prepared for the Willapa-Grays, 2011.1.23.

[30] Folk R L, Ward W C. Brazos River bar: a study in the significance of grain size parameters. Journal of Sedimentary Petrology, 1957, 27: 3.26.

[31] Xu F S, Zhang S P. An illustrated bivalvia Mollusca Fauna of China Seas. Beijing, Science Press, 2008.1.336. (in Chinese)

[32] Yang D J, Sun R P. Coastal Polychaetes of China. Beijing, Agriculture press, 1988, 1.352. (in Chinese)

[33] Tilman D, Knops J, Wedin D, *et al*. The influence of functional diversity and composition on ecosystem processes. Science, 1997, 277: 1300.1302.

[34] Steneck R S, Watling L. Feeding capabilities and limitation of herbivorous molluscs: a functional group approach. Marine Biology, 1982, 68(3): 299.319.

[35] Terborg J, Robinson S. Guilds and their utility in ecology. In: Kikkawa J, Anderson D J ed. Community Ecology: Pattern and Processes. Melbourne: Blackwell Scientific Publications, 1986, 65.99.

[36] Anderson A N. A classification of Australian ant communities, based on functional groups which parallel plant life-forms in relation to stress and disturbance. Journal of Biogeography, 1995, 22: 15.29.

[37] Roth S, Wilson J G. Functional analysis by trophic guilds of macrobenthic community structure in Dublin Bay, Ireland. Journal of Experimental Marine Biology and Ecology, 1998, 222: 195.217.

[38] Boaventura D, da Fonseca L C, Teles-Ferreira C. Trophic structure of macrobenthic communities on the Portuguese coast. A review of lagoonal, estuarine and rocky littoral habitats. Acta Oecologica, 1999, 20(4): 407.415.

[40] Magalhaes W F, Barros F. Structural and functional approaches to describe polychaete assemblages: ecological implications for estuarine ecosystems. Marine and Freshwater Research, 2011, 62: 918.926.

[41] Douglas J S, Mitsch W J. A model of macroinvertebrate trophic structure and oxygen demand in freshwater wetlands. Ecological Modelling, 2003, 161: 183.194.

[42] Wieking G, Kröncke I. Is benthic trophic structure affected by food quality? The Dogger Bank example. Marine Biology, 2005, 146: 387.400.

[43] Whanpetch N, Nakaoka M, Mukai H, *et al*. Temporal changes in benthic communities of seagrass beds impacted by a tsunami in the Andaman Sea, Thailand. Estuarine, Coastal and Shelf Science, 2010, 87: 246.252.

[44] Snelgrove P V R, Butman C A. Animal–sediment relationships revisited: cause versus effects. Oceanography and Marine Biology: Annual Review, 1994, 32:111.177.

[45] Gaston G R. Benthic polychaeta of the Middle Atlantic Bight: feeding and distribution. Marine Ecology Progress Series, 1987, 36: 251.262.

[46] Sprung M. Macrobenthic secondary production in the intertidal zone of Ria Formosa-a lagoon in southern Portugal. Estuarine Coastal and Shelf Science, 1994, 38: 539.558.

[47] Dolbeth M, Teixeira H, Marques J C. Feeding guild composition of a macrobenthic subtidal community along a depth gradient. Scientia Marina, 2009, 73(2): 225.237.