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RESEARCH PAPER

Spatial zonation of macrobenthic fauna in Zhanjiang Mangrove Nature Reserve, Guangdong, China

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Abstract: The spatial zonation of macrobenthic fauna in the core region of Zhanjiang Mangrove Nature Reserve was studied with two transects vertical to the shoreline. The first transect was near Deyao Village where three faunal zones of the mangrove swamp could be divided into the following types from the high tide part to the low tide part: the *Assiminea lutea-Uca arcuata- Paracleistostoma crassipilum* zone, the *Cleistostoma dilatatum-Macrophthalmus erato-Littoraria melanostoma* zone, and the *Paracleistostoma depressum-Cerithidae cingulata* zone. Mollusck and crustacean exhibited the highest individual density in this transect. Mollusck mainly influenced the dynamics of community biomass as well as the species diversity index. In the second transect near Hongzhai Village, the following four faunal zones could be determined: the *Littoraria melanostoma-Pseudoringicula sinensis-Ceratonereis burmensis* zone, the *Assiminea lutea-Cleistostoma dilatatum* zone with a dominant species belonging to the *Ellobiidae*, *Upogebia* sp.*-Paracleistostoma depressum* zone, and the *Metaplax sheni-Cerithidae cingulata* zone. The crustacean showed the highest individual density in this transect. Similar to the Deyao transect, dynamics of community biomass and the species diversity index of the Hongzhai transect were mainly influenced by mollusck. By hierarchical clustering and nonmetric multidimensional scaling, the macrobenthic fauna communities could be divided into three and four groups in the Deyao and Hongzhai transects, respectively. These groups corresponded to different types of vegetation of the mangrove swamp. Taken together, our observations indicated that the spatial zonation of the macrobenthic fauna was mainly affected by the characteristics of the mangrove community, sediment characteristics and the tidal line.

Key Words: mangrove; macrobenthic fauna; spatial zonation

There have been lots of reports covering vertical zonation characteristics of the macrobenthic fauna of foreign mangrove-distribution areas, such as Australia, Malaysia, Chile, India, *et al*[1–6]. These kinds of studies contribute to a more complete understanding of the ecological distribution patterns of macrobenthic fauna within the mangrove and their close relationship with mangrove ecosystem. Research in this area concerning subtropical regions has rarely been reported in China[7].

Moreover, such kind of surveys in relation to the macrobenthic fauna communities in the mangrove tend to overlook the differences among mangrove communities in mangrove areas since researchers would focus on how to set up the sampling plots in high, middle and low tidal zones. In fact, the different mangrove communities that exist in the same mangrove area appear to have a greater difference in their soil chemical properties[8,9]. Will this lead to a larger difference in spatial zonation for macrobenthic fauna? This aspect has not yet been reported.

The Zhanjiang Mangrove Nature Reserve is one of China's 21 wetlands of international importance. Reports on mangrove communities are available[10], but there has been no research yet on the spatial distribution of macrobenthic fauna. In the present study, two transects, Deyao Village and Hongzhai Village, which are situated in the core zone of Gaoqiao Town of the Zhanjiang Mangrove Nature Reserve, whose mangrove communities exist greatly differently, were applied for the purposes of comparing the vertical changes of the density, biomass, diversity and spatial zonation characteristics of the macrobenthic fauna communities. This helps to explore the

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relationship between the spatial zonation of macrobenthic fauna communities and the mangrove communities as well as environmental factors, and to provide scientific basis so that the ecosystem of mangrove swamp wetland and related resources can be protected, developed and utilized.

1 Materials and methods

1.1 Sampling methods and sample processing

In January, April, July and October 2005 representing Winter, Spring, Summer and Autumn respectively, two transects, vertical to coastal line and near Deyao Village and Hongzhai Village in the core protection zone of Gaoqiao Town, Zhanjiang Mangrove Nature Reserve, were set up. Plots were distributed at different places: 35, 65, 95, 125, 155, 185, 215, 275, 305, 335m and 405m (marked as A1–A11) as well as 70, 90, 100, 130, 160, 190, 220, 250, 280, 310, 340, 420m and 470m (marked as B1–B11) away from the coast. Quantitative sample frames of 25 cm × 25 cm were applied and 4 frames were used for each sampling plot. First, the macrobenthic fauna at the sediment surface were picked up; second, a layer of sediment mud were dredged to a depth of 30 cm and a sifter of 0.5-mm aperture were used to separate the macrobenthic fauna from the sediments. Samples thus acquired were fixed using 5% formaldehyde solution and identified in laboratory. The weighing, calculating and data analysis of samples were executed according to the Specification for Oceanographic Survey-Marine Biological Survey (GB 12763.6 -91). Meanwhile, each sampling plot was established with a sampling square of 10 m × 5 m, where all plants was carried out a comprehensive survey, including tree height, crown width (NS × EW), stem height under branch and chest diameter. Characteristic value of the mangrove community in each sampling square were also calculated, including average tree height, average crown width (NS × EW), average stem height under branch, basic covering and mean density. Besides, 5 points in each sampling square were selected randomly by diagonally sampling, and soil at the layer of 0–30 cm was excavated and mixed, and about 1 kg of such mixed soil samples were taken for testing. Soil particle composition, salt content and organic matter content were measured and determined using the hydrometer method, the weight method and the potassium dichromate method, whereas pH value was measured using the electrode method. Steps were repeated for three times for each sample.

1.2 Data analysis

The macrobenthic fauna dominance (Y) and the diversity indexes (H') were calculated, respectively, using the following formula:

$$Y = \frac{Ni}{N} fi$$

$$H' = -\sum_{i=2}^{s} (p_i)(\ln p_i)$$

Where S is the number of species of the samples; p_i is the ratio value of the individual number of i species and that of all species; Ni is the individual number of i species; fi is the frequency of i species occurring in each sampling plot; N is the total individual number of all species.

The primitive abundance data of the macrobenthic fauna communities, after its transformation and standardization via the calculation of the fourth root, was analyzed by hierarchical clustering (using group-average linkage method) and nonmetric multidimensional scaling (NMMDS) based on the measurement of Bray-Curtis similarity.

SPSS12.0 software was used to analyze all relations and significant differences.

2 Results

2.1 Characteristics of mangrove communities and sediments

Characteristics of mangrove communities and sediments are shown in Tables 1 and 2. Along the declining of tide lines, the mangrove communities of the transect near Deyao Village can be divided into the following three types: *Aegiceras corniculatum* (A1), *Aegiceras corniculatum* + *Rhizophora stylosa* (A2–A7), and *Aegiceras corniculatum* + *Avicennia marina* (A8–A10). Variance analysis (one-way ANOVA) shows that there is significant difference (p<0.01) in tree height, basic cover and stem height under branch among these different mangrove communities, and there is also significant difference (p<0.05) in tree crown width (West × East) and mean density among these different mangrove communities. There is also significant difference (p<0.05) in organic matter and silt content of sediments from one mangrove community to another. The mangrove communities of transects near Hongzhai Village can be divided into four types as follows: *Aegiceras corniculatum* (B1, B2, B11 and B12), *Aegiceras corniculatum+Bruguiera gymnorrhiza* (B3, B6–B10), *Kandelia candel+Bruguiera gymnorrhiza* (B4, B5), and *Aegiceras corniculatum+Avicennia marina* (B13). Variance analysis shows that the characteristic difference of mangrove communities is not significant (p>0.05), but the pH value of sediments and silt content is significantly different (p<0.05) from one mangrove community to another.

2.2 Composition of the species of macrobenthic fauna communities

There are a total of 60 species of macrobenthic fauna of the transect near Deyao Village belonging to 30 families, 6 classes and 5 Phylum (Tabele 3). Dominant species (Y>0.01) include *Assiminea lutea*, *Macrophthalmus erato*, *Paracleistostoma depressum*, *Cleistostoma dilatatum*, *Littoraria melanostoma*, *Ceratonereis burmensis*, *Uca arcuata* and *Pseudoringicula sinensis*. It is obvious that different species exist in different tidal zones. The main species existing in a zone 0–35 m away from the coast are *Assiminea lutea*, *Uca arcuata* and *Para-*

Table 1 Characteristics of mangrove community in each sampling plot

Sampling plot	Community type	Tree height (m)	Tree crown North×South (m)	Tree crown West×East (m)	Base coverage (%)	Stem height under branch (m)	Average density (ind./m^2)
A1	*Aegiceras corniculatum*	2.40	1.45	1.32	1.00	1.31	1.10
A2	*A. corniculatum+Rhizophora stylosa*	2.55	1.86	1.83	1.06	1.34	0.52
A3	*A. corniculatum+ R. stylosa*	2.54	1.69	1.60	0.86	1.57	0.72
A4	*A. corniculatum+ R. stylosa*	2.11	1.43	1.44	0.79	1.29	0.86
A5	*A. corniculatum+ R. stylosa*	2.35	1.61	1.35	1.09	1.25	0.82
A6	*A. corniculatum+ R. stylosa*	2.03	1.15	1.31	0.76	1.14	0.56
A7	*A. corniculatum+ R. stylosa*	2.06	1.89	1.79	0.71	0.64	0.46
A8	*A. corniculatum+ Avicennia marina*	1.62	1.04	1.01	0.34	0.49	1.10
A9	*A. corniculatum+A. marina*	1.14	1.19	1.12	0.15	0.22	0.66
A10	*A. corniculatum+A. marina*	1.57	1.11	1.03	0.55	0.48	1.10
A11	*A. corniculatum+A. marina*	1.83	1.32	1.31	0.36	0.53	1.32
B1	*A. corniculatum*	4.83	3.59	5.02	0.33	0.56	0.12
B2	*A. corniculatum*	0.76	0.43	0.46	0.05	0.20	1.06
B3	*A. corniculatum+ Bruguiera gymnorrhiza*	1.30	0.57	0.52	0.30	0.47	1.94
B4	*Kandelia candel+ B. gymnorrhiza*	2.40	1.75	1.75	0.44	0.43	0.62
B5	*K．candel+ B. gymnorrhiza*	3.05	2.00	2.02	0.58	1.12	0.56
B6	*A. corniculatum+B.gymnorrhiza*	2.92	1.80	1.84	0.44	1.33	0.64
B7	*A. corniculatum+B. gymnorrhiza*	2.81	2.01	1.85	0.68	0.68	0.56
B8	*A. corniculatum+B. gymnorrhiza*	2.63	2.18	2.10	1.02	0.93	0.46
B9	*A. corniculatum+B. gymnorrhiza*	2.53	2.03	1.96	0.63	1.38	0.44
B10	*A. corniculatum+B. gymnorrhiza*	2.55	1.42	1.43	0.51	1.14	0.82
B11	*A. corniculatum*	1.57	1.16	1.07	0.41	0.36	0.82
B12	*A. corniculatum*	0.61	0.52	0.52	0.02	0.19	1.58
B13	*A. corniculatum+A. marina*	0.61	0.70	0.72	0.03	0.25	1.38

cleistostoma crassipilum; those existing at 35–215 m are *Macrophthalmus erato*, *Littoraria melanostoma* and *Cleistostoma dilatatum*; the ones existing at 215–405 m are *Paracleistostoma depressum* and *Cerithidae cingulata*. Some species, such as *Assiminea lutea* and *Littoraria melanostoma*, are distributed throughout all the transect.

There are a total of 47 species of macrobenthic fauna of the transect near Hongzhai Village belonging to 24 families, 6 classes and 5 Phylum (Table 3). Dominant species (Y>0.01) include *Assiminea lutea*, *Upogebia* sp., *Paracleistostoma depressum*, *Cleistostoma dilatatum*, a species of *Ellobiidae*, *Littoraria melanostoma*, *Pseudoringicula sinensis*, *Parapenaeopsis hardwickii*, *Uca arcuata* and *Ceratonereis burmensis*. It is obvious that different species exist in different tidal zones. The main species existing in zones 0–90 m and 340–420 m away from the coast are *Littoraria melanostoma*, *Parapenaeopsis hardwickii* and *Ceratonereis burmensis*; those existing at 100–160 m are *Upogebia* sp. and *Paracleistostoma depressum*; the ones existing at 90–100 m and 160–340 m are *Assiminea lutea*, *Cleistostoma dilatatum* and a species of *Ellobiidae*; species that exist in 420–470 m are *Cerithidae cingulata* and *Metaplax sheni*. Some species, such as *Assiminea lutea* and *Littoraria melanostoma*, are distributed throughout all the transect.

2.3 Vertical changes in biomass and density of macrobenthic fauna

For the macrobenthic fauna of the transect near Deyao Village, the maximum and the second highest average values of biomass occur at plots of 405 and 65 m away from the coast, respectively, whereas its minimum and the last but one values of biomass occur at plots of 95 and 335 m away from the coast, respectively, and the biomass appears to increase slowly from the plot of 95–305 m. Correlation analysis shows that the total biomass and the biomass of mollusks appear to have a significant positive correlation (p<0.01) and the correlation coefficient is 0.960. The vertical changes in biomass of the macrobenthic fauna of the transect near Hongzhai Village have been dominated by the biomass of mollusks and the correlation coefficient is 0.994 (p<0.01). The maximum value occurs at the sampling plot of 100 m away from the coast and the

Table 2 Characteristics of sediments in each sampling plot

Sampling plot	pH	Organic matter (g/kg)	Salt (g/kg)	Sand (%)	Slit (%)	Clay (%)
A1	6.6	27.3	16.0	49.6	49.6	0.8
A2	6.6	36.5	18.9	46.6	50.8	2.6
A3	6.5	45.7	21.9	43.6	52.0	4.4
A4	6.5	43.3	21.6	50.1	47.7	2.2
A5	6.4	40.9	21.3	56.6	43.4	0.0
A6	6.5	39.7	21.1	54.7	42.4	2.9
A7	6.5	38.4	20.8	52.8	41.3	5.9
A8	6.9	30.3	21.6	49.0	39.2	11.8
A9	6.3	33.8	21.5	57.8	36.3	5.9
A10	5.6	37.3	21.4	66.6	33.4	0.0
A11	6.5	15.6	13.6	65.4	22.4	12.2
B1	6.4	8.9	5.5	86.6	12.6	0.8
B2	6.4	28.0	11.8	68.6	25.4	6.0
B3	6.4	47.0	17.8	50.6	38.2	11.2
B4	6.3	46.7	18.2	53.9	36.7	9.4
B5	6.2	46.2	18.5	57.3	35.1	7.6
B6	6.1	46.2	19.1	60.6	33.6	5.8
B7	6.1	54.9	21.3	56.6	38.9	4.5
B8	6.1	72.4	24.2	52.6	43.8	3.6
B9	6.1	89.7	26.9	48.6	48.2	3.2
B10	6.2	71.9	23.7	48.1	40.9	11.0
B11	6.3	53.9	20.4	47.6	33.6	18.8
B12	6.6	40.8	18.7	59.3	27.2	13.5
B13	6.8	27.6	16.8	71.0	20.8	8.2

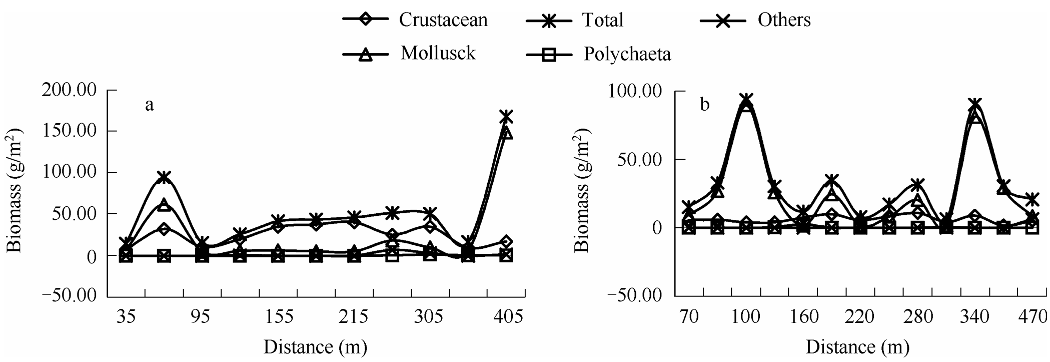

Fig. 1 Dynamics of the biomass of macrobenthic fauna along the mangrove swamp transect
(a) near Deyao Village; (b) near Hongzhai Village

second highest value of biomass occurs at the sampling plot of 340 m away from the coast, and the biomass fluctuates at a lower level from the plot of 160–310 m.

The vertical changes in the density of the macrobenthic fauna of the transect near Deyao Village have been dominated by the densities of mollusks and crustacean. The correlation coefficient is 0.905 (p<0.01) and 0.799 (p<0.01), respectively. The maximum value and the second highest value occur at the sampling plots of 405 m and 275 m away from the coast, respectively, the lowest value at the plot of 335 m, and the density appears to decrease first, and then increase slowly from the plot of 35–215 m. Along the transect near Hongzhai Village, the changes in density from the high tide part to the low tide part have been dominated mainly by the crustacean and

Table 3 The macrobenthic fauna species found in the investigation

Phylum	Class	Family	Specie
Annelida	Polychaeta	Nereidae	^{DH}*Ceratonereis burmensis*, ^{D}*Tylonereis bogoyawleskyi*, ^{D}*Perinereis cultrifera*
		Glyceridae	^{DH}*Glycera chirori*
		Lumbrineridae	^{DH}*Lumbrineris heteropoda*
		Opheliidae	^{DH}*Traoisia* sp.
		Maldanidae	^{DH}*Maldane sarsi*
Sipuncula	Phascolosomatidae	Phascolosomatidae	^{H}*Phascolosoma* sp., ^{DH}*P. esculenta*
Mollusca	Gastropoda	Ringiculidae	^{DH}*Pseudoringicula sinensis*
		Neritidae	^{D}*Neritina violacea*
		Littorinidae	^{DH}*Littoraria melanostoma*, ^{D}*L. scaber*
		Assimineidae	^{DH}*Assiminea lutea*
		Potamididae	^{DH}*Cerithidae cingulata*, ^{DH}*C. ornata*
		Cerithiidae	^{H}*Cerithum sinense*
		Nassariidae	^{D}*Nassarius hepaticus*, ^{D}*N. siquijorensis*
		Ellobiidae	^{DH}*Ellobium aurismidae*, ^{DH}*a species of Ellobiidae*
	Bivalvia	Arcidae	^{D}*Didimacar tenebrica*
		Mytilidae	^{D}*Modiolus philippinarum*, ^{H}*Septifer excisus*
		Ostreacea	^{D}*Ostrea mordax*
		Tellinidae	^{D}*Moerella iridescens*
		Corbiculidac	^{DH}*Polymesoda erosa*
		Veneridae	^{DH}*Clausinella isabellina*, ^{DH}*Meretrix meretrix*
		Glauconomidae	^{H}*Glauconome cerea*, ^{DH}*G*. sp.
		Laternulidae	^{D}*Laternula truncata*
Arthropoda	Crustacea	Penaeidae	^{DH}*Metapenaeus affinis*, ^{DH}*Parapenaeopsis hardwickii*
		Sergestidae	^{D}*Acetes chinensis*
		Palaemonidae	^{DH}*Macrobrachium nipponensis*, ^{D}*M. qracilirostre*
		Alpheoidae	^{D}*Arhanas* sp.
		Upogebidae	^{H}*Upogebia* sp.
		Dorippidae	^{D}*Dorippe astuta*
		Mictyridae	^{H}*Mictyris longicarpus*
		Goneplacidae	^{DH}*Ommatocarcinus macgillivrayi*
		Ocypodidae	^{DH}*Uca arcuata*, ^{D}*U. vocans borealis*, ^{DH}*U. triangularis triangularis*, ^{DH}*Macrophthalmus convexus*, ^{DH}*M. erato*, ^{D}*M. definitus*, ^{DH}*M. latreillei*, ^{D}*M. boscii*, ^{D}*M. dilatatum*, ^{DH}*Cleistostoma dilatatum*, ^{DH}*Paracleistostoma depressum*, ^{DH}*P. crassipilum*, ^{D}*P. cristatum*, ^{DH}*Ilyoplax serrata*, ^{H}*Il. Dentimerosa*, ^{H}*Il. tansuiensis*
		Grapsidae	^{D}*Nanosesarma pontianacensis*, ^{DH}*Sesarma bidens*, ^{D}*S. sinensis*, ^{DH}*S. plicata*, ^{D}*Neoepisesarma mederi*, ^{DH}*Cyclograpsus incisus*, ^{DH}*Helice sheni*, ^{H}*H. leachii*, ^{DH}*Metaplax longipes*, ^{H}*M. sheni*, ^{D}*Percnon sinense*
Chordata	Osteichthyes	Periphthalmidae	^{DH}*Periophthalmus cantonensis*, ^{H}*Boleophthalmus pectinirostris*

Note: D: found in mangrove swamp transect near Deyao Village; H: found in mangrove swamp transect near Hongzhai Village; DH: found in mangrove swamp transects near both Deyao Village and Hongzhai Village

their correlation coefficient is 0.967 (p<0.01). The maximum value occurs at the sampling plot of 160 m away from the coast.

2.4 Vertical changes in the diversity of macrobenthic fauna

The diversity of macrobenthic fauna of the transect near Deyao Village tends to increase slowly on the whole. The maximum value and the second highest value occur at the plots of 335 m and 405 m away from the coast, respectively, and the lowest value and last but one occur at the plots of 65 m and 35 m, respectively. Correlation analysis shows that the total diversity and the diversity of mollusk appear to have a significant positive correlation (p<0.01) and the correlation coefficient is 0.913. There is no obvious regular change in the diversity of macrobenthic fauna of the transect near Hongzhai village. The maximum value and the second highest value occur at the plots of 470 m and 420 m away from the coast, respectively, and the lowest value and the last but one occur at the plots of 310 m and 280 m, respectively. Correlation analysis shows that the total diversity and the diversity of mollusk appear to have a significant positive correlation (p<0.01) and the correlation coefficient is 0.752.

2.5 Clustering and nonmetric multidimensional scaling (NMMDS) of macrobenthic fauna community

It can be seen from Fig. 4a that macrobenthic fauna communities of 11 plots of the transect near Deyao Village, which are similar up to 45%, are divided into 3 major groups by hierarchical cluster analysis: group of A1; group of A2, A3, A4, A5, A6, A7; group of A8, A9, A10, A11. It is shown in Fig. 4b that macrobenthic fauna communities of 13 plots of the transect near Hongzhai Village, which are similar up to 48%, are divided into 4 major groups by hierarchical cluster analysis: group of B13; group of B4, B5; group of B3, B6, B7, B8, B9, B10; group of B1, B2, B11, B12. It can be seen from Fig. 5 that NMMDS also supports the result of using the hierarchical cluster analysis and provides a more tangible indication of the

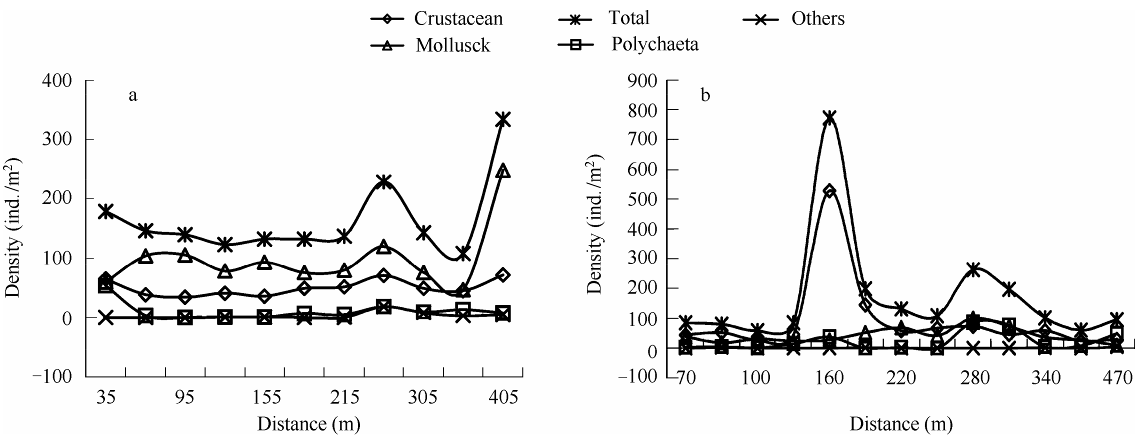

Fig. 2 Dynamics of the density of macrobenthic fauna along the mangrove swamp transect
(a) near Deyao Village; (b) near Hongzhai Village

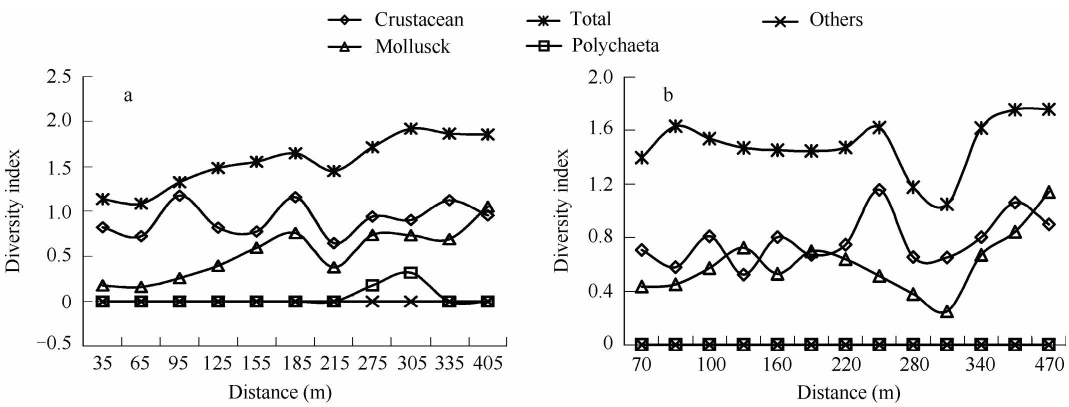

Fig. 3 Dynamics of the diversity indexes of macrobenthic fauna along the mangrove swamp transect
(a) near Deyao Village; (b) near Hongzhai Village

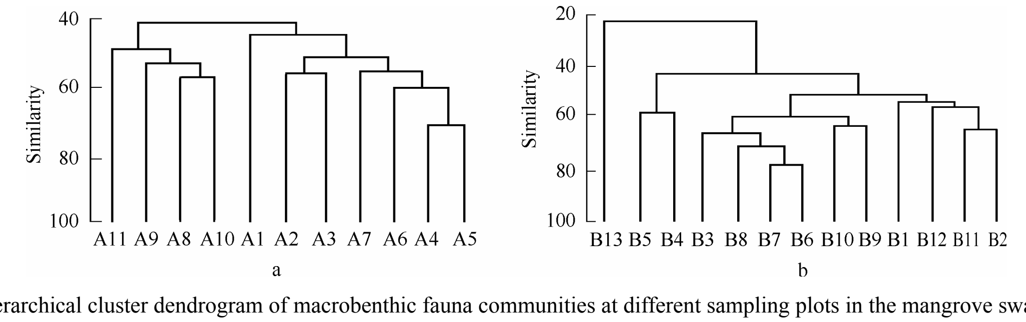

Fig. 4 Hierarchical cluster dendrogram of macrobenthic fauna communities at different sampling plots in the mangrove swamp transect
(a) near Deyao Village; (b) near Hongzhai Village

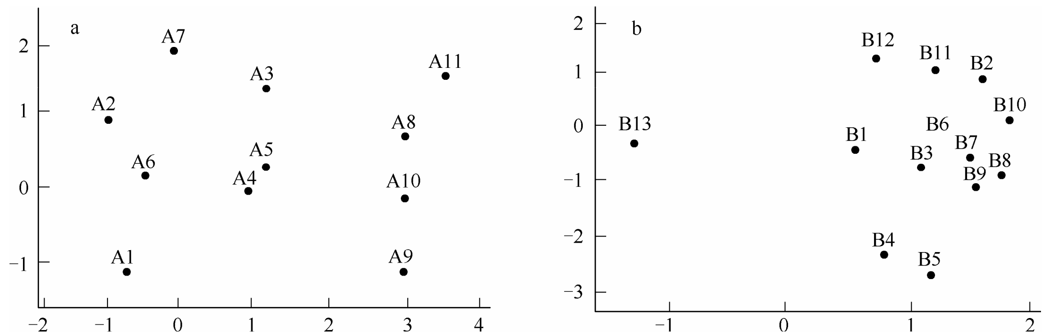

Fig. 5 NMMDS ordination of macrobenthic fauna communities at different sampling plots in the mangrove swamp transect
(a) near Deyao Village; (Stress = 0.09); (b) near Hongzhai Village (Stress = 0.08)

distance between macrobenthic fauna communities of various plots and their similarity status.

2.6 Seasonal changes

Results of the survey on the density of macrobenthic fauna of the transect near Deyao Village in the four seasons are: Spring (222 ind./m^2) > Winter (185 ind./m^2) > Autumn (144 ind./m^2) > Summer (103 ind./m^2). The single-variable and multi-factor analysis of variance (two-way ANOVA) shows that there is neither obviously different density of macrobenthic fauna nor interaction among the seasons or among mangrove community types (p>0.05). Biomass in the four seasons is recorded as follows: Spring (86.3 g/m^2) > Winter (44.1 g/m^2) > Autumn (43.5 g/m^2) > Summer (31.6 g/m^2). The biomass of macrobenthic fauna communities of different vegetation types of mangrove differs significantly (p<0.05), but there is no obvious difference among the seasons (p>0.05) and there is no interaction among the seasons or among mangrove communities (p>0.05). Diversity Indexes in the four seasons are as follows: Summer (1.7306) > Autumn (1.6042) > Winter (1.4584) > Spring (1.3932). The single-variable & multi-factor analysis of variance shows that, for all plots, there is no obviously different diversity among the seasons (p>0.05), but significant difference exists among different vegetation types of mangrove (p<0.01) and there is no interaction among the seasons or among mangrove communities (p>0.05).

Density values of macrobenthic fauna of the transect near Hongzhai Village in the four seasons are: Spring (220 ind./m^2) > Winter (201 ind./m^2) > Autumn (168 ind./m^2) > Summer (102 ind./m^2). The single-variable and multi-factor analysis of variance shows that, for all plots, there is no obviously different density nor interaction among the seasons or among mangrove community types (p>0.05). Biomass values in the four seasons are: Autumn (50.8 g/m^2) > Summer (33.4 g/m^2) > Spring (23.9 g/m^2) > Winter (21.4 g/m^2). There is neither obviously different biomass of different plots nor interaction among the various seasons or among mangrove community types (p>0.05). Diversity Indexes in the four seasons are: Spring (1.5542) > Autumn (1.5535) > Winter (1.5437) > Summer (1.3112). The single-variable and multi-factor analysis of variance shows that, for all plots, there is no obviously different diversity among seasons (p>0.05), but there is significant difference of diversity among mangrove community types (p<0.01), and significant interaction among the seasons or among mangrove community types (p<0.01).

2.7 Relationships between macrobenthic fauna and mangrove communities as well as environmental factors

Table 4 shows for the correlation of biomass, density and diversity of macrobenthic fauna of two transects with various characteristic values of mangrove communities and Table 5 shows the correlation with environmental factors.

3 Discussion

For macrobenthic fauna communities of the transect near Deyao Village, it is obvious that there is zonation phenomenon from the high tide part to the low tide part, which is consistent with reports of other scholars[1,2]. According to the survey result based on the features including dominant species and limitations, macrobenthic fauna communities can be divided basically into 3 distribution zones: (1) Zone of *Assiminea lutea-Uca arcuata-Paracleistostoma crassipilum*, which is 0–35 m away from the coast, whose mangrove communities are *Aegiceras corniculatum* and an average tree height is 2.40 m, basic coverage is 1.00%, soil quality is of powder sandy loam, average content of organic matter is 27.3 g/kg, and silt is 49.6%. The main species are *Assiminea lutea*, *Uca arcuata* and *Paracleistostoma crassipilum*; (2) Zone of *Cleistostoma dilatatum-Macrophthalmus erato-Littoraria melanostoma*, which is 35–215 m away from the coast, whose mangrove communities are *Aegiceras corniculatum* + *Rhizophora stylosa* and an average tree height is 2.27 m, basic coverage is 0.88%, soil quality is of powder sandy loam or sandy loam, average content of organic matter is 40.8 g/kg, and silt is 46.3%. The main species are *Cleistostoma dilatatum*, *Macro- phthalmus erato* and *Littoraria melanostoma*; (3) Zone of *Paracleistostoma depressum-Cerithidae cingulata*, which is 215–405 m away

Table 4 The correlation between the mean biomass, density and diversity indexes of macrobenthic fauna with mangrove community characteristics

Item	Tree height	Tree crown North×South	Tree crown West×East	Base cover	Stem height under branch	Average density
D biomass of crustacean	NS	NS	NS	NS	NS	–0.685*
H biomass of crustacean	NS	NS	NS	NS	0.627*	–0.555*
D biomass of polychaeta	–0.878**	NS	NS	–0.893**	–0.851**	NS
D biomass of others	–0.606*	NS	NS	–0.687*	NS	NS
D density of crustacean	NS	NS	NS	NS	NS	0.613*
H density of mollusck	NS	NS	NS	0.562*	0.735**	NS
D density of others	–0.636*	–0.615*	–0.644*	–0.702*	–0.624*	NS
H density of others	NS	NS	NS	–0.580*	NS	NS
D total density	NS	NS	NS	NS	NS	0.640*
H total density	NS	NS	NS	NS	0.554*	NS
D diversity indexes of polychaeta	–0.750**	NS	NS	–0.722*	–0.628*	NS
D diversity indexes of mollusck	–0.703**	–0.697*	–0.653*	–0.722*	–0.690*	NS
D total diversity indexes	–0.878**	–0.730*	–0.727*	–0.833**	–0.806**	NS
H total diversity indexes	–0.575*	NS	NS	NS	–0.734**	NS

Note: *$p < 0.05$; **$p < 0.01$; NS: $p > 0.05$; D: Deyao Village; H: Hongzhai Village; the same below.

Table 5 The correlation between the mean biomass, density and diversity indexes of macrobenthic fauna with environment factor

Item	Distance	Organic matter	Salt	Sand	Slit	Clay	pH
H biomass of crustacean	NS	NS	NS	NS	NS	NS	–0.562*
D biomass of polychaeta	0.696*	NS	NS	NS	–0.628*	NS	NS
D biomass of mollusck	NS	–0.760**	–0.787**	NS	NS	NS	NS
H biomass of mollusck	NS	NS	NS	NS	NS	0.636*	NS
D biomass of others	NS	NS	NS	NS	NS	0.710*	NS
H biomass of others	0.554*	NS	NS	NS	NS	NS	0.723**
D total biomass	NS	–0.712*	–0.679*	NS	–0.611*	0.638*	NS
H total biomass	NS	NS	NS	NS	NS	0.621*	NS
D density of crustacean	NS	–0.866**	–0.611*	NS	NS	0.697*	NS
D density of mollusck	NS	–0.679*	–0.645*	NS	NS	0.751**	NS
H density of mollusck	NS	0.736**	0.595*	NS	0.627*	NS	–0.704**
D density of others	NS	NS	NS	NS	NS	0.690*	NS
H density of others	NS	NS	NS	NS	NS	NS	0.662*
D total density	NS	–0.886**	–0.759**	NS	–0.607*	0.805**	NS
D diversity indexes of mollusck	0.894**	NS	NS	0.762**	–0.898**	NS	NS
D total diversity indexes	0.920**	NS	NS	0.768**	–0.840**	NS	NS
H diversity indexes of mollusck	NS	NS	NS	NS	NS	NS	0.680*
H total diversity indexes	NS	NS	NS	NS	NS	NS	0.606*

from the coast, whose mangrove communities are *Aegiceras corniculatum* + *Avicennia marina* and an average tree height is 1.54 m, basic coverage is 0.35%, soil quality is of loamy sand or sandy loam soil, average content of organic matter is 29.3 g/kg, and silt is 32.8%. The main species are *Paracleistostoma depressum* and *Cerithidae cingulata*. For macrobenthic fauna communities of the transect near Hongzhai Village, the zonation phenomenon is not as obvious as that of Deyao Village, but its macrobenthic fauna communities can also be divided basically into 4 distribution zones: (1) Zone of *Littoraria melanostoma-Pseudoringicula sinensis- Ceratonereis burmensis*, which is 0–90 m and 340–420 m away from the coast, whose mangrove communities are *Aegiceras corniculatum* and an average tree height is 1.94 m, basic coverage is 0.2%, soil quality is of loamy sand or sandy loam soil, pH value is 6.4, and silt is 24.7 %. The main species are *Littoraria melanostoma*, *Pseudoringicula sinensis* and *Ceratonereis burmensis*; (2) Zone of *Assiminea lutea-Cleistostoma dilatatum*-a species of *Ellobiidae*, which is 90–100 m and 160–340 m away from the coast, whose mangrove communities are *Aegiceras corniculatum* + *Bruguiera gymnorrhiza* and an average tree height is 2.46 m, basic coverage is 0.60%, soil quality is of clay loam or sandy loam soil, pH value is 6.1, and silt is 40.6%. The main species are *Assiminea lutea*, *Cleistostoma dilatatum* and a species of *Ellobiidae*; (3) Zone of *Upogebia* sp.-*Paracleistostoma depressum*, which is 100–160 m from the coast, whose mangrove communities are *Kandelia candel* + *Bruguiera gymnorrhiza* and an average tree height is 2.54 m, basic coverage is 0.57%, soil quality is of sandy loam soil, pH value is 6.3, and silt is 35.9%. The main species are *Upogebia* sp. and *Paracleistostoma depressum*; (4) Zone of *Metaplax sheni-Cerithidae cingulata*, which is 420–470 m from the coast, whose mangrove communities are *Aegiceras corniculatum* + *Avicennia marina* and an average tree height is 0.61 m, basic coverage is 0.03%, soil quality is of loamy sand, pH value is 6.8, and silt is 20.8%. The main species are *Metaplax sheni-Cerithidae cingulata*.

It is shown by the hierarchical clustering and non-metric multi-dimensional scaling that the zonation of macrobenthic fauna communities is consistent with the distribution of the vegetation types of the mangrove (Figs. 4 and 5). Although the communities of *Aegiceras corniculatum* near the Hongzhai Village grow in two places that are 0–90 m and 340–420 m away from the coast, the macrobenthic fauna communities in these two plots are very similar, reaching a level of 48 %, so that these macrobenthic fauna communities can be clustered into a group (Fig. 4b). Similarly, the communities of *Acgiceras corniculatum* + *Bruguiera gymnorrhiza* grow at two places that are 90–100 m and 160–340 m away from the coast, but the macrobenthic fauna communities in these two plots can be clustered into a group in a similarity to a level of 57% (Fig. 4b). Also, the single-variable & multi-factor analysis of variance shows that, for all plots established in the two transects, there is no obviously different diversity of the macrobenthic fauna among the seasons (p>0.05), but significant difference exists among the vegetation types of mangrove (p < 0.01), which indicates that types of mangrove communities influence the zonation of macrobenthic fauna owing to the growing environment provided by different mangrove communities.

First, chemical nature of sediments of different types of mangrove communities is influenced by the types of mangrove communities, especially by the growth rate of the dominant species, residual volume and content of nutrient elements, whereas nature of soil quality impacts largely on the macrobenthic fauna communities. Comparative analysis of the chemical properties of soils at succession stages of mangrove communities in Yingluo Bay of Guangxi conducted by Hebin shows that, as succession follows, all soil's total N, the total P, hydrolytic N, available P, the total salt, the total S, water soluble S, and exchangeable acid tend to increase. The same rules happen to soil's organic matter, humic acid (HA) and fulvic acid (FA), whereas pH value of soils shows a reverse trend[9]. As the area being discussed belongs virtually to the same gulf where Yingluo Bay of Guangxi Province is located, the growing environment for mangrove communities is similar. This study shows that different mangrove communities near Deyao Village are significantly different (p<0.05) in their organic matter and silt content of sediments and different mangrove communities near Hongzhai Village are significantly different (p<0.05) in their pH value and silt content of sediments. Tables 4 and 5 show that the biomass, density and diversity of some macrobenthic fauna groups are related notably to sediment properties. It is obvious that the difference in sediment properties of different types of mangrove communities would affect the distribution of macrobenthic fauna.

The community characteristics of mangrove communities may also affect the distribution of macrobenthic fauna. Different mangrove communities near Deyao Village have significant difference in trees' height, basic coverage, stem height under branch, crown width (EW) and the mean density (p< 0.01 or p<0.05). Different heights of plants cause different underground biomass[10], resulting in different plant rhizosphere, different complexity extent of rhizome structure and the structural heterogeneity of the surface environment. It is well-known that the heterogeneity of growing environment is very important for the distribution and diversity of macrobenthic fauna. That is a cause resulting in the difference of macrobenthic fauna community structure in different mangrove communities. Besides, difference of basic coverage in different mangrove communities affects the light intensity in forest. This will also affect the diversity of macrobenthic fauna. The research on Australian natural mangrove done by Nobbs shows that the existence of the mangrove vegetation has significant impacts on the types and distribution of crabs, which is caused mainly by the difference of shade conditions of mangrove[11]. Vannini's study also shows that light intensity in the forest of natural mangrove has important influence on the distribution of sesarma[12]. Tables 4 and 5 show that the biomass, density and diversity of some groups of macrobenthic fauna are related notably to mangrove community characteristics. It is obvious that the difference in properties of different types of mangrove communities would affect the distribution of macrobenthic fauna.

In addition, mangrove communities would often form an ecological series from the shore edge to the sea edge along with the decrease of tide lines[13]. Generally, different mangrove communities would distribute at different tide-line parts, which, in turn, shall influence the distribution of macrobenthic fauna[1,2]. Table 5 shows that the biomass and diversity of some groups of macrobenthic fauna are related notably to the offshore distance. It is obvious that the different parts in the tide line at which different types of mangrove communities distribute would affect the distribution of macrobenthic fauna.

The spatial zonation phenomenon of macrobenthic fauna in the mangrove area is the result of long-term ecological adaptation. The ecological series of mangrove communities near Deyao Village is more obvious than that near Hongzhai Village (Table 1), hence causing a clearer zonation of macrobenthic fauna than that near Hongzhai Village (Figs. 4 and 5). The biomass of macrobenthic fauna in the mangrove communities near both Deyao and Hongzhai is dominated by the biomass of mollusks with special phenomena of minimum biomass emerging during the middle-tidal zone (Fig. 1), which is consistent with Chao-Yu Liang's study [14], but inconsistent with other researches on macrobenthic fauna of mangrove areas[15]. All these are caused by high and low tidal parts in the two mangrove areas whose bottom mud contains less sediment accumulation of organic matter, soil with high pH value, weaker acidity, and mud with loose nature. This kind of bottom mud is suitable for the life forms of infaunal (such as *Meretrix meretrix*) and easy for drilling holes. These life forms of infaunal are big in size with high biomass, which significantly resulted in higher biomass than that in the middle-tidal zone whose mudflats bear high content of organic debris, deep and thick mud, low pH value, poor ventilation and disgusting smell overflowing. This serious environmental condition restricts the survival of life forms of infaunal, but helps to develop the population of some dominant species, such as *Assiminea lutea*, which are adapted to this environment. However, these infaunal life forms are small in size with low biomass, which significantly decreases the biomass of the middle-tidal areas.

In short, although the two mangrove areas near Deyao and Hongzhai Villages located around the same area of sea, they have different types of mangrove communities and different community characteristics. The different mangrove communities have different sediment properties and different distributions of tide lines resulting in the different vertical changes in species, biomass, density and diversity of macrobenthic fauna (Figs. 1–3). This indicates exactly that the types of mangrove communities influence the zonation of macrobenthic fauna. Therefore, any research on the ecosystem for macrobenthic fauna of mangrove should, based on different mangrove communities, choose the representative sections for an investigation. For any mangrove area with complex mangrove communities, one sectional investigation alone is not enough. For any mangrove, an ecological series of mangrove communities from the edge of shore to the sea margin should be formed because macrobenthic fauna communities have more complicated changes in the vertical space. The result would not be enough if only one plot is established at high, middle and low tidal zones, respectively. In order to analyze accurately, the more investigation plots should be set up as far as possible, and the best way to do is to complete the successive investigation on transects.

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