Zoological Studies **51**(6): 745-754 (2012)

Zoological Studies

The Community Structure of Molluscs in Three Different Wetland Types in the Qi'ao-Dan'gan Island Mangrove Nature Reserve at Qi'ao Island, Pearl River Estuary, China

Ya-Fang Li[1], Run-Lin Xu[1,*], and Chang-Fu Wang[2]

[1]*School of Life Sciences, Sun Yat-sen University, Guangzhou 510275, China*
[2]*Institute of Urban Environment, Chinese Academy of Sciences, 1799 Jimei Road, Xiamen 361021, China*

(Accepted March 8, 2012)

Ya-Fang Li, Run-Lin Xu, and Chang-Fu Wang (2012) The community structure of molluscs in three different wetland types in the Qi'ao-Dan'gan Island Mangrove Nature Reserve at Qi'ao Island, Pearl River estuary, China. *Zoological Studies* **51**(6): 745-754. The benthic mollusc communities in 3 different types of wetlands (mangrove arbor, emergent plants, and seaweed) at Qi'ao-Dan'gan I. were studied from Jan. 2008 to Nov. 2010. During this period, 16 species consisting of 11 species of gastropods and 5 species of bivalves were found. All of the bivalve species were found among the seaweeds. Compared to other mangrove habitats, the species richness of molluscs was lower while the abundance (68 individuals (ind.)/m^2) was higher. The community composition significantly differed among these wetland types (p < 0.05), and a significant serial shift occurred during the 3rd year of sampling in the seaweed wetland. At the mangrove arbor and seaweed wetlands, the mollusc community compositions exhibited no significant differences in different seasons or different years. In this article, relationships between the distribution of molluscs and environmental parameters are discussed as well. It is suggested that molluscs may possess strong adaptability in these 3 wetlands. This study provides useful baseline information on conservation and sustainable use of the wetlands.
http://zoolstud.sinica.edu.tw/Journals/51.6/745.pdf

Key words: Molluscs, Biodiversity, Wetland type, Environmental parameter.

Intertidal estuarine mudflats, adjacent to mangrove communities, are highly productive, and serve as habitats and breeding grounds for a diverse array of macrobenthic invertebrates. Invertebrate communities, in turn, are important in terms of biodiversity and ecosystem health and comprise an important trophic component of detrital-based estuarine food webs (Coull et al. 1995). A lot of research has examined estuarine ecological systems of the world (Alongi 1987, Jiang and Li 1995, Magni et al. 2006, Mendes et al. 2007).

The Pearl River is the 2nd-largest river in China in terms of annual flow. Its drainage area covers 4.5 × 10^5 km^2, and the discharge is about 350 × 10^9 m^3 annually (Chen et al. 2006). A few studies were conducted on the macrobenthic community composition of the Pearl River estuary and adjacent tidal flats (Su et al. 1989, Yu et al. 1996, Wang et al. 2010, Zhang et al. 2009). However, little is known about mangrove molluscs of Qi'ao I. Molluscs are one of the dominant invertebrate groups in mangrove communities, and are thought to play significant ecological roles in the structure and function of mangrove systems (Nagelkerken et al. 2008, Printrakoon et al. 2008). Despite their importance, there are few specific quantitative data on the diversity, density, and biomass of molluscs in mangroves (Wells 1984, Jiang and Li 1995, Printrakoon et al. 2008),

*To whom correspondence and reprint requests should be addressed. Tel: 86-20-84113185. E-mail:xurunlin_1960@yahoo.com

with few long-term studies that rarely exceeded 1 yr. It is accepted that significant spatial and temporal variability are characteristics of benthic assemblages in estuarine sediments (Jones et al. 1987, Morrisey et al. 1992, Chapman 1998). Therefore, the study presented here attempted to determine temporal and spatial patterns of benthic mollusc communities at Qi'ao I. and relationships between mollusc communities and environmental conditions. Specific objectives were (1) to provide a species record of molluscs at the sampling sites, (2) to determine the diversity, density, and composition of molluscs in different wetlands, (3) to follow the benthic mollusc communities for 3 yr, (4) to analyze relationships between the community composition and environmental variables, and (5) to establish a foundation for future biomonitoring activities in the Pearl River estuary.

MATERIALS AND METHODS

Study sites

With an area of 23.8 km^2, Qi'ao I. (Fig. 1) is located in the western portion of the Pearl River estuary. The Qi'ao-Dan'gan I. Mangrove Nature Reserve with 18.65 km^2 was established in 2004 in order to protect the fauna and flora (Lei et al. 2008). All sampling sites of this study were within the Qi'ao-Dan'gan I. Mangrove Nature Reserve.

Three sites with different vegetation types were selected, representing different wetland areas. The mangrove arbor (MA) area was dominated by the mangrove species, *Sonnerati acaseolaris* Buch-Ham and *Kandelia candel* (Linn.) Druce. The emergent plant (EP) area was dominated by *Phragmites communis* Trin. The seaweed (SW) area was dominated by *Myriophyllum* sp. All vegetation was natural. The MA and EP wetlands were located in the intertidal zone, and were intermittently flooded by tides. The SW wetland was a shallow fish pond which was almost completely closed by controlling the ingress and egress of water through a gate.

Sampling procedures

Quantitative samples were taken every 2 months from Jan. 2008 to Nov. 2010 using a Peterson grab with a sampling area of 0.0625 m^2. Four replicates were taken at each site in order to ensure the reliability of the investigation and preserve the biotope for subsequent samplings. Samples were sieved through a 0.5-mm screen and preserved in a 4% diluted formalin solution.

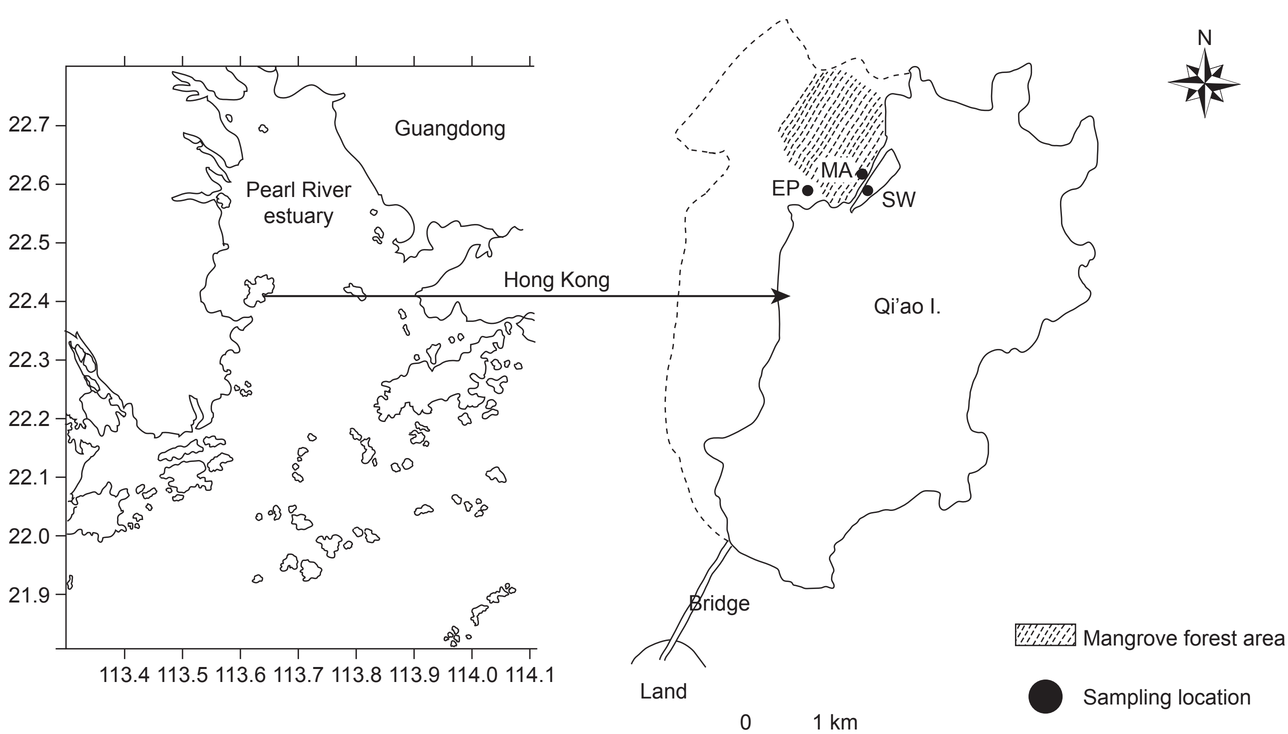

Fig. 1. Sampling sites at Qi'ao I. of the Pearl River estuary. SW, seaweed; EP, emergent plants; MA, mangrove arbor.

After 3 d, samples were washed and transferred to 75% ethanol. Molluscs were sorted to species, counted, and identified. Species were identified using the following references: Abbott (1958), Pace (1973), Brandt (1974), Ponder (1984), Cai et al. (2006), and Xu et al. (2008). In addition, some species required further identification. Environmental parameters were simultaneously measured during the sampling period, including sediment pH (S-pH), organic matter in the sediment (S-OM), available phosphorous in the sediment (S-AP), total nitrogen in the sediment (S-TN), total phosphorous in the sediment (S-TP), water salinity, water temperature, pH of the water (W-pH), reactive phosphorous in the water (W-RP), total phosphorous in the water (W-TP), and total nitrogen in the water (W-TN). Measurements were made as follows: S-OM used a spectrophotometric method with ferrous sulfate as the standard solution; S-AP in acid sediments used an acid ammonium fluoride spectrophotometric method and in alkaline sediments, used a sodium bicarbonate spectrophotometric method; S-TN used the Kjeldahl nitrogen determination method; S-TP used an alkali fusion Mo-Sb anti-spectrophotometric method; water salinity was measured with a portable salinometer (PN001746, Yacite, Beijing); water temperature and W-pH were measured with a portable pH meter (HI991003N, Hanna, Jiangsu); W-RP used a potassium persulfate digestion molybdenum-antimony anti-spectrophotometric method; W-TP used a potassium persulfate oxidation molybdenum-antimony anti-spectrophotometric method; W-TN used an alkaline potassium persulfate oxidation-UV spectrophotometric method (GB/T 12763.4-2007, 2007).

Data analysis

Diversities of molluscs at the 3 wetlands were expressed with Margalef's species richness index (*D*), the Shannon diversity index (*H'*, base-2 logarithm), and Pielou's evenness (*J'*). Non-parametric multivariate techniques contained in the PRIMER6 (Plymouth Routines In Multivariate Ecological Research) software package (Clarke and Gorley 2006) were used because they are powerful tools in the analysis of non-parametric community-structure data. Similarity matrices were constructed using the Bray-Curtis similarity measure on non-standardized, fourth-root-transformed mollusc abundance data. Sample relationships based on a comparison of similarity matrices were displayed using multi-dimensional scaling (MDS). One or two-way analyses of similarity (routine ANOSIM) were applied to identify differences in the species composition between sites. The routine (SIMPER) was applied to test which species could explain major differences in community compositions among sites and months. The routine, RELATE, was applied to test whether the communities showed a serial shift within the investigation period or a cyclic variation within a year.

Abiotic data (S-pH, S-AP, W-pH, and W-TP) were normalized, and similarity matrices were constructed using the Euclidean distance similarity measure. A principal components analysis (PCA) was used to analyze the abiotic data, and then the main environmental parameters which could explain temporal and spatial differences at the 3 wetlands were obtained. BEST/BIOENV (Biota and/or Environment matching, using Spearman rank correlations) was used to determine the series of environmental parameters which properly explained the community compositions.

RESULTS

Environmental data

The environmental parameters in this study are given in table 1. Sediments of the SW and EP wetlands were light clay, while that of the MA wetland was clay. The S-pH at the SW and EP wetlands were alkaline for most of the year, while the S-pH at the MA wetland was acidic. Differences in S-pH among the 3 wetlands were significant ($F = 11.309$, $p = 0.000$). Mean values of the S-OM, S-AP, S-TP, and S-TN were generally higher in the MA wetland than in the SW and EP wetlands. There were little differences among the W-pH, water temperature, and water salinity in the 3 wetlands. But the W-RP, W-TP, and W-TN showed the same trend as those in sediments. Basic results of the PCA (Fig. 2) were that in principal component 1 (PC1, x-axis), data of the MA wetland were on the left side, data of the EP wetland were in the middle, and data of the SW wetland were on the right side. The S-pH and S-OM played main roles on this axis. There were mainly temporal differences in PC2 (the y-axis), and water temperature and water salinity were the main parameters on this axis. The 1st 2 components explained 52.4% of the variation. The BIOENV analysis is shown in table 2. The single environmental variable, total nitrogen in the soil produced maximum correlations with both abundance and biomass ($R = 0.570$).

Species composition, and spatial and temporal variabilities of molluscs

In total, 16 species of molluscs, i.e., 11 gastropods and 5 bivalves, were found at the 3 wetlands (Table 3). There were 10, 5, and 10 species at the SW, EP, and MA wetlands, respectively. At the SW wetland, 1/2 of the molluscs were bivalves, which were only found here. At the MA and EP wetlands, there were gastropod species, belonging to the families Assimineidae, Stenothridae, Potamodidae, Iravadiidae, and Thiaridae. The abundance and diversity of molluscs were lowest at the EP wetland. The mean value of the abundance was 68 individuals (ind.)/m^2 at Qi'ao I. in the Pearl River estuary. Margalef's species richness index (*D*) and the Shannon diversity index (*H'*) of the 3 wetlands were in the order of MA > SW > EP, and Pielou's

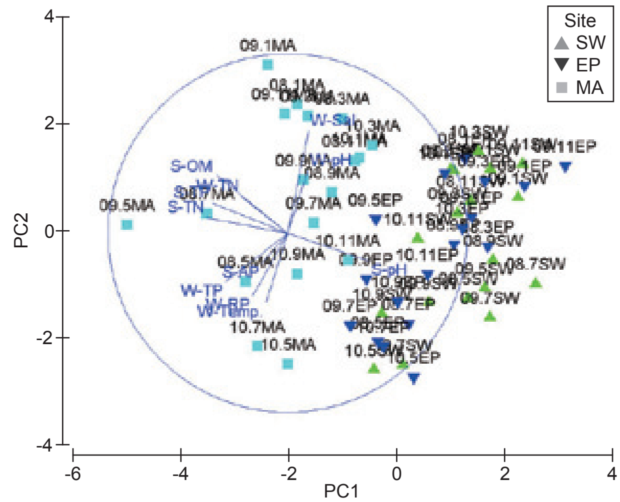

Fig. 2. PCA ordination of 3 yr of environmental data for 3 sites at Qi'ao I. SW, seaweed; EP, emergent plants; MA, mangrove arbor; S-pH, sediment pH; S-OM, organic matter in the sediment; S-AP, available phosphorous in the sediment; S-TP, total phosphorous in the sediment; S-TN, total nitrogen in the sediment; W-RP, reactive phosphorous in the water; W-TP, total phosphorous in the water; W-TN, total nitrogen content in the water.

Table 1. Environmental parameters of sediment and water samples from the different types of wetlands at Qi'ao-Dan'gan I., Pearl River estuary

Environmental parameter	Wetlands		
	SW wetland	EP wetland	MA wetland
S-pH	7.17 (6.23-7.87)	7.24 (4.77-7.97)	4.91 (3.60-8.05)
S-OM (g/kg)	28.5 (21.88-40.38)	20.24 (16.36-30.78)	77.3 (37.8-104.73)
S-AP (mg/kg)	12.02 (6.45-16.24)	9.56 (5.31-20.46)	19.36 (9.89-36.81)
S-TP (g/kg)	0.329 (0.110-0.562)	0.531 (0.418-0.650)	0.657 (0.482-0.813)
S-TN (g/kg)	1.28 (0.91-1.51)	1.24 (0.13-3.71)	2.61 (1.50-3.31)
Water temperature (°C)	25.91 (17.00-33.00)	26.62 (17.00-33.00)	26.62 (17.00-33.00)
Water salinity (‰)	6.50 (3-13)	8.22 (3-17)	8.44 (3-17)
W-pH	7.69 (7.51-7.97)	7.70 (7.42-7.91)	7.61 (7.26-7.80)
W-RP (mg/L)	0.029 (0-0.051)	0.111 (0.014-0.310)	0.071 (0.022-0.119)
W-TP (mg/L)	0.063 (0.023-0.092)	0.122 (0.064-0.320)	0.207 (0.089-0.800)
W-TN (mg/L)	0.743 (0.266-1.769)	1.277 (0.558-2.533)	1.626 (0.645-2.514)

SW, seaweed; EP, emergent plants; MA, mangrove arbor; S-pH, sediment pH; S-OM, organic matter in the sediment; S-AP, available phosphorous in the sediment; S-TP, total phosphorous in the sediment; S-TN, total nitrogen in the sediment; W-RP, reactive phosphorous in the water; W-TP, total phosphorous in the water; W-TN, total nitrogen content in the water.

evenness (J') was in the order of EP > MA > SW (Table 4).

Results of the ANOSIM indicated that there were significant differences in abundances and biomass values among the 3 types of wetlands ($R = 0.499$, $p = 0.001$; $R = 0.514$, $p = 0.001$ respectively). This trend was basically the same as the results of the similarity matrices and MDS which were based on abundances (Figs. 3, 4). There were generally 3 groupings on the dendogram. The largest was comprised of all of the MA wetland and parts of the EP and SW wetlands. All other EP wetland samples were separated from the main group. All other SW wetland samples formed a 2nd group on the dendogram (Fig. 3). Figure 4 shows the MDS ordination of molluscs. Stress values were low, so the ordinations gave a good representation of the composition of molluscs. Samples of the MA wetland were toward the bottom-left corner of the ordinations, samples of the SW wetland were toward the bottom-right hand corner, and samples of the EP wetland were toward the upper-right of the ordination (Fig. 4). Although there were significant differences among these 3 wetlands, the MA and SW wetlands were the most

Table 2. Summary results from BIOENV for molluscs in the Qi'ao-Dan'gan I. Mangrove Nature Reserve

K	Mollusc abundance	Mollusc biomass
1	**S-TN (0.570)**	**S-TN (0.570)**
2	S-TN, S-OM (0.550)	S-TN, S-OM (0.550)
3	S-TN, S-OM, W-RP (0.496)	S-TN, S-OM, W-RP (0.496)
3	S-TN, S-OM, W-TN (0.487)	S-TN, S-OM, W-TN (0.487)
3	S-TN, S-OM, Water salinity (0.483)	S-TN, S-OM, Water salinity (0.483)

Combination of environmental variables, K, at a time that gives the highest Spearman rank correlations, given in parentheses, between the molluscan data and environmental similarity matrices for each K. Bold type indicates overall the optimum. Environmental parameters abbreviations are given in the legend to table 1.

Table 3. Distribution of molluscs in the 3 types of wetlands from Jan. 2008 to Nov. 2010 in the Pearl River estuary

Species	Habitat			Species	Habitat		
	SW	EP	MA		SW	EP	MA
Class Gastropods				Class Bivalves			
Family Thiaridae				Family Veneridae			
Melanoides tuberculata (O.F. Müller, 1774)	+		+	*Meretrix lusoria* (Rŏding, 1798)	+		
Family Iravadiidae				Family Corbulidae			
Fairbankia cochinchinensis Bavey & Dautzenberg, 1910			+	*Potamocorbula amurensis* (Schrenck, 1867)	+		
Iravadia ornate Blanford, 1867	+	+	+	*Potamocorbula* sp.	+		
Iravadia sp. 1			+	Family Semelidae			
Iravadia sp. 2	+		+	*Abra* sp.	+		
Family Stenothyridae				Family Mytilidae			
Stenothyra sp.	+	+	+	*Modiolus plicatus* (Lamarck)	+		
Family Assimineidae							
Assiminea brevicula Pfeiffer, 1855		+					
Assiminea estuarina T. Habe, 1946	+	+	+				
Assiminea sp. 1			+				
Family Potamididae							
Cerithidea sinensis (Philippi, 1849)			+				
Family Ellobiidae							
laemodonta punctatostriata	+	+	+				

SW, seaweed; EP, emergent plants; MA, mangrove arbor.

similar (ANOSIM) in both abundances ($R = 0.447$, $p = 0.001$) and biomass values ($R = 0.464$, $p = 0.001$). Results based on the abundance SIMPER analysis were that the average dissimilarity between the SW and EP wetland was 96.95%, and the taxa, in order of decreasing importance, which together contributed 65.54% to this difference were *Abra* sp., *Potamocorbula* sp., and *Melanoides tuberculata*. The dissimilarity between the SW and MA wetlands was 91.77%, and the taxa which together contributed 61.49% were *Abra* sp., *M. tuberculata*, and *Potamocorbula* sp. The dissimilarity between the EP and MA wetlands was 96.71%, and the taxa which together contributed 58% were *M. tuberculata*, *Stenothyra* sp., and *Iravadia ornate*.

Since the communities significantly differed among the wetlands, their temporal changes were separately analyzed. Molluscs were not found at the EP wetland in several months; therefore, only molluscs at the SW and MA wetlands were analyzed. At the SW and MA wetlands, the mollusc community compositions did not sharply differ in either seasons or years (two-way ANOSIM, $p > 0.05$). But a significant serial shift occurred at the SW wetland during the 3rd sampling year (RELATE, $p = 0.673$, $p = 0.041$). This serial shift was attributed to an increased abundance of *Potamocorbula* sp. and a decreased abundance of *M. tuberculata* (SIMPER). Temporal distributions of the abundance and biomass of *M. tuberculata* vs. *Potamocorbula* sp. in 2010 at the SW wetland is shown in figure 5.

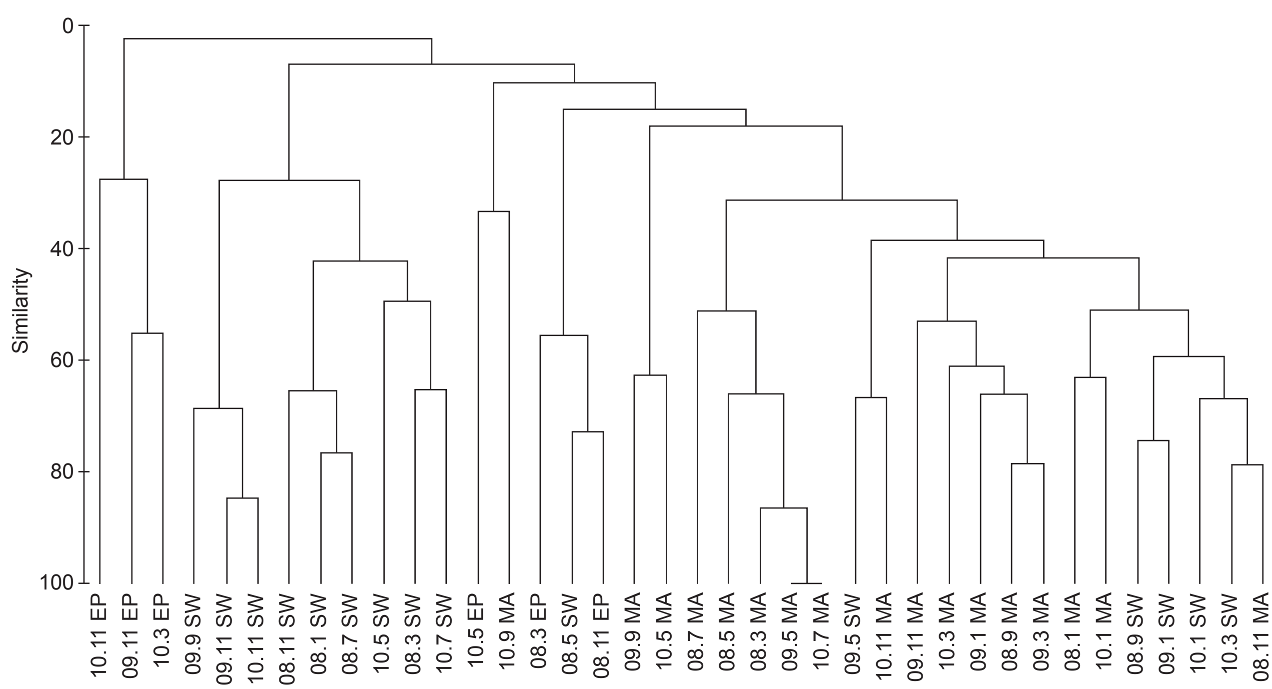

Fig. 3. Bray-Curtis similarity cluster using 3 yr of samples at Qi'ao I. SW, seaweed; EP, emergent plants; MA, mangrove arbor.

Table 4. Molluscan community structures of the 3 types of wetlands at Qi'ao-Dan'gan I., Pearl River estuary

Wetland type	Molluscan community structural parameters				
	Number of species	Abundance (ind./m^2)	*D*	*J'*	*H'*
SW	10	1824	1.20	0.645	2.14
EP	5	112	0.848	0.778	1.81
MA	10	1736	1.21	0.720	2.39

SW, seaweed; EP, emergent plants; MA, mangrove arbor; *D*, Margalef's species richness index; *J'*, Pielou's evenness; *H'* (log 2), Shannon diversity index.

DISCUSSION

In this study, the number of molluscs species was 16, which was lower than that of other mangrove forests reported in the literature. There were 23 species of molluscs in a mangrove area at Daya Bay (Wu et al. 1992), 52 species in a Hong Kong mangrove (Cai et al. 1997), 52 species in a mangrove areas in the estuary of the Jiulong River (Jiang and Li 1995), 20 species in mangrove at Ximen I. (Gao et al. 2005) all in China, 44 species in the Sematan mangrove forest, Sarawak, Malaysia (Ashton et al. 2003), and 47 species in mangroves at 2 sites in the upper Gulf of Thailand (Printrakoon et al. 2008). Although the number of species was less than those in the Jiulong River, China and a northwestern Australian mangrove, the abundance (68 ind./m^2) was higher in the present study (Wells 1984, Jiang and Li 1995). The abundance of molluscs was also higher in the other intertidal areas, for example 224 ind./m^2 in mangrove at Ximen I., China (Gao et al. 2005) and 261 ind./m^2 in mangroves at 2 sites in the upper Gulf of the Thailand (Printrakoon et al. 2008). Similar results were found for the Peracarida in the Pearl River estuary (Wang et al. 2010). Probably

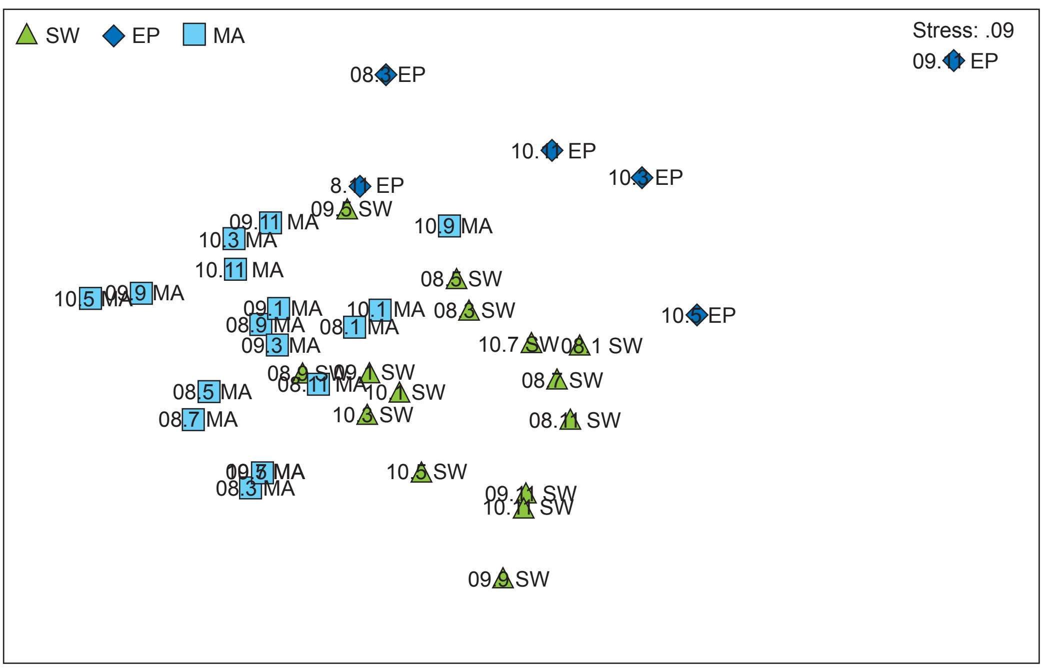

Fig. 4. The MDS ordination based on the abundance of molluscs. SW, seaweed; EP, emergent plants; MA, mangrove arbor.

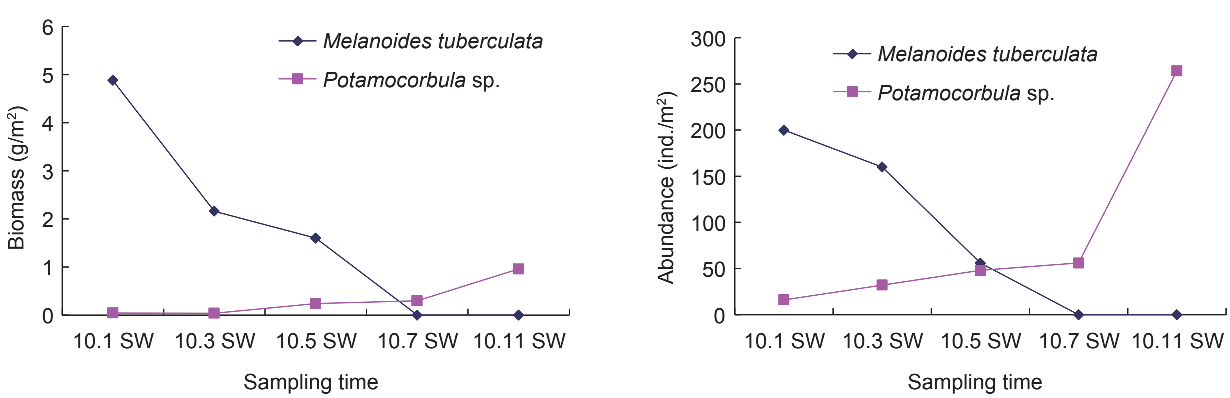

Fig. 5. Temporal distributions of biomass and abundance of *Melanoides tuberculata* vs. *Potamocorbula* sp. in 2010 at the seaweed (SW) wetland.

the lower biodiversity in this study mainly resulted from large amounts of industrial wastewater that is discharged into most rivers and excessive marine aquaculture along the littoral zone in China (Luo et al. 2008b).

The spatial variability was significant among the 3 wetlands. All bivalve species were found at the SW wetland, while gastropod species were distributed at all 3 wetlands. Differences between the SW and other wetland types were mainly caused by bivalve species. Plaziat (1984) found that bivalves were often considered to be confined to a narrow seaward zone, due to restrictions of feeding and larval settlement. In this study, it was probably due to the relationship between molluscs and the sediment texture (Rhoads and Young 1970). Although the sediment texture showed no difference between the SW and EP wetlands, the EP wetland located in the intertidal zone was intermittently flooded by tides. The sampling site experienced the sharpest salinity changes and never sustained a significant bivalve assemblage (Desmond et al. 2002). The reason why bivalves were not present at the MA wetland might have been the lower S-pH. The S-pH was acidic at the MA wetland and alkaline at the SW wetland. A lower S-pH could result in exterior exoskeleton and shell erosion (Ashton et al. 2003). The bivalves collected in this study had thin transparent shells. Another likely reason is that it may be impossible for the soft fleshy feet of infaunal molluscs to penetrate the root masses found at the MA wetland (Wells 1984). All of the bivalves recorded here were infaunal molluscs (Cai et al. 2006). The MA wetland was temporally flooded with tidewater, and bivalves are obviously unable to tolerate long periods of exposure to air and fluctuating salinities (Sasekumer 1974). The conspicuous absence of bivalves from the MA wetland could also have been related to higher S-OM values. Confounding natural variables, especially the organic content, often influence community structures and can mask the effects of low levels of contamination (Gaston et al. 1988, Wilson and Elkaim 1992). The MA wetland is located in the intertidal zone and is intermittently flooded by tides, while the SW wetland is a shallow fish pond which is almost completely closed, so some low levels of contamination not measured may have played a potential role in the absence of bivalves. It would be necessary to conduct a further survey to determine this. Rakocinski et al. (1997) found that dissolved oxygen (DO) had a higher loading on the PCA than salinity, but was not strongly correlated with macrobenthic trophic diversity. They thought that this may indicate a high degree of adaptation of the benthos in the region. In this study, results of the PCA on the environment parameters indicated that S-pH and S-OM had a higher loading on PCA1 than the S-TN, but the S-TN produced the maximum correlations with community compositions. As mentioned above, there was mainly spatial variability in the PCA1 direction, so perhaps molluscs possess strong adaptability in these 3 wetlands.

At the MA and EP wetlands, mollusc community compositions did not significantly differ in either seasons or years. Desmond et al. (2002) found that invertebrates showed little seasonal variation, but a much higher degree of interannual variation. Stream flow and DO were significant predictors of invertebrate assemblages. Irregular disturbances, such as flooding events, had a more-important effect on the invertebrate assemblages than predictable seasonal cues, such as temperature. There was no significant difference in 3 yr in this study. The reason could be that there were no great fluctuations in environmental parameters during these 3 yr. At the SW wetland, a significant serial shift occurred during the 3rd sampling year. This serial shift was attributed to an increased abundance of *Potamocorbula* sp. and a decreased abundance of *M. tuberculata* juveniles. The abundance of *M. tuberculata* reached a maximum in Jan. (the dry season), and then the abundance began to decline until it had disappeared in June (the rainy season). But the abundance of *M. tuberculata* peaked in the rainy season in other studies (Pointier et al. 1993, Nordhaus et al. 2009). Each habitat differs, since many ecological factors may be involved in snail dynamics depending on the type of ecosystems. The SW wetland is a fish pond which was more frequently disturbed by humans, and the dominant vegetation was seaweed that is characterized by many microhabitats and ecological niches. Pointier (1993) found that the dynamics of *M. tuberculata* in cattle-ponds was irregular due to more complex macrophyte associations and more frequent disturbances by man or cattle in the pond.

The abundance of *Potamocorbula* sp. in the 3rd year increased with time and displayed the highest abundance in Nov. Since the measured abiotic factors were not significantly correlated with the abundance of *Potamocorbula* sp., other factors, probably biotic ones, were more important for the distribution of this species. *M. tuberculata* was abundantly found in Jan., Mar., and May in the

3rd year, but the rate of increase of *Potamocorbula* sp. was slower in those same months. So food competition with *M. tuberculata* might have occurred.

CONCLUSIONS

This study provides important baseline information on the structure of molluscan communities in the Qi'ao-Dan'gan I. Mangrove Nature Reserve on Qi'ao I. in the Pearl River Estuary, China. There was a significant spatial variability among the 3 wetlands. Differences in species assemblages among the sites were correlated with environmental parameters. Molluscan community assemblages and their relationships with environmental variables provide important baseline data against which any future anthropogenic impacts might be assessed, and could be useful and sensitive indicators of future environment change. A significant serial shift occurred at the SW wetland during the 3rd sampling year, although there were no significant differences in the mollusc community composition among seasons or years in this study. Since temporal variability was characteristic of benthic assemblages in estuarine sediments in other studies, monitoring over time to assess potential impacts is necessary.

Acknowledgments: The authors sincerely thank graduate students, X. Ye and N. Wei, for their help with collecting specimens. This work was supported by the National Nature Fund of China (U0633002).

REFERENCES

Abbott RT. 1958. The gastropod genus Assiminea in the Philippines. Proc. Acad. Nat. Sci. Phil. **110:** 213-278.

Alongi DM. 1987. Intertidal zonation and seasonality of meiobenthos in tropical mangrove estuaries. Mar. Biol. **95:** 447-458.

Ashton EC, DJ Macintosh, PJ Hogartht. 2003. A baseline study of the diversity and community ecology of crab and molluscan macrofauna in the Sematan mangrove forest, Sarawak, Malaysia. J. Trop. Ecol. **19:** 127-142.

Brandt RAM. 1974. The non-marine aquatic Mollusca of Thailand. Archiv Molluskenkunde Senckenbergischen Naturforschenden Gesellschaft **105:** 1-423.

Cai LZ, YS Wong, NFY Tam. 1997. Ecological studies of Mollusca in mangrove stands in Hong Kong. Stud. Mar. Sin. **39:** 103-114. (in Chinese with English abstract)

Cai YY, SH Xie. 2006. Seashells of Guangdong. China: Shantou Univ. Press. (in Chinese)

Chapman MG. 1998. Relationships between spatial patterns of benthic assemblages in a mangrove forest using different levels of resolution. Mar. Ecol. Prog. Ser. **162:** 71-78.

Chen FR, YQ Yang, DR Zhang, L Zhang. 2006. Heavy metal associated with reduced sulfur in sediments from different deposition environments in the Pearl River estuary, China. Environ. Geochem. Health **28:** 265-272.

Clarke KR, RN Gorley. 2006. PRIMER v6: User Manual/ Tutorial. PRIMER-E Ltd.

Coull BC, JG Greenwood, DR Fielder, BA Coull. 1995. Subtropical Australian juvenile fish eat meiofauna: experiments with winter whiting *Sillago maculata* and observations on other species. Mar. Ecol. Progr. Ser. **125:** 13-19.

Desmond JS, DH Deutschman, JB Zedler. 2002. Spatial and temporal variation in estuarine fish and invertebrate assemblages: analysis of an 11-year data set. Estuaries **25:** 552-569.

Gao AG, QZ Chen, JN Zeng, YB Liao, JY Yang. 2005. Macrofauna community in the mangrove area of Ximen Island, Zhejiang. J. Mar. Sci. **23:** 33-40. (in Chinese with English abstract)

Gaston GR, JC Nasci. 1988. Trophic structure of macrobenthic communities in the Calcasieu Estuary, Louisiana. Estuaries **11:** 192-200.

GB/T 12763.4-2007. 2007. Specifications for oceanographia survey - Part 4: Survey of chemical parameters in sea water. Beijing: Standards Press of China. (in Chinese)

Jiang JX, RG Li. 1995. An ecological study on the Mollusca in mangrove areas in the estuary of the Jiulong River. Hydrobiology **295:** 213-220.

Jones AR. 1987. Temporal patterns in the macrobenthic communities of the Hawkesbury estuary, New South Wales. Aust. J. Mar. Freshw. Res. **38:** 607-624.

Lei ZS, M Li, BW Liao. 2008. Current situation and protection of mangrove wetlands biodiversity on Qi'ao Island, Zhuhai City. Guangdong For. Sci. Technol. **24:** 56-60. (in Chinese with English abstract)

Luo XJ, BX Mai, QS Yang, SJ Chen, EY Zeng. 2008b. Distribution and partition of polycyclic aromatic hydrocarbon in surface water of the Pearl River estuary, South China. Environ. Monit. Assess. **145:** 427-436.

Magni P, S Como, S Montani, H Tsutsumi. 2006. Interlinked temporal changes in environmental conditions, chemical characteristics of sediments and macrofaunal assemblages in an estuarine intertidal sandflat (Seto Inland Sea, Japan). Mar. Biol. **149:** 1185-1197.

Mendes CLT, M Tavares, A Soares-Gomes. 2007. Taxonomic sufficiency for soft-bottom sublittoral mollusks assemblages in a tropical estuary, Guanabara Bay, southeast Brazil. Mar. Pollut. Bull. **54:** 377-384.

Morrisey DJ, AJ Underwood, L Howitt, JS Stark. 1992. Temporal variation in soft sediment benthos. J. Exp. Mar. Biol. Ecol. **164:** 233-245.

Nagelkerken I, SJM Blaber, S Bouillon, P Green, M Haywood, LG Kirton et al. 2008. The habitat function of mangroves for terrestrial and marine fauna: a review. Aquat. Bot. **89:** 155-185.

Nordhaus I, FA Hadipudjana, R Janssen, J Pamungkas. 2009. Spatio-temporal variation of macrobenthic communities in the mangrove-fringed Segara Anakan lagoon, Indonesia, affected by anthropogenic activities. Reg. Environ.

Change **9:** 291-313.
Pace GL. 1973. The freshwater snails of Taiwan (Formosa)[1]. Malacology Review, Supplement 1. Museum of Zoology, University of Michigan Ann Arbor, Michigan, U.S.A., 118 pp.
Plaziat JC. 1984. Mollusc distribution in the mangal. *In* FD Por, I Dor, eds. Hydrobiology of the mangal - ecosystem of the mangrove forests. Developments in Hydrobiology 20. The Hague: Junk Publishers, pp. 111-143.
Pointier JP, A Théron, G Borel. 1993. Ecology of the introduced snail *Melanoides tuberculata* (Gastropoda: Thiaridae) in relation to *Biomphlaria glabrata* in the marshy forest zone of Guadeloupe, French West Indies. J. Moll. Stud. **59:** 421-428.
Ponder WF. 1984. A review of the genera of the Iravadiidae (Gastropoda: Rissoacea) with an assessment of the relationships of the family. Malacology **25:** 21-71.
Printrakoon C, FE Wells, Y Chitramvong. 2008. Distribution of mollusks in mangrove at six sites in the upper gulf of Thailand. Raffles Bull. Zool. **18:** 247-257.
Rakocinski CF, SS Brown, GR Gaston, RW Heard, WW Walker, JK Summers. 1997. Macrobenthic responses to natural and contaminant-related gradients in northern Gulf of Mexico estuaries. Ecol. Appl. **7:** 1278-1298.
Rhoads DC, DK Young. 1970. The influence of deposit-feeding organisms on sediment stability and community trophic structure. J. Mar. Res. **28:** 150-177.
Sasekumar A. 1974. Distribution of macrofauna on a Malayan mangrove shore. J. Anim. Ecol. **43:** 51-69.
Su BZ, WX Li, ZX Lai. 1989. The surveys of benthic fauna in Pearl River (Guangdong). Chin. J. Zool. **24:** 15-19. (in Chinese)
Wang CF, XQ Ren, RL Xu. 2010. Composition, abundance, and diversity of the Peracarida on different vegetation types in the Qi'ao-Dan'gan Island Mangrove Nature Reserve on Qi'ao Island in the Pearl River estuary, China. Zool. Stud. **49:** 608-615.
Wells FE. 1984. Comparative distribution of macromolluscs and macrocrustaceans in a north-western Australian mangrove system. Freshw. Res. **35:** 591-596.
Wilson JG, B Elkaim. 1992. Estuarine bioindicators - a cause for caution. Acta Oecol. **13:** 345-358.
Wu QQ, FW Zheng, L Lu, JX Jiang. 1992. Benthic communities of mangrove area in Daya Bay. J. Oceanogr. Taiwan. Strait **11:** 161-166. (in Chinese with English abstract)
Xu FS, SP Zhang. 2008. An illustrated bivalvia Mollusca fauna of China seas. China: Science Press. (in Chinese)
Yu RQ, GZ Chen, YS Wong, NFY Tam. 1996. Spatial zonation of benthic macrofauna and possible effects of sewage discharge on it in futian mangrove swamp, Shenzhen. Acta Ecol. Sin. **16:** 283-288. (in Chinese with English abstract)
Zhang JH, JJ Zhou, HD Fang. 2009. Characters of macrobenthic community in southeast sea of the Pearl River Estuary. Mar. Sci. Bull. **29:** 26-33. (in Chinese with English abstract)