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Changes of the Macrobenthic Faunal Community with Stand Age of a Non-native Mangrove Species in Futian Mangrove National Nature Reserve, Guangdong, China

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Ya-Fang Li, Fei-Yan Du, Yang-Guang Gu, Jia-Jia Ning, and Liang-Gen Wang (2017) *Sonneratia apetala*, a non-native superior rapidly growing mangrove species with wide environmental tolerance, has been introduced to Futian National Nature Reserve in Shenzhen, Guangdong, China, for mangrove restoration since 1993. However, the community structure of the associated macrobenthic fauna, a vital component of energy flow and nutrient recycling, remains obscure. The present study analyzed the macrobenthic faunal community, associated habitat characteristics and physico-chemical properties of sediment in rehabilitated *S. apetala* forests at stand ages of 8, 9, 14, 16 and 20 years from November 2014 to May 2015. Habitat complexity and stand structural heterogeneity varied with stand age. Sediment physico-chemical properties were similar for all stands analyzed, although soil organic matter (SOM) content was significantly higher in the 20-year-old stand than in others. Shannon-Weaver (*H'*) and Pielou's evenness (*J*) indices of macrobenthic fauna were highest in 14- and 16-year-old stands, respectively, and lowest in 8-year-old stands. In contrast, abundance and biomass peaked in 8-year-old stands and were lowest in 16-year-old stands. Multivariate analysis (cluster, ANOSIM and SIMPER) showed that the macrobenthic faunal community in the 20-year-old stand was different from other stand ages because of a greater abundance of small-sized mollusks and opportunistic species. Spearman correlation analysis showed that *H'* was positively correlated with salinity. The distance-based linear model suggested that SOM was a significant predictor variable correlated with the macrobenthic faunal community. However, SOM was the only significant predictor variable explaining 12.7% of the total variation; this implies that the spatial variation of the macrobenthic faunal community here was mostly independent of the sediment properties measured. Therefore, we conclude that habitat characteristics such as vegetation characteristics can potentially explain the majority of the variation.

Key words: Stand age, Habitat characteristics, Macrobenthic faunal community, Sediment physico-chemical properties, *Sonneratia apetala*.

BACKGROUND

Mangroves serve as unique and vital ecosystems bridging the land and sea in tropical and subtropical coastal regions (Alongi 2008; Barbier et al. 2008; Morrisey et al. 2003), playing an important role worldwide. These ecosystems provide diverse ecological benefits including promoting biodiversity by offering habitats for coastal animals and birds, while protecting coastlines against disturbance, such as cyclones, tsunamis and water pollution (Luo et al. 2010).

Despite their unique properties and ecological functions, mangrove ecosystems around the world risk being destroyed. During the last few decades, the population boom and rapid economic development in agriculture, aquaculture, industry and urban construction has greatly reduced

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the spatial extent of China's mangrove forests (Chen et al. 2009a). In 1983, the United Nations Development Program and the Environment, Scientific, and Community Organization established a regional project concerned with the value of mangrove ecosystems in Asia and the Pacific; many countries have made considerable effort to restore mangroves (Bosire et al. 2008). The Chinese government has also made great efforts in mangrove reforestation since the early 1990s (Zheng et al. 2003). Because *Sonneratia apetala* from Bangladesh is a fast-growing species with a wide range of environmental tolerance, it has been planted in many locations along the coastline of Southern China, especially in Guangdong Province, even though the invasiveness of this non-native species has not been adequately analyzed (An et al. 2007; Tang et al. 2007; Chen et al. 2009a). Since 1993, as the pioneer species, *S. apetala* has been introduced to Futian National Nature Reserve in Shenzhen, which is the only mangrove forest located in the heart of a major urban area in China and is moderately contaminated with heavy metals. The wastewater discharge from the nearby electroplate factories and electronic instrument factories could be important pollution sources (Wang et al. 2013). As mangrove plants have relatively high heavy metal tolerance following the propagule stage, this species has rapidly become established and there are now forests of different ages up to 20 years.

Lewis (2000) noted that ecosystem restoration should be used to replace persistent vegetative cover, a basic goal of mangrove rehabilitation programs. Macrobenthic fauna represent an important group in a mangrove ecosystem and strongly influence energy flow (Nordhaus et al. 2009). They form an important link between the primary detritus at the base of the food web and consumers of higher trophic levels (Macintosh 1984). In addition, some crabs graze on the propagules of mangrove plants, reducing the competition among seedlings and perhaps enhancing tree growth (Smith et al. 1991). Macrobenthic fauna are also sensitive to anthropogenic contamination; therefore, they can be useful indicator species for changes in ecosystem function (Lui et al. 2002). The recruitment of benthic fauna is one of the main criteria for judging the success of mangrove restoration programs (Field 1998). However, few studies have investigated the nature of the ecology of benthic fauna during rehabilitation of Futian mangroves, while most studies over the past two decades have focused mainly on productivity, seed dispersal and germination rates, litter dynamics, ecological assessment and leaf photosynthetic regimes in these planted forests (Zan et al. 2001, 2002; Chen et al. 2001, 2008, 2009b). Yang et al. (2014) conducted the only study in this region on the microbial community at different stand ages. However, the macrobenthic community structure and its changes with forest age is unknown. Information from these type of studies could provide essential information for improving the conservation and management of the Nature Reserve.

It is; therefore, intriguing to determine how this non-native mangrove rehabilitation project affects the macrobenthic faunal community. The present study attempted to make this determination by analyzing the macrobenthic faunal community and environmental variables, including the physico-chemical properties of sediment and the characteristics of vegetation at different stand age. The findings will provide insight into how the plantation of mangroves influences the macrobenthic faunal community.

MATERIALS AND METHODS

Study area and sampling sites

The study was conducted in the Futian National Reserve (22°30'-22°32'N and 113°56'-114°03'E), located in northern Shenzhen Bay, which is the only mangrove forest located in the heart of a major urban area in Guangdong, China. This nature reserve features a subtropical monsoon climate, with a mean annual rainfall of about 1926 mm and a mean temperature of 22.2°C (Meteorological Bureau of Shenzhen Municipality: http://www.szmb.gov.cn/). This mangrove swamp, the sixth largest in China, covers 23.9 hm^2 planted mangrove, including two non-native species, *S. apetala* and *Sonneratia caseolaris*, and 56.2 hm^2 natural mangrove (Mao et al. 2012). In view of planting history, the sampling sites employed here were 8, 9, 14, 16, and 20 years old with plantation forests of *S. apetala* (abbreviated as SA08, SA09, SA14, SA16 and SA20) (Fig. 1), which were all within the same geographical location (according to the Guangdong Neilingding Futian National Nature Reserve Administration).

Investigation of floral characteristics

In November 2014, a 10 m × 10 m quadrat was randomly established in each of five sites. Parameters related to plant characteristics, including the density, height and diameter at breast height (DBH; ca. 1.5 m above ground) of mature individuals and seedlings of each mangrove species, were determined by the standard methods for plant analysis (HY/T, 081-2005) (Appendix 1). The vertical structure of the community was analyzed by Liu et al. (2016). The canopy

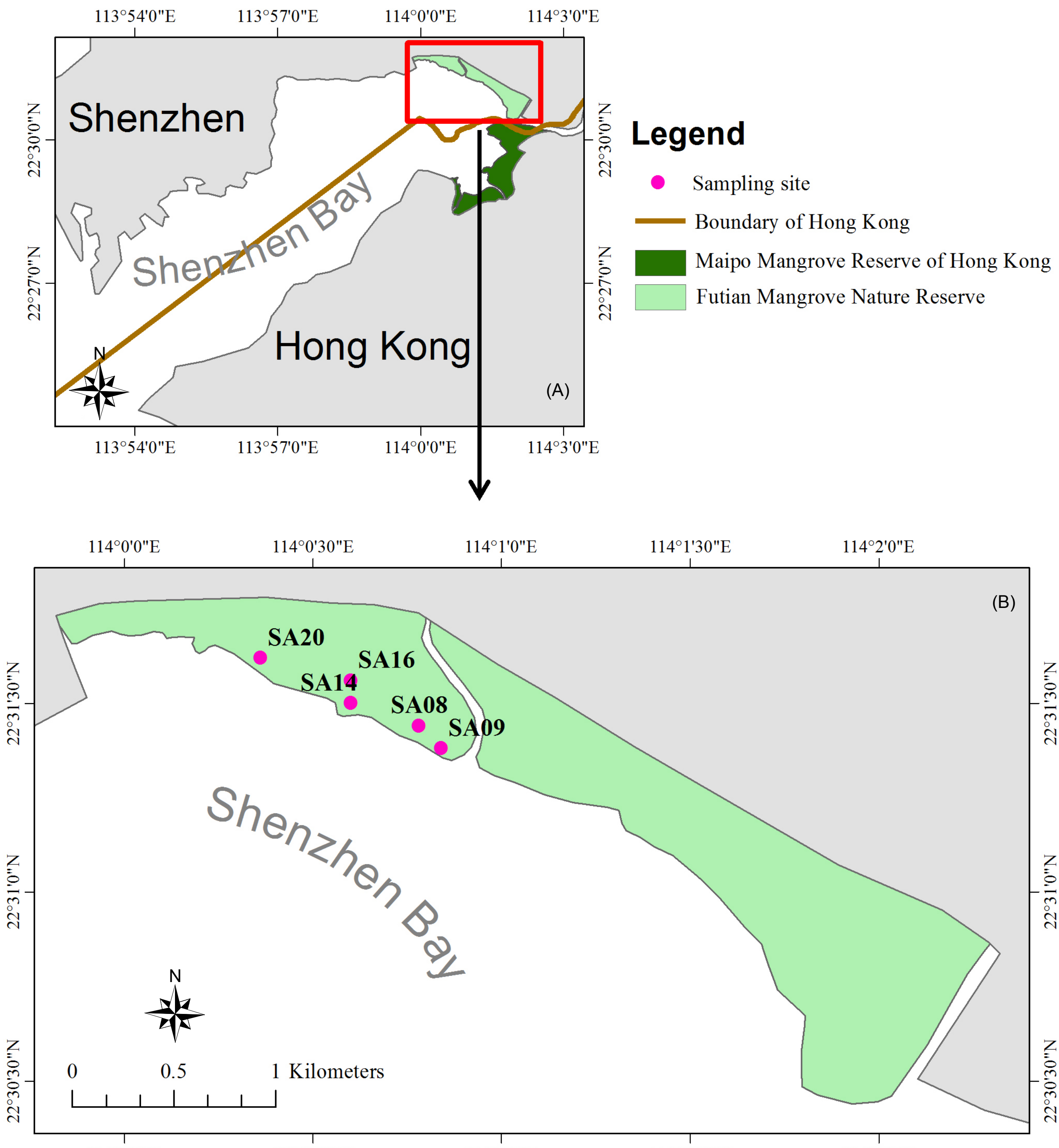

Fig. 1. Locations of the sampling sites in the present study. (A) Vicinity map showing the locations of Shenzhen Bay, Hong Kong, and Shenzhen; (B) site locations in northeastern Shenzhen Bay; SA = *S. apetala*. The numbers in SA08, SA09, SA14, SA16, and SA20 represent different numbers of years since rehabilitation.

coverage of vegetation type was estimated at noon on a sunny day by the decreased percentage of light intensity in the mangrove stands compared with that in the open sunshine.

Collection and treatment of sediment samples for macrobenthic faunal community analysis

In November 2014, and in February and May 2015, the macroinvertebrate fauna were collected from three 50 cm × 50 cm × 30 cm (length × width × depth) blocks of sediment at random locations in each plot. Initially, a steel frame was pressed into sediment to isolate the sample on the surface and prevent crabs from escaping during the excavation. Excavated samples were washed and sieved over a 0.5-mm mesh (Appendix 2). The collected fauna were temporarily preserved in 4% borax-buffered formalin before being identified and weighed. Above-ground gastropods were collected by hand from three replicates of 1 m^2 quadrats randomly placed around the selected trees at each sampling plot. Some species, such as *Neritina violacea*, live within the prop roots of *S. apetala*; therefore, prop root gaps near the ground were checked carefully during collection. In the laboratory, all the fauna samples were sorted to species, and the biomass (fresh weights) and the number of each species was enumerated.

Collection and treatment of sediment samples for sediment property analysis

Five repeats in each sampling site were sampled using diagonal sampling from a single random point, and the soil in the upper 0-30 cm layer was excavated and mixed thoroughly; then, about 1 kg of each mixed soil sample was taken for analysis. The collected sediment samples were then homogenized, air-dried at room temperature, ground into powder and finally sieved through a 2-mm sieve for the subsequent analyses.

Analyses of physico-chemical properties of sediment

The particle size was determined by a particle size analyzer (Mastersizer 2000G Laser Diffraction Particle Analyzer, Malvern Instruments Ltd., UK) with a detection range of 0.02-2000 μm. The pH was measured by mixing 1 g dried sediment sample with 5 ml deionized water in a glass vial using a pH meter (EcoSense pH10A, Forestry Suppliers Inc., USA). Total nitrogen (TN) and carbon (C):N were determined by an elemental analyzer (Vario EL III, Elementar Analysensysteme GmbH, Germany). The salinity of sediment interstitial water was measured with a portable pH meter (Portable refractometer salinometer WYY-II, Chengdu Hao Chuang Photoelectric Instrument Co., Ltd, Chengdu). Total phosphorus (TP) was extracted by the standards measurements and testing (SMT) method (González et al. 2005). Sediment organic matter (SOM) content and Cd, Pb, Cr, Ni, Cu and Zn concentrations were measured based on the methods described by Gu et al. (2014).

Statistical analysis

Two diversity indices, Shannon-Weaver (*H'*, base2 logarithm) and Pielou's evenness (*J'*), were calculated for each macrobenthic faunal sample. One-way analysis of variance was used to test the differences in sediment physico-chemical properties between sites and seasons. Spearman's correlation analysis was applied to examine the relationships between the univariate parameters of macrobenthic fauna and sediment properties. For multivariate analyses, the abundance data were first square-root transformed to down-weigh the very abundant species. The Bray-Curtis similarity coefficient for hierarchical cluster analysis was used to determine the similarity of macrobenthic fauna among sites. Similarity percentages (SIMPER) analysis was applied to determine the major species leading to the differences in community structure between sites. The best distance-based linear model (DistLM) using an Akaike information criterion (AIC) selection method was employed to select the predictor variables that could significantly explain the variation in the macrobenthic faunal community. The predictor variables used in the DistLM included Cd, Pb, Cr, Ni, Cu, Zn, TN, TP, C:N, SOM, pH and particle size in terms of sand, silt and clay fraction. Distance-based redundancy analysis (dbRDA) was used to provide a visual representation of the macrobenthic faunal community fitted to the significant predictor variables. All of the aforesaid analyses were performed using PRIMER 6 with the PERMANOVA + add-on, with the exception of correlation analysis that were performed using SPSS 19.0 for Windows.

RESULTS

Floral characteristics at different stand ages

The floral characteristics analyzed here included vertical structure, individual density, average plant height, DBH, number of seedlings and branches per tree for five stand ages (Table 1). Five mangrove species, namely *S. apetala*, *S. caseolaris*, *Kandelia candel*, *Aegiceras corniculatum* and *Acanthus ilicifolius*, were found in this study area. Vertical structure of the community developed from simple to complex with stand age. SA08 comprised 4 mangrove species, including a tree layer (> 7 m) and a sapling layer (< 1.3 m). The tree layer consisted of only one species, *S. apetala*, while the sapling layer comprised *A. ilicifolius*, *K. candel* and *Ae. corniculatum.* SA09 included a tree layer, a sapling-shrub layer (1.3-2.5 m) and a sapling layer, comprising *S. apetala*, *K. candel*, *A. ilicifolius*, and *Ae. corniculatum*, respectively. SA14 was similar to SA09, except that the tree layer consisted of *S. apetala* and *S. caseolaris*. The tree layer in SA16 was the same as that in SA14, but *A. ilicifolius* replaced *K. candel* in the sapling-shrub layer and the sapling layer comprised *K. candel* and *Ae. corniculatum.* SA20 possessed the most complex vertical community structure, including two tree layers, an upper tree layer (> 7 m) and a secondary tree layer (2.5-7 m); the upper tree layer was *S. apetala* and the secondary tree layer was *K. candel*. The sapling-shrub layers were *Ae. corniculatum* and *A. ilicifolius*. Because of the density of *A. ilicifolius* (> 100 ind./m^2), the sapling layer was not counted. The highest average plant height and DBH occurred in SA16 and the lowest were in SA14 and SA09, respectively. The highest number of branches were in SA20, and the lowest were in SA14.

Sediment physico-chemical properties at different stand ages

Because particle size of the sediment is persistent through time (Chapman and Tolhurst 2007), only the samples collected in November 2014 were analyzed for particle size. All sediments

Table 1. Floral characteristics in the different stand ages of *S. apetala* in the Futian Mangrove National Nature Reserve in November 2014. DBH, diameter at breast height; DGH, diameter at ground height (used only for *Acanthus ilicifolius* because it is shorter than 1.5 m)

site	mangrove species	Number of mature plants per 100 m^2	Average height (m)[a]	DBH or DGH (cm)	Number of seedlings per 100 m^2	Number of branches per tree
SA08	*Sonneratia apetala*	67	9	30.3	39	1.3
	Acanthus ilicifolius	67	1	1.3	0	
	Kandelia candel				26	
	Aegiceras corniculatum				2	
SA09	*Sonneratia apetala*	27	10.6	33.9	11	1.4
	Kandelia candel	13	1.3	7.6	47	
	Acanthus ilicifolius	68	1	1.3		
	Aegiceras corniculatum				15	
SA14	*Sonneratia apetala*	33	7.7	32.9	6	1.2
	Sonneratia caseolaris	3	12.3	50.2	0	1.3
	Kandelia candel	2	1.4		1	
	Acanthus ilicifolius	109	1	1.3	0	
	Aegiceras corniculatum				2	
SA16	*Sonneratia apetala*	13	10.9	52.7	0	1.5
	Sonneratia caseolaris	7	12	51.5	0	1.1
	Acanthus ilicifolius	400	1.5	1.3	0	
	Kandelia candel				16	
	Aegiceras corniculatum				3	
SA20	*Sonneratia apetala*	24	9.5	40.1	9	1.7
	Kandelia candel	2	2.5	15.5	3	1
	Aegiceras corniculatum	1	2	7.3	22	1
	Acanthus ilicifolius	10000	1.5	1.3	0	

collected in the five different stand ages were clay-silt. The other physico-chemical properties of sediments are provided in figure 2. The sediment in the five sites were slightly acidic (pH < 7), except for SA16 in May 2015, which had the highest value (pH = 7.24); SA08 had the lowest pH. Generally, the spatial and temporal variations in pH were not obvious. The sediments were rich in SOM (6.95-13.49%) and this increased with stand age. Although the spatial variation was not remarkable, SA20 had significantly higher SOM content than the other sites ($p < 0.05$). Temporally, SOM content in sediment varied significantly ($p < 0.05$), with the lowest SOM content observed in May 2015. Similar to SOM, TN and C:N showed significant temporal differences, and the spatial variations in TN and C:N were not obvious except that high TN content and low C:N occurred in the older stand ages. Likewise, TP did not show any obvious spatial or temporal variations. Salinity varied temporally, with the lowest salinity concentrations observed in May. Heavy metal content did not vary significantly either spatially or temporally, except for Pb (Appendix 3).

Macrobenthic faunal community at different stand ages

At the five sites surveyed, a total of 35 taxa of macrobenthos were collected belonging to 5 phyla, 6 classes and 27 families (Appendix 4). The phylum Mollusca was the most diverse, composed of 16 species and accounting for 45.7% of the total number of species. The abundance, biomass and three diversity indices of macrobenthic fauna at different stand ages in the Futian mangrove swamp are shown in figure 3. Spatially, *H'* and *J* indices ranged from 0.69 to 2.85 and 0.21 to 0.95, respectively, and were highest in SA14 and SA16, respectively, and lowest in SA08. In contrast, the abundance and biomass of macrobenthic fauna were highest in SA08 and lowest in SA16. Temporally, the *H'* and *J* indices were highest in February 2015 and lowest in May; however, the abundance and biomass were highest in May 2015 and lowest in November 2014.

Cluster analysis depicted the spatial and temporal variations of the macrobenthic faunal community (Fig. 4). Spatially, the macrobenthic faunal community in SA20 differed from the stands with other ages except SA08 in May 2015. No significant difference was observed in the macrobenthic faunal community in the other four ages within each sampling time. Results of the ANOSIM also indicated that significant differences existed in the macrobenthic faunal community among SA20 and other stand ages ($R = 0.508$, $p = 0.002$). Temporally, the samples in May 2015 of SA08 and SA20 differed from those at the other sampling times. Based on SIMPER analysis

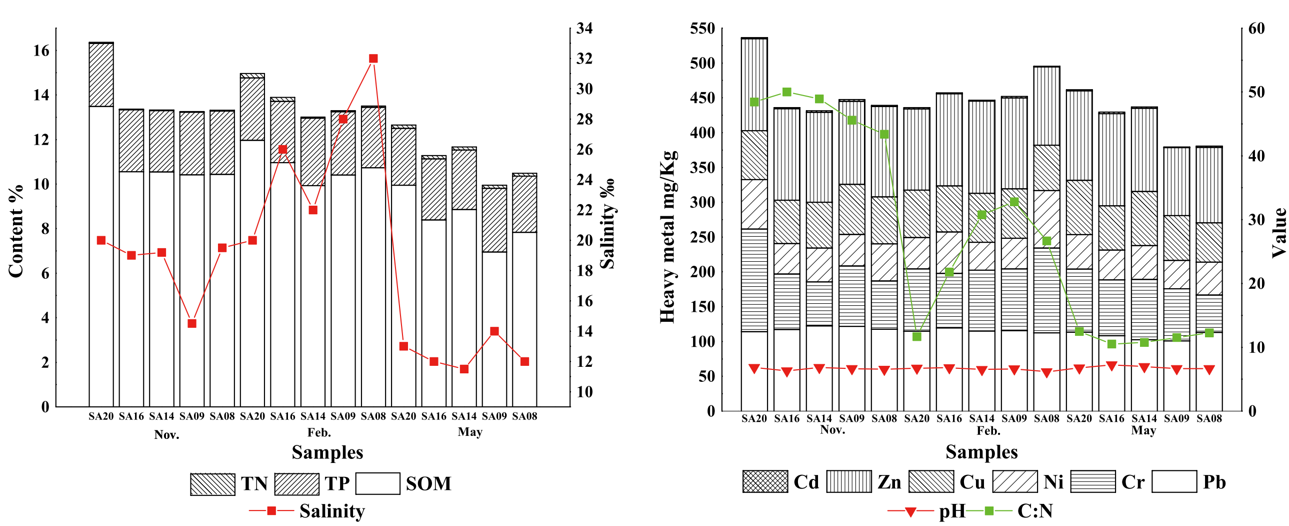

Fig. 2. Spatial and temporal variations of different physico-chemical properties of sediment. The numbers in SA08, SA09, SA14, SA16, and SA20 represent different numbers of years since rehabilitation. TN (%) = total sediment nitrogen content, TP (%) = total sediment phosphorus content, SOM (%) = sediment organic matter content, Salinity (‰) = the salinity content of sediment interstitial water, Cd (mg kg-1) = total sediment Cd content, Zn (mg kg^{-1}) = total sediment Zn content, Cu (mg kg^{-1}) = total sediment Cu content, Ni (mg kg^{-1}) = total sediment Ni content, Cr (mg kg^{-1}) = total sediment Cr content, Pb (mg kg^{-1}) = total sediment Pb content, pH, C:N = the ratio of TC and TN.

(Table 2), a higher abundance of *Leamodonda punctigera*, *Capitella capitata*, *Assiminea* sp., *Stenothyra* sp., *Iravadia cochinchinensis* and *Assiminea brevicula* in SA20 made the macrobenthic faunal community different from that in the other stand ages. In contrast, *Ilyoplax dentimerosa* was more dominant in the other four stand ages when compared with SA20. Comparing

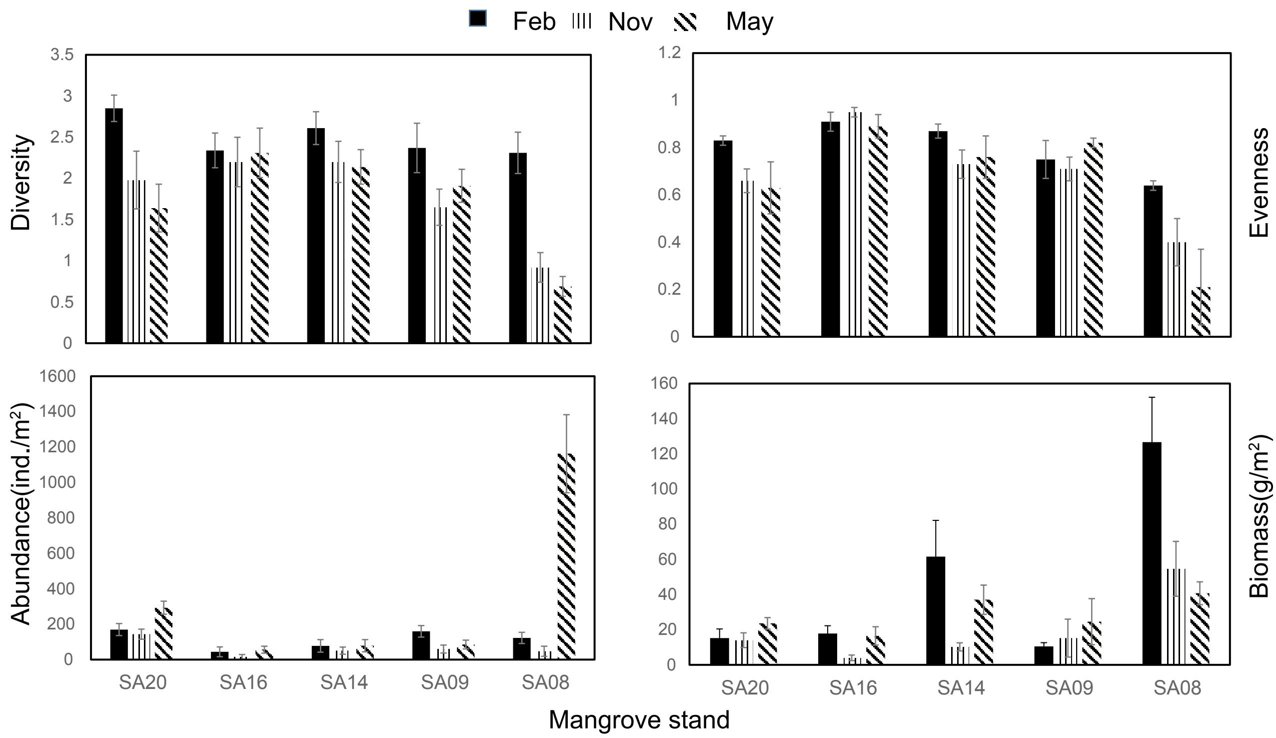

Fig. 3. Spatial and temporal variations of Diversity, Evenness, Abundance and Biomass. SA08, SA09, SA14, SA16, and SA20 represent different site names in figure 1, with the numbers representing years since rehabilitation.

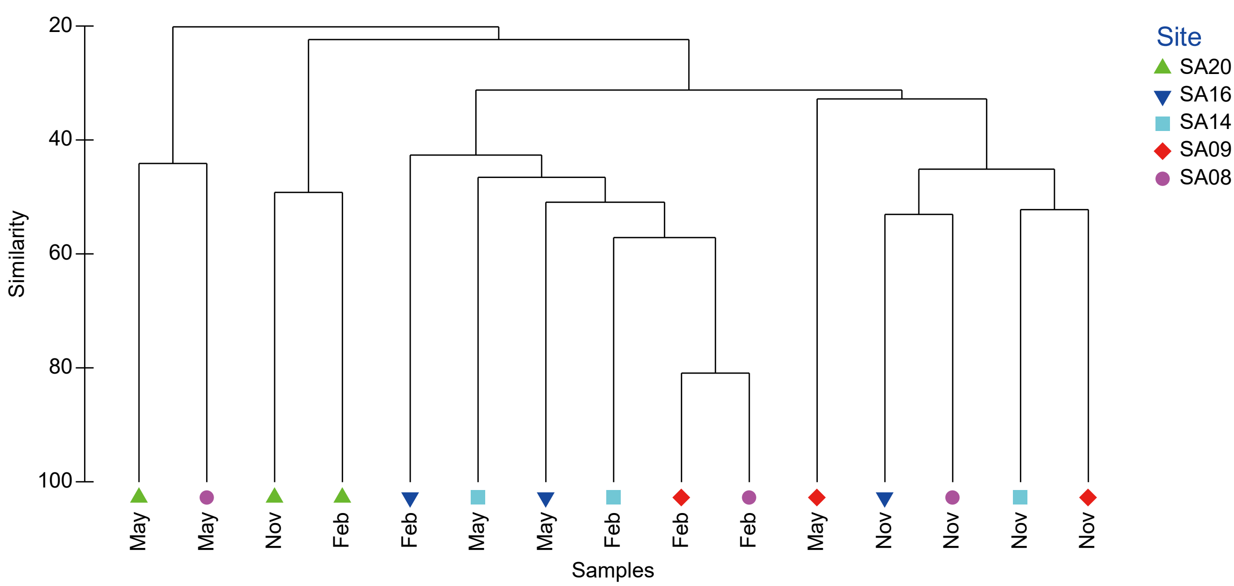

Fig. 4. Dendrogram of hierarchical cluster analysis based on the square-root abundance data delineating the similarity of community structure among sampling sites at different sampling times. SA08, SA09, SA14, SA16, and SA20 represent different site names in figure 1, with the numbers representing years since rehabilitation.

the macrobenthic faunal community between the May samples from SA20, SA08 and the other samples, the polychaetes *Neanthes glandicincta* were more abundant in SA20 and SA08 in May 2015.

Relationships between macrobenthic faunal community and sediment properties

The Spearman's correlation coefficients of the *H'*, *J*, abundance and biomass of the macrobenthic faunal community with the physico-chemical properties of the sediment are shown in table 3. *H'* was positively correlated with salinity. *J* was negatively correlated with Ni. The dbRDA plot, which fitted the macrobenthic faunal community to the significant predictor variables using DistLM, is shown in figure 5. AIC selection of the predictor variables revealed that SOM, C:N, TP, Cu, TN, Pb, Ni, Zn, pH, Cd and Cr were the best combination of predictor variables, explaining 12.7%, 8.6%, 8.9%, 8.1%, 8.3%, 8.2%, 6.0%, 5.5%, 6.4%, 8.8% and 4.9% of total variation, respectively. From the plot, the macrobenthic faunal community in SA20 was different from that at other stand ages because of the high SOM and C:N values. Nevertheless, only one sediment property (SOM) was significant, and it explained 12.7% of the total variation, implying that the spatial variation of the macrobenthic faunal community in the reserve was independent of the sediment properties measured.

Table 2. Similarity percentages analysis (SIMPER) indicating species leading to the difference in community structure between the 20-year-old stand (Site SA20) and stands with younger ages based on the square-root abundance data. Cum. %: Cumulative percentage

species	Stand SA20 Average Abundance	Younger stands Average Abundance	Contribution %	Cum.%
Neanthes glandicincta	63.96	87.95	25.84	25.84
Leamodonda punctigera	39.10	0.00	19.04	44.88
Ilyoplax dentimerosa	14.21	27.06	9.72	54.61
Capitella capitata	15.99	6.88	8.05	62.66
Assiminea sp.	11.11	1.55	5.40	68.06
Stenothyra sp.	11.55	0.78	5.22	73.28
Iravadia cochinchinensis	11.11	0.56	5.17	78.45
Laonome albicingillum	3.55	8.22	3.03	81.48
Assiminea brevicula	5.33	2.89	3.59	85.07

Table 3. Spearman correlation coefficients of the Shannon-Weaver (*H'*), Pielou's evenness (*J*), abundance and biomass of macrobenthic fauna with physicochemical properties of sediment (n = 15)

	Abundance	biomass	*H'*	*J*
Cd	-0.107	-0.189	0.029	0.061
Pb	-0.500	-0.318	0.118	0.061
Cr	0.443	0.025	0.371	-0.032
Ni	0.057	0.139	-0.243	-0.227*
Zn	-0.500	-0.157	0.389	0.486
Cu	0.243	0.111	0.057	-0.171
pH	0.013	-0.175	-0.041	0.138
TC	0.307	-0.229	0.264	0.136
TN	0.381	0.281	0.272	0.209
TP	-0.231	-0.240	0.254	0.252
C:N	-0.375	-0.450	-0.057	-0.114
SOM	-0.181	-0.273	0.359	0.061
Salinity	-0.068	0.000	0.619*	0.097

*$P < 0.05$.

DISCUSSION

Effect of sediment properties and habitat structures on the macrobenthic faunal community

In the present study, there was limited spatial variation of the sediment properties, except for SOM. The SOM increased with stand age; the SOM content in SA20 was significantly higher than in the other stand ages. The increase in SOM might be a result of the high productivity of these stands (Han et al. 2003; Yang et al. 2014; Tam et al. 1998). Additionally, the number and size of prop roots and pneumatophores increased with stand age, which could help the plants trap detritus and increase the amount of litter in the soil (Jonathan 2013). This was especially true for SA20, which contained abundant *A. ilicifolius* plants at densities that reached 100 individuals ind./m^2. Regarding the temporal variation of the environmental factors, the exceptionally low concentrations of salinity and SOM in May were probably attributable to the different rainfall among months. Rainfall peaked in May (303.4 mm; Meteorological Bureau of Shenzhen Municipality: http://www.szmb.gov.cn/), concurrently with the lowest salinity and SOM (Dittmann et al. 2015).

The responses of macrobenthic fauna to sediment properties were analyzed by Spearman correlation analysis and distance-based linear model (DistLM). The results showed that SOM was the best explanatory variable of the community structure of macrobenthic fauna; the abundance and biomass decreased with increasing SOM. Generally, high SOM represents an abundance of food resources, facilitating the growth and reproduction of macrobenthos. However, excessive organic matter might lead to reductions in species diversity and the proliferation of opportunistic species as a result of oxygen depletion and a buildup of toxic by-products (ammonia and sulfide) associated with the decomposition of these materials (Magni et al. 2015). The high SOM in SA20 explained the high abundance of opportunistic species such as *C. capitata* that occurred at this site based on SIMPER analysis. Ryu et al. (2011) found that organic enrichment selectively eliminated large-sized species resulting in the dominance of small-sized species in

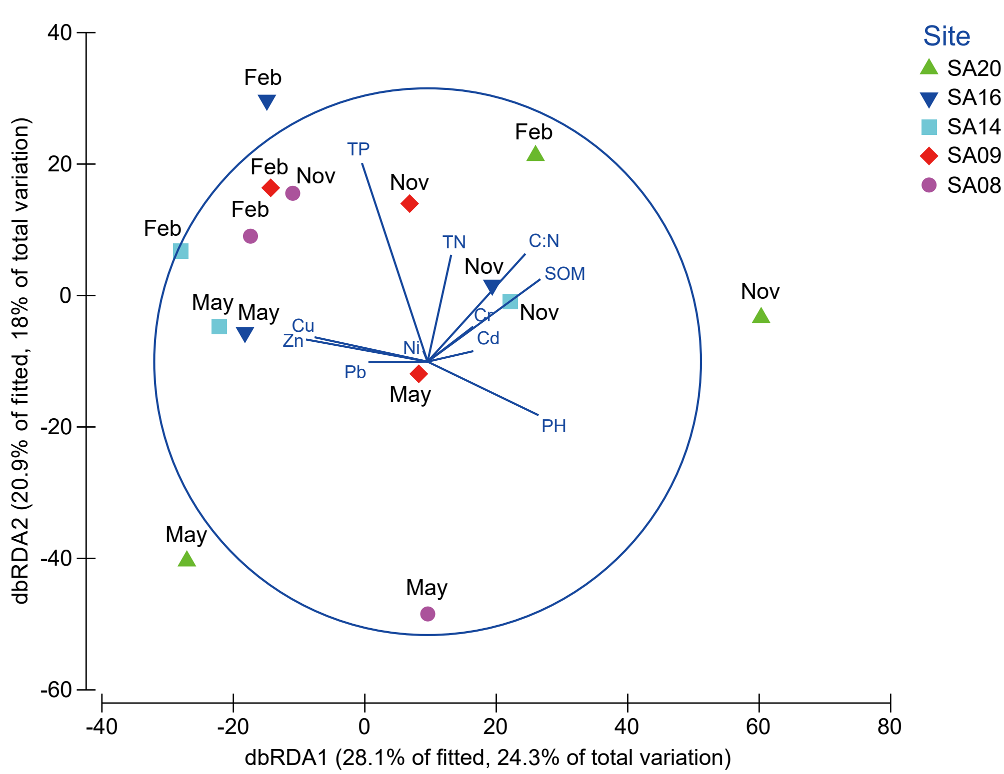

Fig. 5. dbRDA plot of macrobenthic faunal community fitted to significant predictor variables using BEST DistLM selection procedure and AIC selection criterion. SA08, SA09, SA14, SA16, and SA20 represent different site names in figure 1, with the numbers representing years since rehabilitation.

mangroves; however, the mechanism involved remains unclear. Based on SIMPER analysis, small-sized mollusks such as *L. punctigera*, *I. cochinchinensis*, *Stenothyra* sp. and *Assiminea* sp., with the exception of the opportunistic *C. capitata*, were dominant in SA20. Furthermore, the high productivity of mangroves serves as an important source of SOM (Han et al. 2003; Yang et al. 2014; Tam et al. 1998). This might also be associated with a high concentration of tannins, which could trigger a decline in abundance and hinder macrobenthos colonization in mangroves (Lee 1999; Ellis et al. 2004; Shen et al. 2010). It is well known that high concentrations of heavy metals in the sediment can also lead to an unhealthy macrobenthic faunal community characterized by low diversity (Hyland et al. 2000). Although no significant positive correlations between macrobenthic faunal community and heavy metal concentrations were found in this study, high diversity occurred at the site with high heavy metal concentrations, which was inconsistent with other studies (Cai et al. 2000; Shen et al. 2010; Leung and Tam 2013). Li (2008) concluded that the heavy metals existed with high percentages of stable organic matter-sulfide bound fraction because of the high content of organic matter and sulfide in mangroves of China. Therefore, the toxicity of heavy metals was effectively reduced. Chai et al. (2015) also found that taking into account the TOC concentration, there were no adverse effects because of heavy metals in any of the Futian mangrove forest sediments. In addition, salinity can apparently affect the occurrence and distribution of taxa as well as the abundance and biomass of benthic fauna (Dittmann et al. 2015). Nereididae were more prominent and dominant in benthic communities with low salinities (Mariano and Barros 2015). The present study showed that salinity was positively correlated with *H'*. Salinity and SOM were significantly lower in May 2015 than in the other two months because of the heavy rainfall in this period. Hyland et al. (2005) found that excessive organic matter inhibited some species. The SOM content might not have been high enough to limit the distribution of Annelida in May 2015. The patchy distribution is a common phenomenon of these species in breeding season (Sun et al. 2004). So, *N. glandicincta* aggregated in SA08 and SA20, with the highest abundance reaching 1055 ind./m^2. Because of the spatial competition, the dominant worm species was *Laonome albicingillum* in the other sites and the abundance in May 2015 was significantly higher than in the other two months. *H'* emphasizes both the species richness and the equitability components; the high dominance of one single species could lead to a decrease in *H'* (Li et al. 2012). Therefore, *H'* was lower in May, especially in SA08, which was dominated by *N. glandicincta*. Nevertheless, DistLM suggested that the sediment properties could explain only about 40% of the variation in the macrobenthic faunal community in the present study.

Habitat characteristics such as habitat complexity and heterogeneity can have stronger effects than sediment properties on the macrobenthic faunal community on a small spatial scale (Chen et al. 2015), which was demonstrated in previous studies (Chen et al. 2007; Leung and Tam 2013; Yang et al. 2014; Leung 2015a). In this study, the infauna annelids (*N. glandicincta*) were more dominated in the younger stand ages, the increased complexity of roots might reduce the penetrability of the sediment, making it difficult for macrobenthos (especially annelids) to create burrows (Leung 2015a). Furthermore, complex mangrove roots could reduce the velocity of tidal waves, protecting the small gastropods from being washed away (Chen et al. 2007). In addition, more complex mangrove roots could encumber larval dispersal and settlement (Leung 2015b). As a result, small-sized species with direct larval development, such as small gastropods, dominated in SA20 while the populations of *L. punctigera*, *Assiminea* sp., *Stenothyra* sp., *I. cochinchinensis*, *A. brevicula* were also high in SA20 (SIMPER). The results of SIMPER analysis also found that the ocypodid crab *I. dentimerosa* was more abundant in younger stands, a finding that was consistent with Macintosh et al. (2002) and Chen et al. (2007). Choi et al. (2011), using remote sensing and GIS, found that *I. dentimerosa* occurred in areas with a relatively long above-water exposure time. Koo et al. (2005) found that exposure time was one of the main factors affecting the temperature conditions of benthic habitat. In this study, all the study sites were located in the same intertidal zone, so the temperature of the benthic habitat was mainly affected by the penetration of light, which was directly determined by the crown breath and canopy density. In this study, the abundance of *A. ilicifolius* in SA20 reached 100 ind./m^2, reflecting the highest canopy observed at this site. Thus, the canopy density was another factor that affected the distribution of macrobenthos.

Future research directions and management strategy of *S. apetala*

As a non-native species, the invasiveness of *S. apetala* has not been adequately analyzed. Some studies found that this non-native species possessed the characteristics of invasive plants (Chit and Corlett 2002); however, Zhou et al. (2015) believed that *S. apetala* could be used to control *Spartina alterniflora* invasion and promote mangrove restoration, and that this species did not possess invasive characteristics. In addition, it was shown that exotic species invaded the local ecosystem through the food web (Ehrenfeld 2010). Studies on the structure of food webs can be carried out from the following two aspects: community structure and trophic structure. In this study, we studied the changes in the macrobenthic faunal community with stand age of this non-native mangrove species; further investigations are still required to investigate the changes in trophic structure and the differences of the benthic food web between the native and non-native mangrove to provide more information on the invasiveness of *S. apetala*. Considering the uncertainty around the invasiveness of this species, stringent monitoring and control of *S. apetala* should still be undertaken to preclude the potential spread of *S. apetala* so that the integrity of the mangrove ecosystem can be maintained.

CONCLUSIONS

From this study, we concluded that the changes in the macrobenthic faunal community with stand age were mainly associated with changes in the vegetation (mainly habitat complexity and heterogeneity and mangrove tree crown breadth) and sediment physico-chemical properties (mainly organic matter content). SA08, SA09, SA14 and SA16 possessed similar macrobenthic faunal community structure; however, SA20 had a different macrobenthic faunal community structure from the other stand ages. Therefore, we infer that 20 years of rehabilitation might be an important turning point. In view of the importance of the macrobenthic faunal community for the management and restoration of mangrove forest, the long-term performance of benthic fauna in the artificially planted forest is essential.

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Appendix 1. The field investigation of vegetation chacteristics (download)
Appendix 2. The washing of the excavated samples for macroinvertebrate infauna and the collection of the above-ground gastropods (download)
Appendix 3. PERMANOVA table showing the spatial and temporal varations in abiotic variables (download)
Appendix 4. List of macrobenthic fauna collected in different stand ages of *S. apetala* (SA) in Futian Mangrove National Nature Reserve throughout the study period. The presence of a species is shown by a “+”, 08, 09, 14, 16, 20 = different rehabilitated year (download)