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FORAMINIFERAL DISTRIBUTION AND ASSOCIATION PATTERNS IN THE MANGROVE SEDIMENTS OF KAPAR AND MATANG, WEST PENINSULAR MALAYSIA

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Abstract: Twenty-eight foraminiferal species (15 families and 24 genera) were identified from the mangrove surface sediment samples at Kapar and Matang on the West coast of Peninsular Malaysia. The calcareous forms, particularly *Ammonia beccarii* and *Buccella frigida*, were found to be the characteristic of Kapar sediments, whereas agglutinated species like *Arenoparrella mexicana* and *Haplophragmoides wilberti* dominated the Matang environment. Based on faunal abundance (root-transformed data), three species' groupings were distinguished from the Kapar and Matang samples. Group-1 (with two sub-groups) dominated by *Ammotium fragile*, *A. salsum*, *Miliammina fusca* and *Reophax moniliformis* was found to be representative of Kapar, whereas Group-2 dominated by *A. mexicana* and *H. wilberti* was found to be representative of Matang. Group-3 was eventually separated from the Kapar (i.e. Group-1) due to the presence of *A. beccarii* and *B. frigida* which prefer nearshore/seaward areas with high salinity. Canonical Correspondence Analysis (CCA) indicated that (relatively) high salinity (30‰), pH (8), and sandy texture (70%) with low total organic carbon (TOC) (10%), characteristic of Kapar sediments, supported the distribution of *A. fragile*, *A. salsum*, *M. fusca*, *R. moniliformis, A. beccarii* and *B. frigida*, while a high composition of clay (31%) and TOC (30%) supported *A. mexicana* and *H. wilberti* (Matang) species. Overall, the distribution of foraminiferal species was locally governed by two different environmental settings prevailing at Kapar and Matang.

KEYWORDS: Tropical estuary, benthic foraminifera, mangrove sediment, Kapar and Matang, Peninsular Malaysia.

Introduction

Mangroves stabilize soil by trapping sediments in the downstream and protect land from the coastal erosion (Duke *et al*., 2007; Alongi, 2008; Bosire *et al*., 2008; Cannicci *et al*., 2008; Nagelkerken *et al*., 2008). Sedimentation within these areas also maintains an excellent record of environmental conditions such as sediment characteristics, preservation of spores and pollen, including the faunal deposits like foraminifera. The foraminifera are single-celled microscopic bottom dwellers or free floating protozoans with a test protecting their protoplasm (Loeblich & Tappan, 1988). These organisms have long been recognized for studying the environmental disturbances (e.g. pollution) as well as paleo-environmental reconstructions (e.g. sea level rise) (Den Dulk *et al*., 2000; Annin, 2001; Scott *et al*., 2001; Beavington-Penney & Racey, 2004; Edwards *et al*., 2004; Riveiros *et al*., 2007; Leorri *et al*., 2008; Bergamin *et al*., 2009; Carboni *et al*., 2009; Kemp *et al*., 2009).

Though research on mangroves is varied and found in almost every tropical segment of the world (Kairo *et al*., 2001; Satyanarayana *et al*., 2002; Jayatissa *et al*., 2002; Walters, 2003; Bosire *et al*., 2005; Duke, 2006; Berger *et al*., 2008; Neukermans *et al*., 2008;

Satyanarayana *et al*., 2010), information on the ecological significance of foraminifera and their distribution patterns within mangrove swamps is still limited (Debenay *et al*., 2002; Horton *et al*., 2003; Javaux & Scott, 2003; Debenay *et al*., 2004), especially from several locations in Malaysia (Alongi & Sasekumar, 1992; Mohd-Lokman *et al*., 2007, 2008).

In Malaysia, mangrove forests occupy 564,606 ha of which nearly 16% (91,779 ha) of the vegetation is found on the West coast of Peninsular Malaysia due to its sheltered environment (Shamsudin & Nasir, 2005). In contrast, the East coast is entirely exposed to the South China Sea and hosts only 1% of the mangrove cover (5,738 ha) (Mohd-Lokman & Sulong, 2001). The remaining 83% of the mangroves occur in the states of Sarawak (126,400 ha) and Sabah (340,689 ha) in East Malaysia (Shamsudin & Nasir, 2005). In view of the limited scientific investigations on foraminifera in this region, the present study attempts to describe their diversity and distribution in Kapar and Matang mangrove sediments on the West coast of Peninsular Malaysia. In addition, the influence of local environmental anomalies and ecological processes on these (mangrove) foraminifera assemblages was discussed.

Materials and Methods

Kapar mangroves (4,555 ha) are situated in the state of Selangor (3° 00' - 3° 09' N; 101° 18' - 101°24' E) with a network of creeks and canals emanating from Sg. Kapar Besar and Sg. Kecil Rivers (Figure 1a). These intermittent channels are subjected to daily inundation by tides and provide a dynamic environment for the growth of several true mangrove species (*Avicennia alba* Bl., *Bruguiera cylindrica* (L.) Bl., *B. gymnorrhiza* Lamk., *Nypa fruticans* (Thunb.) Wurmb., *Rhizophora apiculata* Bl., *R. mucronata* Lamk., and *Sonneratia alba* Smith), and mangrove associates (*Acanthus ilicifolius* L., *Ipomoea pes-caprae* (L.) Sweet, *Hibiscus tiliaceus* L., and *Acrostichum aureum* L.). On the other hand, Matang mangroves (40,466 ha) are located in the state of Perak (4° 15' - 5° 00' N; 100° 25' - 100° 40' E) (Figure 1b) extending over 51 km along the coastline between Kuala Gula and Panchor. The present study was conducted near Larut Matang (a managed forest about 10 km away from Sangga Besar River mouth) (Figure 1b), where the mangroves are dominated by *Avicennia*, *Bruguiera*, *Rhizophora*, *Sonneratia* and *Xylocarpus* spp. Both Kapar and Matang areas are strongly influenced by their location in the tropics with a mean annual temperature of 23.7 - 33.4 °C and high humidity (76.5 - 83.5%). Mean annual precipitation is 2380.1 mm (unpublished data). The tidal regimes are semi-diurnal with a range of 1.60 and 2.98 m, respectively (JUPEM, 2004).

Sampling was carried out in transects from the mangrove front to inside the forest (30 m inside based on accessibility) (Figure 1) (April-August, 2004). At each location (Kapar and Matang), a temporary bench mark was fixed using a survey leveling instrument (Topcon, AT-G7 N, Japan), and the elevation (with reference to mean sea level - MSL) was measured along the transect with sampling stations at 3 m intervals. Three transects (at a distance of 100-120 m intervals) were investigated at each location to encompass a wide range of sub-environmental settings representing that area. Altogether, 56 stations were surveyed along six transects (30 from Kapar and 26 from Matang) with a data collection on sediment, pore-water salinity and pH.

For foraminifera, the surface sediment samples (10 cm^2 area by 1 cm thickness) were collected during low tide with a hand shovel and placed in polythene bags. All samples were washed within 36 h of collection using a set of sieves (63 - 600 µm mesh size) as exposure of mangrove sediments to oxidation or to the action of oxidizing bacteria might destroy the organic wall of the foraminiferal tests (Scott & Medioli, 1986). The sample fraction retained on the small sieve (i.e. 63 µm) was placed in a liquid suspension and formalin/Rose Bengal mixture was added for staining and preservation. At the laboratory, each sample was poured into

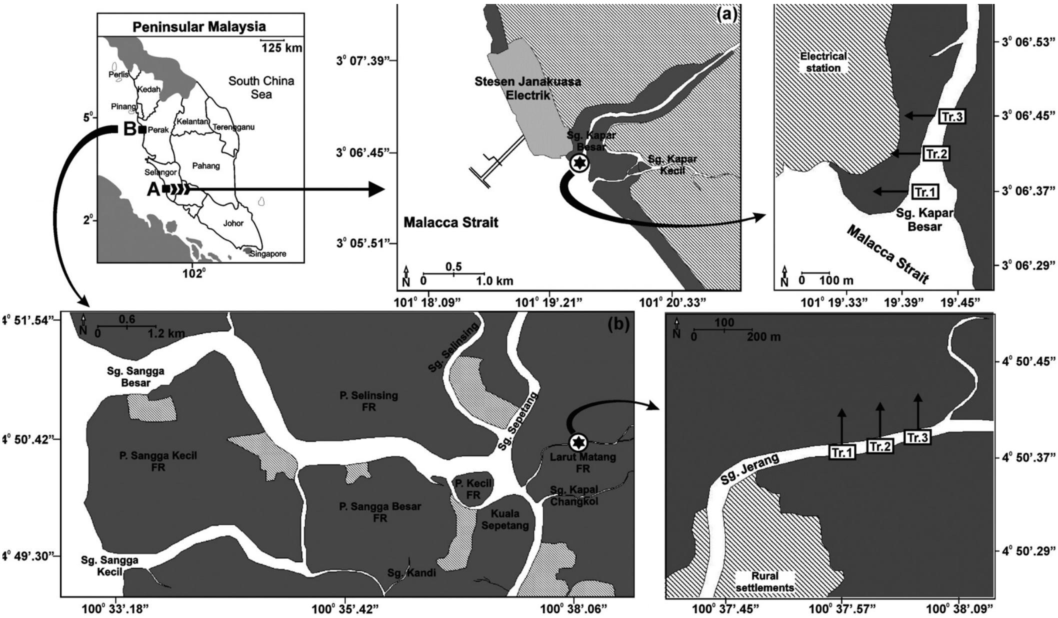

Figure 1: Study Area: (a) Kapar and, (b) Matang mangrove environments (dark shade) on the west coast of peninsular Malaysia (location of the study was indicated by stars in both panels; Tr: Transect; FR: Forest Reserve).

a petri dish, and the specimens (living + empty tests) were identified and counted (total count) under a binocular microscope (LICA, Japan) in wet medium. Samples with high numbers of specimens (mostly from Matang) were split into aliquots of 300-500 individuals using a plankton splitter (Scott *et al*., 1996) and counted separately. The nomenclature suggested by Loeblich & Tappan (1988) was followed and a checklist of foraminifera in the mangrove sediments of Kapar and Matang prepared.

A separate portion of sediment (about 250 g) was collected from each station and used for textural (sand, silt and clay) analysis by applying the initial (wet) sieving method (mesh No. 240, British Standard) followed by pipette analysis (Krumbein & Pettijohn, 1938). To measure pore-water salinity and pH, ground water from the waterfront areas was collected with the help of a PVC tube (2 cm diameter and its lower end covered by 500 mm nylon mesh) (*cf.* De Rijk, 1995), whereas water from the flooded ditches or crab burrows was used in the areas inside the forest. Oxidation dichromate acid technique (Holme & McIntyre, 1971) was used to determine the percentage (%) of total organic carbon (TOC) in the sediments.

For identifying the similarity between sampled stations, the faunal abundance (root-transformed data) was analyzed through Bray-Curtis similarity (clustering mode: group average) and Non-metric Multi-dimensional Scaling (NMDS) plots implemented in PRIMER *v*.5 (Clarke & Gorley, 2001). Canonical Correspondence Analysis (CCA) was used to determine the species-environment relationship (CANOCO for windows *v*.4.5), and for quantifying their correlations (ter Braak & Smilauer, 2002).

Results

Twenty-eight species (including 2 thecamoebians) belonging to 15 families and 24 genera were identified from the surface sediment samples of Kapar and Matang (Appendix-1) (Plate 1). Among these, 11 species were found to be common in both areas, 9 species were exclusive to Kapar and, another 8 were exclusive to Matang (Table 1). The distribution of selective

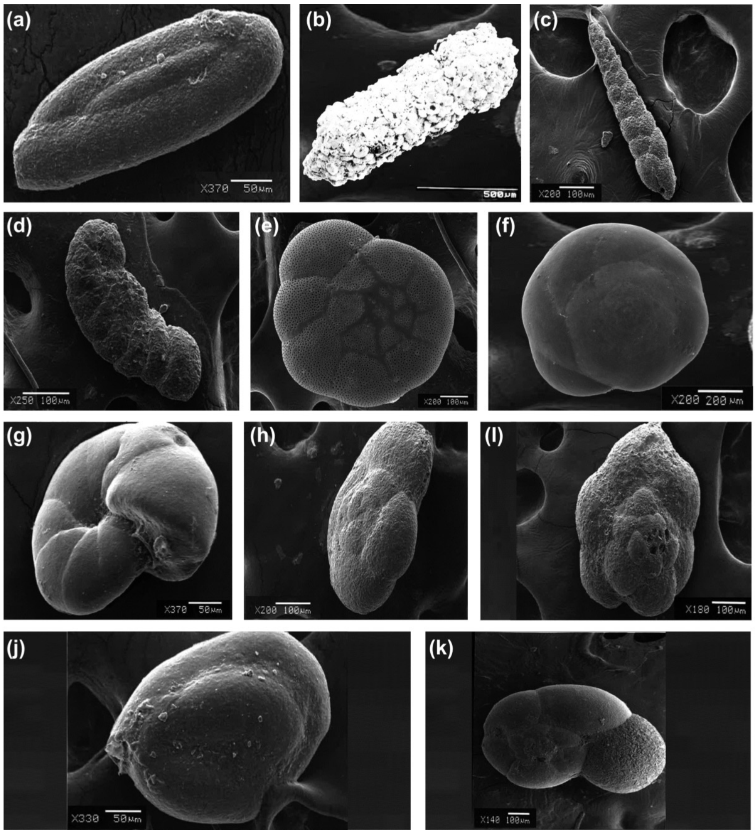

Plate 1

Scanning Electron Photographs of the Characteristic Foraminiferal Species in Kapar and Matang Mangrove Sediments: (a) *Miliammina fusca,* (b) *Reophax moniliformis,* (c) *Textularia earlandi,* (d) *Ammobaculites exiguous,* (e) *Ammonia beccarii,* (f) *Buccella frigida,* (g) *Haplophragmoides wilberti,* (h) *Arenoparrella mexicana,* (i) *Tiphotrocha comprimata,* (j) *Quinqueloculina seminulum,* and (k) *Trochammina inflata.*

species along transects in Kapar and Matang was provided in Figures 2 and 3 (species with < 5% abundance are not represented).

The Kapar mangrove sediments are characterized by 20 species along three transects (Table 1). In transect-1, *Miliammina fusca* (Brady) was widely distributed (8-288, average 114 ind 10cm^{-3}), followed by *Ammotium salsum* (Cushman and Bronnimann) (16-416, 82 ind 10cm^{-3}), *A. fragile* (Warren) (8-272, 69 ind 10cm^{-3}), *Reophax moniliformis* (Siddall) (16-224, 50 ind 10cm^{-3}), *Textularia earlandi* (Parker) (8-96, 25 ind 10cm^{-3}), and *Ammobaculites exiguus* (Cushman and Bronnimann) (32-64, 21 ind 10cm^{-3}) in the order of their abundance (Figure 2a). The remaining species on transect-1 (e.g. *Ammonia beccarii* (Linne), *Arenoparrella mexicana* (Kornfeld), *Haplophragmoides wilberti* (Andersen), *Tiphotrocha comprimata* (Cushman and Bronnimann), and *Trochammina macrescens* (Brady) contributed less than 5% of the total count.

Along transect-2, the predominant species were *M. fusca* (16-592, 172 ind 10cm^{-3}), *A. beccarii* (78-1216, 162 ind 10cm^{-3}), *Buccella frigida* (Cushman) (64-1152, 152 ind 10cm^{-3}), and *H. wilberti* (28-96, 45 ind 10cm^{-3}) (Figure 2b). Both (calcareous) *A. beccarii* and *B. frigida* were noticed only at the first two sampling stations (with higher abundance) indicating their preference to the nearshore areas. Transect-3 was dominated by *A. salsum* (32-1568, 400 ind

Table 1: Foraminiferal Percentage Distribution in Kapar and Matang Mangrove Sediments (x = <1%).

	Kapar			Matang		
Species	Transect 1	Transect 2	Transect 3	Transect 1	Transect 2	Transect 3
Ammotium fragile	17	4	14	x	-	x
Ammotium salsum	20	-	30	1	2	2
Ammobaculites balkwilli	-	-	-	x	x	-
Ammobaculites exiguus	5	x	4	-	-	-
Ammoastuta inepta	-	-	-	1	2	2
Ammonia beccarii	2	26	-	-	-	-
Arenoparrella mexicana	2	-	9	38	49	40
Brizalina striatula	-	x	-	-	-	-
Buccella frigida	-	24	-	-	-	-
Cassidulina sp.	-	x	-	-	-	-
Centropyxis constricta	-	-	-	x	-	-
Cuneata arctica	-	-	x	-	x	-
Difflugia oblonga	-	-	-	x	-	-
Gaudryina exilis	-	3	-	x	x	-
Haplophragmoides wilberti	3	7	2	29	22	22
Haynesina depressula	-	1	-	-	-	-
Lituola sp.	-	-	x	x	1	2
Miliammina fusca	28	28	8	8	5	11
Miliammina obliqua	-	x	-	-	-	-
Psammosphaera sp.	-	-	-	-	x	x
Quinqueloculina seminulum	-	-	-	8	8	10
Reophax moniliformis	12	1	19	-	-	-
Siphotrochammina sp.	-	x	-	-	-	-
Textularia earlandi	6	2	3	x	x	x
Tiphotrocha comprimata	3	-	8	4	4	3
Trochammina inflata	-	-	-	6	3	2
Trochammina macrescens	2	x	3	4	4	5
Trochamminita salsa	-	-	-	-	-	x
Elevation (cm) above MSL	26 - 86	100 - 133	135 - 162	257 - 298	264 - 298	263 - 280
Total no. of species	11	15	12	16	15	14
Total no. of ind 10 cm^{-3}	4112	4990	13243	225600	55382	44982

10cm^{-3}) along with *R. moniliformis* (48-1152, 248 ind 10cm^{-3}), *A. fragile* (32-384, 180 ind 10cm^{-3}), *A. mexicana* (8-288, 121 ind 10cm^{-3}), *M. fusca* (8-448, 112 ind 10cm^{-3}), and *T. comprimata* (64-576, 107 ind 10cm^{-3}) (Fig. 2c). Species, *A. exiguus*, *H. wilberti*, *Lituola* sp., *T. earlandi*, and *T. macrescens* represented less than 5% abundance along transect-3.

The Matang mangrove sediments were represented by 19 species (Table 1). Despite its rich faunal diversity, only two (agglutinated) species namely *A. mexicana* and *H. wilberti*,

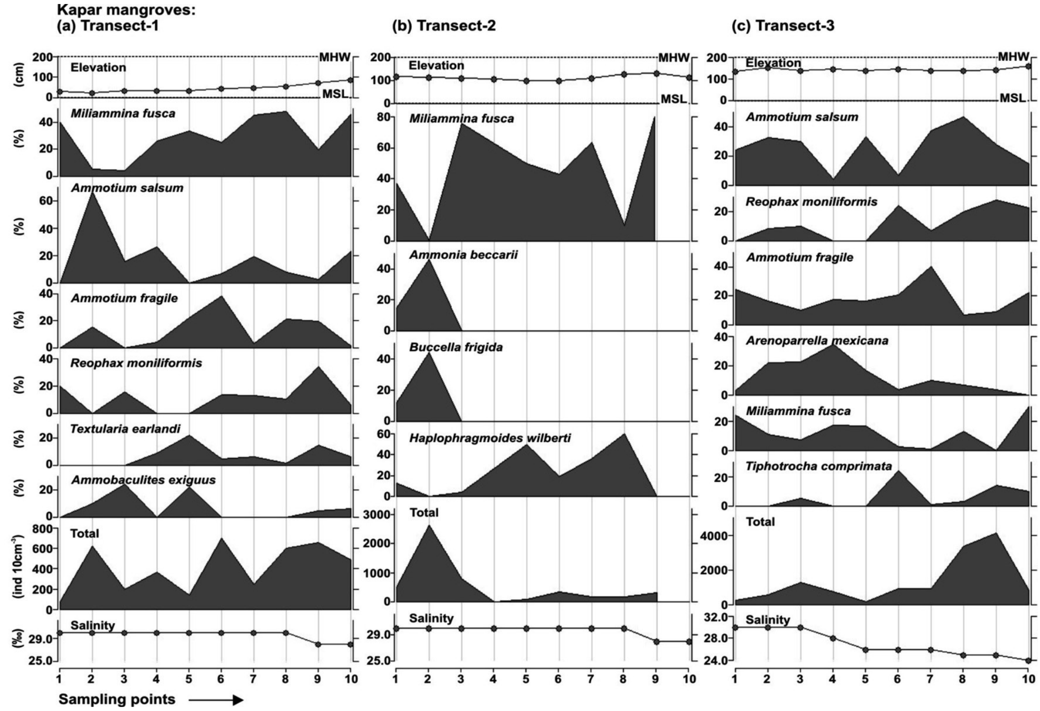

Figure 2: Transect-wise Distribution of Foraminiferal Species (% composition) at Kapar (sampling stations with no data indicates the absence of species) (MSL: Mean Sea Level; MHW: Mean High Water).

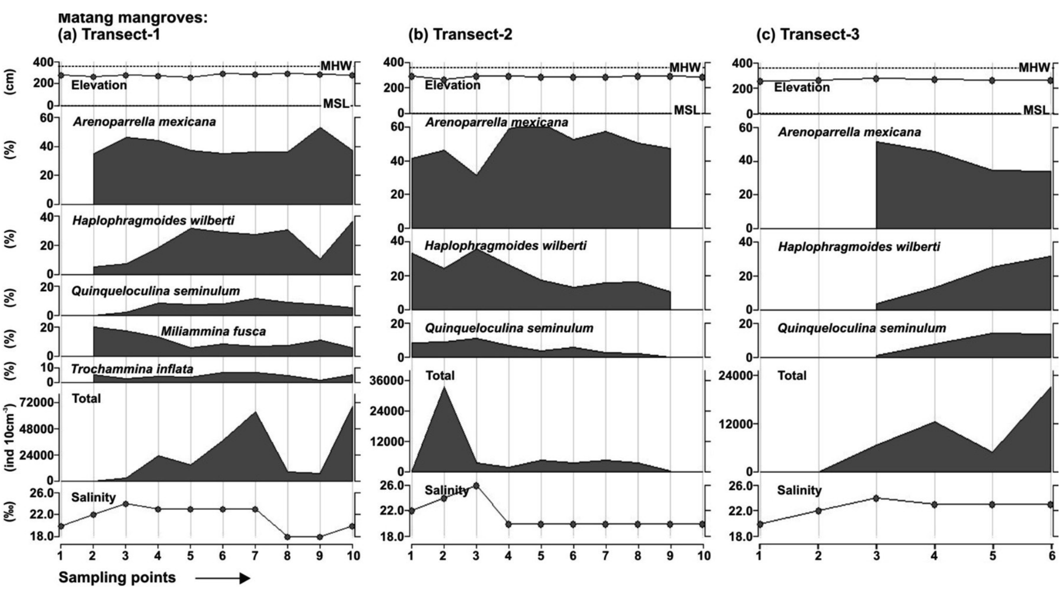

Figure 3: Transect-wise Distribution of Foraminiferal Species (% composition) at Matang (no species found in transect-1: P.1, transect-2: P.10, and transect-3: P.1-2) (MSL: Mean Sea Level; MHW: Mean High Water).

Table 2: Sediment Characteristics.

Variable	Kapar Range (mean ± 1SD)	Matang Range (mean ± 1SD)
pH	7 – 8	6 – 7
	(7.5 ± 0.5)	(6.5 ± 0.5)
Salinity (%)	24 – 30	18 – 26
	(28.7 ± 1.9)	(21.6 ± 2)
Sand (%)	10 – 70	6 – 7
	(35 ± 15.7)	(26.7 ± 10)
Silt (%)	25 – 68	44 – 63
	(51.9 ± 11.7)	(54.5 ± 5.1)
Clay (%)	5 – 24	12 – 31
	(12.8 ± 4.2)	(18.8 ± 5.8)
TOC (%)	9.8 – 10	28 – 30
	(9.9 ± 0.1)	(28.8 ± 0.6)

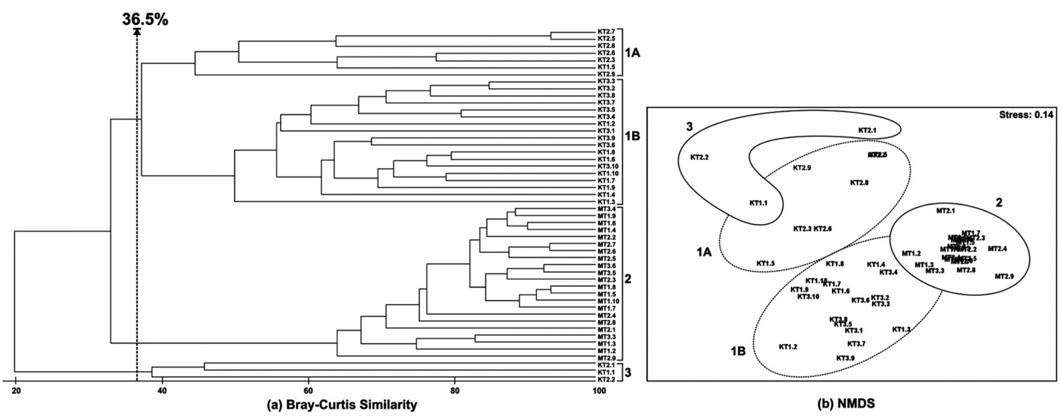

Figure 4: (a) Dendrogram showing Bray-Curtis similarity between Kapar and Matang mangrove sediment samples based on the foraminiferal abundance (root-transformed data); (b) NMDS ordination based on species abundance and Bray-Curtis similarity (KT: Kapar transect, and MT: Matang transect with their respective sampling points).

were dominant along transects from mangrove front to inside the forest. Along transect-1 (Figure 3a), these species formed up to 70% of the total abundance (16-25536, 8389 ind 10cm^{-3}), while others such as *M. fusca*, *Quinqueloculina seminulum* (Linne) and *Trochammina inflata* (Montagu) showed 6-8%. The same group of individuals (i.e. *A. mexicana* and *H. wilberti*) also remained widespread throughout the transect-2 (32-15488, 2182 ind 10cm^{-3}) (Figure 3b), and transect-3 (256-7200, 3458 ind 10cm^{-3}) (Figure 3c) with more than 60% of their abundance.

Although sediments were predominantly of sandy-silt in nature at Kapar and Matang (Table 2), there were appreciable differences in the sediment characteristics between these two sites. At Kapar, close to the river mouth (Malacca Strait), the pH ranged between 7 and 8 (7.5 ± 0.5, mean ± 1SD), and salinity 24 and 30‰ (28.7 ± 1.9). At Matang (located 10 km away from Sangga Besar River mouth), the pH and salinity were recorded as 6-7 (6.5 ± 0.5) and 18-26‰ (21.6 ± 2), respectively. The sediment analysis revealed that in the areas where sand content

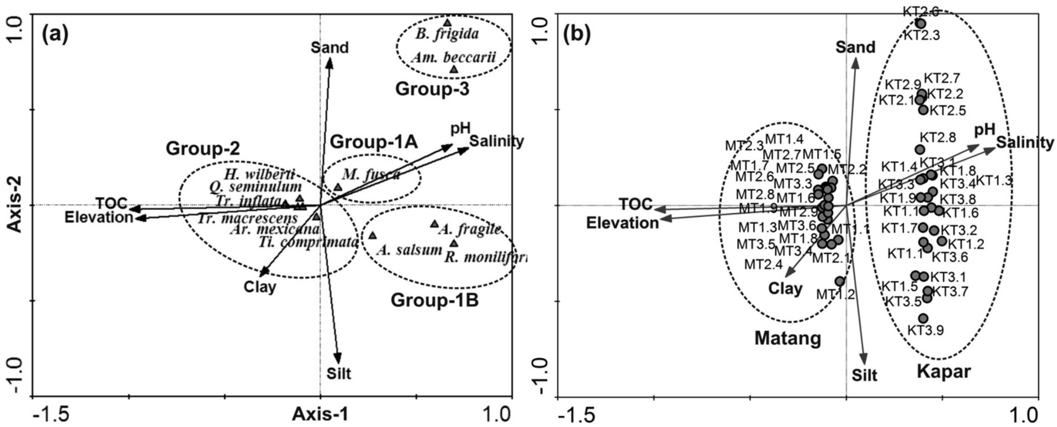

Figure 5: Canonical Correspondence Analysis (CCA) showing the correlation between environmental variables and foraminiferal species/sediment samples in Kapar and Matang mangroves: (a) Species-Environment biplot superimposed by species groupings (Genus names - A: *Ammotium*, Am: *Ammonia*, Ar: *Arenoparrella*, B: *Bucella*, H: *Haplophragmoides*, M: *Miliammina*, Q: *Quinqueloculina*, R: *Reophax*, Ti: *Tiphotrocha*, and Tr: *Trochammina*) and, (b) Environmental-Area biplot (KT: Kapar transect, and MT: Matang transect with their respective sampling points).

Table 3: Canonical Correspondence Analysis (CCA): Monte Carlo Permutation Test.

	Axis-1	Axis-2
Eigenvalue	0.396	0.118
Species-environment correlation	0.921	0.461
Cumulative percentage variance of species data	28.7	37.2
Cumulative percentage variance of species-environment relation	93.4	72.0
Correlation coefficient		
pH	2.201	-0.207
Salinity	2.121	-0.205
Sand	2.286	0.071
Silt	-2.117	-0.104
Clay	-1.757	0.021
TOC	-1.942*	0.296
Elevation	-1.807	0.286

*significant at $p < 0.05$

was high (Kapar), TOC was comparatively low (9.9 ± 0.1) (Table 2). In contrast, the mangrove sediments at Matang had high TOC (28.8 ± 0.6).

Based on species' cluster and the accompanying non-metric multi-dimensional scaling plots, the Kapar and Matang samples could be ideally distinguished into 3 groups (at 36.5% similarity) (Figure 4). While Group-1A indicated the abundance of *M. fusca*, Group-1B represented a combination of *A. salsum*, *R. moniliformis*, *A. fragile* and *M. fusca* (correlation: 0.953). A strong association among *A. mexicana* and *H. wilberti* along with *Q. seminulum, M. fusca, T. macrescens*, *T. inflata*, and *T. comprimata* was responsible for Group-2 (correlation: 0.951). Group-3 was separated from Group-1 (Kapar) due to the presence of exclusive/calcareous foraminifera such as *A. beccarii* and *B. frigida*.

In the CCA (Figure 5), axis 1 (eigenvalue: 0.4) explained up to 93% variance between species and environmental parameters tested; axis 2 (eigenvalue: 0.1) showed 72% (Table 3). On the positive side of axes 1 and 2, the variables associated were pH, salinity and sand characteristics of Kapar sediments. On the other side, the Matang sediments having high TOC and clay showed negative correlation.

Discussion

Majority of the foraminiferans live in marine to marginal marine environments i.e., from intertidal to deep ocean trenches, while few occur in freshwater (Boersma, 1978). They adapt naturally to high salinity (~35‰) and exhibit greater diversity, in contrast to those found in brackish water lagoon/salt marshes (Scott *et al*., 2001). Most of the agglutinated species observed at Kapar (*A. exiguus*, *A. fragile*, *A. salsum*, *M. fusca*, *R. moniliformis* and *T. earlandi*) are also known to occur abundantly in other mangrove areas elsewhere (Debenay *et al*., 2002; Horton *et al*., 2005; Berkeley *et al*., 2009a; Ghosh *et al*., 2009). In contrast, the Matang sediments are dominated by *A. mexicana* and *H. wilberti*. The recent literature on world benthic foraminiferal distribution (*cf.* Javaux & Scott, 2003) indicates that these two species *A. mexicana* and *H. wilberti* are most prevalent in mangrove-dominated settings near the equator, and Matang is indeed one of the well-managed mangrove habitats with a history of more than 100 years in Malaysia (Shamsudin & Nasir, 2005). Nevertheless, high organic content enhances the nutritive value of both water and substrate and ultimately foraminiferal species development (Debenay *et al*., 2004; Armynot du Châtelet *et al*., 2009). In this context, the overwhelming presence of *A. mexicana* and *H. wilberti* at Matang due to enriched organic matter through leaf litter and other bio-organic substances (Table 2) is convincing. The two thecamoebians namely, *Difflugia oblonga* (Ehrenberg) and *Centropyxis constricta* (Ehrenberg) are indicative of considerable freshwater influence in this area (Hayward *et al*., 1996; Riveiros *et al*., 2007).

Foraminifera assemblages from the mangrove swamps of Acupe (Brazil) were described by Hiltermann *et al*., (1981). They suggested four types of sub-environments such as internal, sub-internal, sub-external and external areas based on salinity and distribution. Similarly, De Rijk (1995), De Rijk & Troelstra (1997), Debenay *et al*., (2004), and Hayward *et al*., (2004), have all described the modern foraminiferal patterns in salt marsh and mangrove environments that allowed recognition of some indicator species and their associations with respect to the salinity regimes. In fact, foraminiferal assemblages in mangrove swamps include many well-known species of the salt marshes (Debenay *et al*., 2002). Most recently, Fatela *et al*., (2009) found salinity as a clear constraint to the composition of foraminiferal assemblages. In the present study, Group-1A dominated by *M. fusca* was distributed from low to upper mangrove areas (Figure 2), indicating their tolerance to a wide range of salinity (24-30‰) (Table 2) (Horton *et al*., 2003, 2005). Group-1B (the combination of *A. salsum*, *R. moniliformis*, *A. fragile* and *M. fusca*) was abundant at the end of transects showing its preference to those upper mangrove areas usually influenced by low salinity (24-28‰). Group-2 (dominated by *A. mexicana* and *H. wilberti*) was also distributed from the low to upper mangrove areas (Figure 3), however, under relatively less saline conditions (18-26‰) (Table 2) (Debenay *et al*., 2002; Hayward *et al*., 2004). In majority of cases, *A. mexicana* remained widespread with *M. fusca*, *H. wiberti* and *T. inflata* in mangrove sediments (Bronnimann *et al*., 1981). Group-3 (the combination of *A. beccarii* and *B. frigida*) inhabited the nearshore/seaward areas (30‰) (Figure 2) that exist with warm temperature and high salinity (Debenay *et al*., 2004).

The mangrove biota appear to distribute itself in response to micro-topographic characteristics related to elevation and frequency of inundation (Gehrels *et al*., 2001; Patterson *et al*., 2005; Riveiros *et al*., 2007). Following the concept of vertical zonation of marsh foraminifera relative to mean sea level (Scott & Medioli, 1978), several authors have established

Table 4: Foraminiferal Associations with Respect to the Environmental Conditions in Kapar and Matang.

Area	Species' associations determined	Elevation (cm) above MSL	Flooding frequency (no. of times/ month)	Salinity ($^0/_{00}$)	Environment
Kapar	Group-1A: *Miliammina fusca*	26–162	50–60	24–30	Low, middle and upper mangrove areas of lower estuary
	Group-1B: *Ammotium fragile* *Ammotium salsum* *Miliammina fusca* *Reophax moniliformis*	140–162	50–60	24–28	Upper mangrove area of lower estuary
	Group-3: *Ammonia beccarii* *Buccella frigida*	26–119	57–60	30	Nearshore area of lower estuary
Matang	Group-2: *Arenoparrella mexicana* *Haplophragmoides wilberti* *Miliammina fusca* *Quinqueloculina seminulum* *Tiphotrocha comprimata* *Trochammina inflata* *Trochammina macrescens*	257–298	52-60	18–26	Low, middle and upper mangrove areas of upper estuary

the relationship between elevation and foraminiferal distribution in mangrove as well as adjacent salt marsh and mudflat environments (Horton *et al*., 2003; Edwards *et al*., 2004; Patterson *et al*., 2005; Woodroffe *et al*., 2005; Southall *et al*., 2006; Hawkes *et al*., 2007; Kemp *et al*., 2009). Hawkes *et al*., (2007) and Armynot du Châtelet *et al*., (2009) have inferred that the grain size (sediment texture) is important for foraminiferal distribution, along with freshwater input (i.e. salinity) and distance to the creek/ inlets of the marshes (i.e. flooding regime). In contrast, both elevation and grain size are said to be ineffective if the sediment shows little or no spatial variation in the mangroves (Debenay *et al*., 2002, 2004). Foraminiferal assemblages are therefore controlled by a number of parameters whose variability and importance changes with the local environmental conditions (Scott & Medioli, 1986).

In the present study, we consider Kapar as a "lower estuarine environment" and Matang as an "upper estuarine environment" on the basis of their location and marine influences (Wightman *et al*., 1994). Elevation (Figures 2 and 3) and tide data measurements (JUPEM, 2004) indicated that both Kapar (elevation: 26-162 cm) and Matang (elevation: 257-298 cm) areas are submerged daily with rising tides (mean high water - MHW: 208 and 370 cm, respectively), implying an inundation frequency of 50-60 times a month. The distribution of foraminiferal species' associations in Kapar and Matang with respect to land elevation, flooding frequency, salinity and the environment (Table 4) reveals that each of these areas has its own characteristic fauna representing the opportunistic behaviour of mangrove agglutinants (Semensatto-Jr *et al*., 2009).

In addition to the season and taphonomic processes (Morvan *et al*., 2006; Berkeley *et al*., 2009a, 2009b), pH and salinity also influence the assemblages of foraminifera inside the mangroves (Debenay *et al*., 2002, 2004; Carboni *et al*., 2009). The Monte Carlo Permutation test indicated high correlation coefficient values for salinity (2.1), pH (2.2), and sand (2.3), whereas TOC was significant (P = 0.02) (directly or indirectly) with the species distribution (Table 3). On the other hand, elevation remained unimportant (P = 0.7), perhaps due to daily inundation of all the sampled stations. The species preferring sandy/muddy substrates as well as high/low salinity regimes were evidently separated (Figure 5). While high salinity, pH and sand with low TOC supported the distribution of Groups-1 and 3 (Kapar), high composition (%) of clay and TOC supported Group-2 (Matang) species (Table 2).

Conclusion

The abundance and distribution of foraminiferal species at Kapar and Matang revealed significant differences (P = 0.04, One-way ANOVA) in response to soil salinity, pH, grain size and TOC. Besides their group-wise dominance, species contributing to the abundance at each location were characteristically different. At Kapar, *A. fragile*, *A. salsum*, *M. fusca*, and *R. moniliformis* (agglutinated), and *A. beccarii* and *B. frigida* (calcareous) were dominant, while *A. mexicana*, *H. wilberti*, *M. fusca*, *T. comprimata*, *T. macrescens*, and *T. inflata* (agglutinated), and *Q. seminulum* (calcareous) were characteristic of Matang. Among the 17 exclusive species at Kapar and Matang, only five species (*A. beccarii*, *B. frigida*, *Q. seminulum, R. moniliformis* and *T. inflata*) showed their predominance in determining the community structure of foraminifera. The present results could be used as baseline data for future foraminifera investigations in Malaysian mangroves.

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APPENDIX – 1

(Classified list of foraminifera in the mangrove sediments of Kapar and Matang)

Phylum				:	Protozoa
	Order			:	Foraminifera Eichwald, 1830
		Family		:	Saccamminidae Brady, 1884
			Genus	:	*Psammosphaera* Schulze, 1875
				Species:	*Psammosphaera* sp.
		Family		:	Hormosinidae Haeckel, 1894
			Genus	:	*Cuneata* Fursenko, 1979 *Reophax* de Montfort, 1808
				Species:	*Cuneata arctica* (Brady) 1881 *Reophax moniliformis* Siddall, 1886
		Family		:	Rzehakinidae Cushman, 1993
			Genus	:	*Miliammina* Heron-Allen and Earland, 1930
				Species:	*Miliammina fusca* (Brady) 1870 *Miliammina obliqua* Heron-Allen and Earland, 1930
		Family		:	Lituolidae de Blainville, 1827
			Genus	:	*Ammoastuta* Cushman and Bronnimann, 1948 *Ammobaculites* Cushman, 1910 *Ammotium* Loeblich and Tappan, 1953 *Haplophragmoides* Cushman, 1910 *Lituola* Lamark, 1804 *Trochamminita* Cushman and Bronnimann, 1948
				Species:	*Ammoastuta inepta* (Cushman and McCulloch) 1939 *Ammobaculites balkwilli* Haynes, 1973 *Ammobaculites exiguus* Cushman and Bronnimann, 1948 *Ammotium fragile* Warren, 1957 *Ammotium salsum* (Cushman and Bronnimann) 1948 *Haplophragmoides wilberti* Andersen, 1953 *Lituola* sp. *Trochamminita salsa* (Cushman and Bronnimann, 1948)
		Family		:	Textulariidae Ehrenberg, 1838
			Genus	:	*Textularia* Defrance, 1824
				Species:	*Textularia earlandi* Parker, 1952
		Family		:	Trochamminidae Schwager, 1877
			Genus	:	*Arenoparrella* Andersen, 1951 *Siphotrochammina* Saunders, 1957 *Tiphotrocha* Saunders, 1957 *Trochammina* Parker and Jones, 1859

		Species:	*Arenoparrella mexicana* (Kornfeld) 1931 *Siphotrochammina* sp. *Tiphotrocha comprimata* (Cushman and Bronnimann) 1948 *Trochammina inflata* (Montagu) 1808 *Trochammina macrescens* Brady, 1870
Family		:	Verneuilinidae Cushman, 1911
	Genus	:	*Gaudryina* d'Orbigny, 1839
		Species:	*Gaudryina exilis* Cushman and Bronnimann, 1948
Family		:	Miliolidae Ehrenberg, 1839
	Genus	:	*Quinqueloculina* d'Orbigny, 1826
		Species:	*Quinqueloculina seminulum* (Linne) 1758
Family		:	Bolivinidae Glaessner, 1937
	Genus	:	*Brizalina* Costa, 1856
		Species:	*Brizalina striatula* (Cushman) 1922
Family		:	Discorbidae Ehrenberg, 1838
	Genus	:	*Buccella* Anderson, 1952
		Species:	*Buccella frigida* (Cushman) 1921
Family		:	Rotaliidae Ehrenberg, 1839
	Genus	:	*Ammonia* Brunnich, 1772
		Species:	*Ammonia beccarii* (Linne) 1758
Family		:	Cassidulinidae d'Orbigny, 1839
	Genus	:	*Cassidulina* d'Orbigny, 1826
		Species:	*Cassidulina* sp.
Family		:	Elphidiidae Galloway, 1933
	Genus	:	*Haynesina* Banner and Culver, 1978
		Species:	*Haynesina depressula* (Walker and Jacob, 1798)
Thecamoebians:			
Family		:	Difflugidae Stein, 1859
	Genus	:	*Difflugia* Leclerc in Lamarck, 1816
		Species:	*Difflugia oblonga* Ehrenberg, 1832
Family		:	Centropyxididae Deflandre, 1953
	Genus	:	*Centropyxis* Stein, 1859
		Species:	*Centropyxis constricta* (Ehrenberg) 1843