Tropical Life Sciences Research, 24(1), 35–43, 2013

A Survey of Benthic Assemblages of Foraminifera in Tropical Coastal Waters of Pulau Pinang, Malaysia

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Abstrak: Satu kajian terhadap taburan Foraminifera bentik di sekitar perairan Taman Negara Pulau Pinang, Malaysia telah dijalankan untuk mengkaji kesan aktiviti antropogenik seperti penangkapan ikan, eko-pelancongan dan akuakultur sangkar terapung. Sampel telah dikutip pada selaan 200 m bermula dari zon subpasang surut sehingga jarak 1200 m dari pantai di Teluk Bahang, Teluk Aling, Teluk Ketapang dan Pantai Acheh. Kedalaman perairan berjulat di antara 1.5 m dan 10.0 m, dengan substrat yang berlumpur di kebanyakan stesen. Analisis kualiti air menunjukkan variasi kecil dalam kepekatan mikronutrien (nitrit, NO_2; nitrat, NO_3; amonia, NH_4 dan ortofosfat, PO_4) antara stesen kajian. Suhu (29.6±0.48°C), saliniti (29.4±0.28 ppt), kandungan oksigen terlarut (5.4±0.95 mg/l) dan pH (8.5±0.13) juga menunjukkan perubahan kecil antara stesen. Sebanyak sembilan genera Foraminifera telah dikenal pasti dalam kajian ini (*Ammonia*, *Elphidium*, *Ammobaculites*, *Bolivina*, *Quinqueloculina*, *Reopax*, *Globigerina*, *Textularia* dan *Nonionoides*). Taburan Foraminifera bentik didominasi oleh kumpulan oportunis yang mempunyai toleransi tinggi terhadap tekanan antropogen. *Ammonia* menunjukkan frekuensi kepadatan yang tinggi (84.7%) diikuti oleh *Bolivina* (50%), *Ammobaculites* (44.2%) dan *Elphidium* (38.9%). Indeks *Ammonia-Elphidium* (AEI) telah digunakan untuk menunjukkan keadaan hipoksik dalam komuniti bentik di setiap lokasi. Teluk Bahang mempunyai nilai AEI yang paling tinggi. Himpunan dan taburan Foraminifera di Teluk Bahang, Teluk Aling dan Pantai Acheh tidak menunjukkan sebarang kolerasi dengan parameter persekitaran fizikal atau kimia.

Kata kunci: Foraminifera Bentik, Perairan Tepi Pantai, Amonia, Kualiti Air

Abstract: The distribution of benthic Foraminifera throughout the coastal waters of Taman Negara Pulau Pinang (Penang National Park), Malaysia was studied to assess the impact of various anthropogenic activities, such as fishing, ecotourism and floating cage culture. Samples were obtained at 200 m intervals within the subtidal zone, extending up to 1200 m offshore at Teluk Bahang, Teluk Aling, Teluk Ketapang and Pantai Acheh. The depth within coastal waters ranged between 1.5 m and 10.0 m, with predominantly muddy substrate at most stations. Water quality analysis showed little variation in micronutrient (nitrite, NO_2; nitrate, NO_3; ammonia, NH_4 and orthophosphate, PO_4) concentrations between sampling stations. Temperature (29.6±0.48°C), salinity (29.4±0.28 ppt), dissolved oxygen content (5.4±0.95 mg/l) and pH (8.5± 0.13) also showed little fluctuation between stations. A total of nine genera of foraminifera were identified in the study (i.e., *Ammonia, Elphidium, Ammobaculites, Bigenerina, Quinqueloculina, Reopax, Globigerina, Textularia* and *Nonion*). The distribution of benthic foraminifera was dominated by opportunistic groups that have a high tolerance to anthropogenic stressors. *Ammonia* had the highest frequency of occurrence (84.7%), followed by *Bigenerina* (50%), *Ammobaculites* (44.2%) and *Elphidium* (38.9%). The *Ammonia-Elphidium* Index (AEI) was used to describe the

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hypoxic condition of benthic communities at all sites. Teluk Bahang had the highest AEI value. The foraminiferal assemblages and distribution in Teluk Bahang, Teluk Aling, Teluk Ketapang and Pantai Acheh showed no correlation with physical or chemical environmental parameters.

Keywords: Benthic Foraminifera, Coastal Water, *Ammonia*, Water Quality

INTRODUCTION

Foraminifera are increasingly being recognised as valuable indicators of the health of marine and coastal environments (Jayaraju *et al.* 2011; Narayan & Pandolfi 2010; Natsir 2010; Carnahan 2005). The idea of using benthic foraminiferal assemblages as proxy indicators was initiated in the 1960s (Alve 1995). Benthic foraminifera are a useful proxy for environment monitoring, especially in coastal areas, because (1) they have high preservation potential (Bousi *et al.* 2010), (2) their use is inexpensive and they are high in abundance (Carnahan 2005; Alve 1995), (3) they are very sensitive to even slight changes in environmental conditions (Carnahan 2005; Sen Gupta 2003; Alve 1995) and (4) foraminiferal sampling itself causes negligible impacts to the marine environment (Carnahan 2005).

Coastal areas have long been recipients of terrestrial effluents associated with various types of pollution. The fast growing human population of Pulau Pinang creates challenges for both terrestrial and marine ecosystems. Coastal areas around Pulau Pinang have already experienced many environmental changes due to such factors as land reclamation, domestic and agricultural waste and industrial effluent (Koh *et al.* 1997). The act of gazetting Pantai Acheh Forest Reserve as Taman Negara Pulau Pinang (Penang National Park) in 2003 may help reduce further loss of faunal and floral diversity on Pulau Pinang. However, this action does not apply to the marine ecosystem around the Penang National Park. The undefined boundaries of the open ocean means that any pollutant originating from other parts of Penang Island may be carried to and impact the coastal areas of the national park.

The goals of this study were 1) to assess the water quality of Penang National Park coastal waters, 2) to describe the distribution of benthic foraminiferal assemblages and 3) to investigate the relationship between benthic foraminifera and physical and chemical parameters.

MATERIALS AND METHODS

This study was conducted in the coastal waters of Penang National Park. Sediment samples were collected at four sampling sites (Fig. 1): Teluk Bahang (N 05’ 47.1”, E 100’ 20.8”), Teluk Aling (N 05’ 47.7”, E 100’ 19.8”), Teluk Ketapang (N 05’ 39.6”, E 100’ 15.8”) and Pantai Acheh (N 05’ 46.2”, E 100’ 16.6”). The depth of the collection sites ranged between 1.5 m and 10.0 m, with a predominantly muddy bottom at most stations.

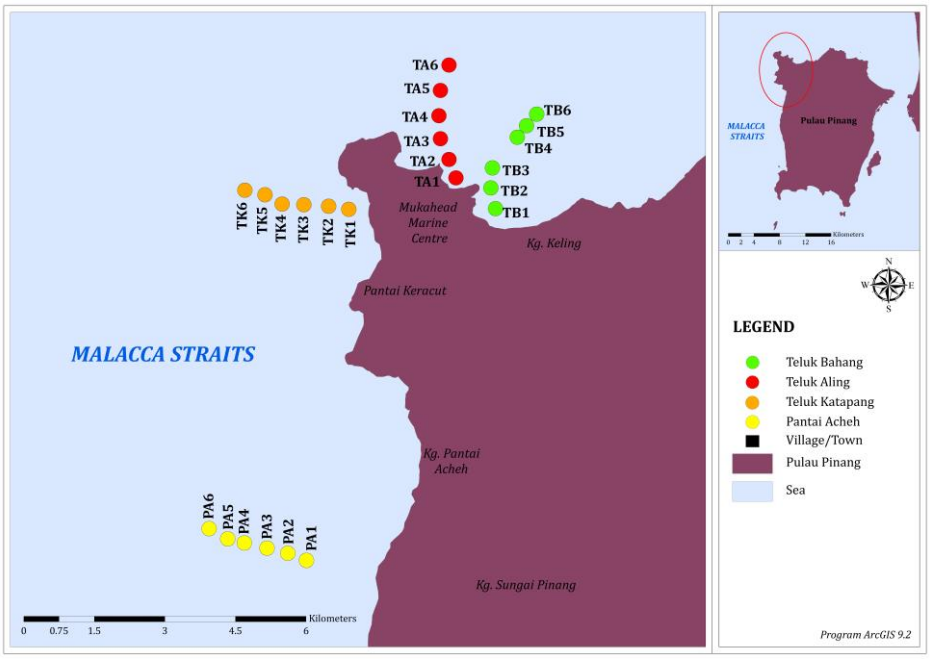


Figure 1: The distribution of sampling stations on the North-west side of Pulau Pinang.

Teluk Bahang is an important fishery landing ground on Pulau Pinang. Fishing, together with floating-cage culture, are major economic activities carried out in this area. Teluk Aling is situated in a sheltered coastal area where the Centre for Marine and Coastal Studies (CEMACS), Universiti Sains Malaysia (USM), is located. Teluk Ketapang is a sheltered bay with no development adjacent to its intertidal area; this location was therefore considered more pristine and appropriate for reference purposes. The Pantai Acheh sampling location was situated seaward of the mangrove ecosystem of Sungai Pinang, Balik Pulau, and is subject to salinity fluctuation as well as various anthropogenic activities (such as domestic use, aquaculture and agriculture) that discharge directly into Sungai Pinang (Nurul Ruhayu 2011) and eventually into the sea.

Samples were collected bimonthly (on October 2010, December 2010 and February 2011) during the wet northeast monsoon season (November – February). Samples were obtained along a transect in the subtidal zone at 200 m intervals, extending up to 1200 m offshore. Bulk sediments were obtained using a Ponar grab (Wildlife Supply Company, Florida, USA) from a small vessel, and these were then sub-sampled immediately on board using a hand corer with 5 cm inner diameter to give a sample with a volume of 200 ml. The sub-samples collected were transferred into 250 ml pre-labelled containers and immediately fixed with 4% formalin to minimise Foraminifera test degradation (Hulings & Gray 1971). In situ benthic environmental parameters [salinity (ppt), temperature (°C), dissolved oxygen content (mg/l) and pH] were recorded using YSI 30 and YSI 50 meters (YSI Incorporated, Ohio, USA). Water samples were collected from the

base of the water column using a water sampler and kept in 1 litre polyethylene bottles.

Preserved samples were returned to the laboratory for identification and enumeration. From each 200 ml preserved sample, two 2 ml sub-samples containing sediment and Foraminifera were taken randomly. The subsamples were wet-sieved using 1000 µm and 63 µm sieves. The residue on the 63 µm sieve was then carefully transferred into a 10 ml counting chamber using distilled water (Somerfield *et al.* 2005). Counting and sorting were completed with the aid of a dissecting microscope (Meiji EMZ 57378, Japan). A very fine pin tip was used during the inspection of the specimens. A micro-pipette was used to pick up wet specimens and place them in 10 ml pre-labelled vials containing 70% ethanol solution for preservation purposes. Sample identification was completed based on Sen Gupta (2003), Loeblich and Tappan (1998), Millet (1970) and Cushman (1928). Selected samples were dried and a more detailed identification was made by looking at the images produce by a Scanning Electron Microscope (SEM) from Carl-Ziess SMT, Oberkochen, Germany. SEM images assisted in identification of Foraminifera by exposing fine structures on the organism. Collected sea water samples were analysed for nutrients (nitrite, NO_2; nitrate, NO_3; ammonia, NH_4 and orthophosphate, PO_4) and total suspended solids based on Strickland and Parson (1984). These nutrients are believed to be the limiting factors of phytoplankton growth in many parts of the ocean (Hales *et al.* 2004). Thus, it was hypothesised that the concentrations of these nutrients would influence foraminiferal distribution.

Frequency of occurrence (FO) (Narayan & Pandolfi 2010) and the *Ammonia-Elphidium* Index (AEI) (Sen Gupta 2003) were determined for each sample. The *Ammonia-Elphidium* Index value is an established indicator of hypoxia (Martinez-Colon & Hallock 2010; Sen Gupta 2003), thus this index was used to investigate the benthic condition at all sites. Correlations between water quality, environmental parameters and species assemblages were assessed using SPSS 14.0 (Bousi *et al.* 2010).

RESULTS AND DISCUSSION

Physical and chemical parameters showed little variation between the sampling stations [temperature (29.6±0.48°C); salinity (29.4±0.28 ppt); dissolved oxygen content (5.4±0.95 mg/l) and pH (8.5± 013)], likely due to mixing between bottom and surface water in these shallow coastal areas. The micronutrients analysed from each station showed some slight variations (Table 1). Overall, the concentration of ammonia (NH_4) varied between 0.01 to 0.05 mg/l. Nitrite (NO_2) and nitrate (NO_3) concentrations were between 0 to 0.02 mg/l. The concentration of phosphate (PO_4) had a minimum value of 0.07 mg/l and at maximum value of 0.16 mg/l. The concentration of total suspended solids varied between 71.7 mg/l and 218.3 mg/l. Nutrient analysis indicated that water quality at Teluk Bahang, Teluk Aling, Teluk Ketapang and Pantai Acheh could be classified as Class 2 according to the Malaysia Marine Water Quality Criteria and Standard (Appendix 1).

Table 1: Maximum and minimum concentrations of micronutrients in the coastal waters of Penang National Park.

Parameters	Min (mg/l)	Max (mg/l)
Ammonia (NH_4)	0.01	0.05
Nitrite (NO_2)	0	0.02
Nitrate (NO_3)	0	0.02
Phosphate (PO_4)	0.07	0.16
Total suspended solid	71.7	218.3

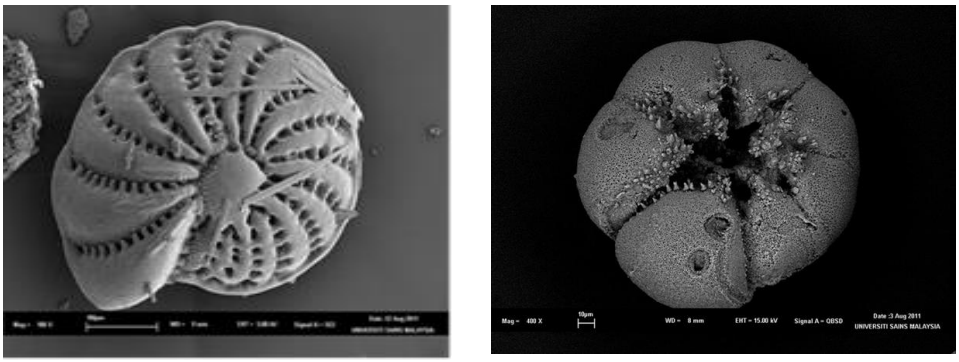
Nine genera of foraminifera were identified in this study: *Ammonia, Elphidium, Bigenerina, Quinqueloculina, Reopax, Globigerina, Textularia, Ammobaculites* and *Nonion* (Table 2). Common species such as *Ammonia* sp., *Elphidium* sp. and *Bigenerina* sp., were found at most of the sampling stations. *Ammonia* showed the highest FO, occurring at up to 84.7% of 24 sampling stations (Table 2), followed by *Bigenerina* (50%), *Ammobaculites* (44.2%) and *Elphidium* (38.9%). According to Hallock *et al.* (2003), the opportunist group includes taxa that are known to have high tolerance to anthropogenic stressors. Both *Ammobaculites* and *Elphidium* (Fig. 2) belong to this group and dominated the species assemblages at all four study sites.

Table 2: The FO and the functional group (see Hallock *et al.* 2003) of the foraminifera identified in this study.

Genera	FO (%)				Functional group
	October	December	February	Mean	
Ammonia	70.8	83.3	100.0	84.7	Opportunists
Elphidium	50.0	16.7	50.0	38.9	Opportunists
Bigenerina	45.8	50.0	54.2	50.0	Agglutinates
Quinqueloculina	16.7	20.8	16.7	18.1	Smaller miliolids
Reopax	50.0	50.0	16.7	38.9	Other small taxa
Globigerina	20.8	8.3	20.8	16.7	Other small taxa
Textularia	12.5	16.7	20.8	16.7	Agglutinates
Ammobaculites	25.0	20.8	86.8	44.2	Opportunists
Nonion	16.7	16.7	0.0	11.1	Other small taxa

Teluk Bahang is an intensely developed bay in which much human activity takes place (e.g., cage-culture activities). The foraminiferal community at Teluk Bahang was dominated by *Ammonia* occurring at an average of 83.5%, followed by *Elphidium* (0.7%). Teluk Aling the adjacent bay situated west of Teluk Bahang showed a very similar community pattern. *Ammonia* again dominated, occurring at an average of 91.9% of sites, followed by *Elphidium* at 4.6%. In Teluk Ketapang, *Ammonia* occurrence was 73.8% followed by an agglutinated group, *Textularia* 9.5%. The Pantai Acheh coastline is characterised by a

mangrove ecosystem. *Ammonia* (62.3%) also dominated the foraminiferal assemblage here, although at a smaller overall proportion, followed by *Elphidium* (18.7%).



(a) (b)

Figure 2: Two most common Foraminifera genera collected in the coastal waters of Penang National Park: (a) *Ammonia* sp., (b) *Elphidium* sp.

The AEI was formerly established as an indicator of hypoxic conditions. Studies have shown that the AEI correlates strongly with sediment hypoxia (Sen Gupta & Platon 2006). The high AEI in Teluk Bahang (99.2) suggests that this site may be subject to hypoxia (Carnahan *et al.* 2009). Teluk Aling also had a high AEI (94.9), suggesting an influence of hypoxia in the sediment. The highly reduced number of *Elphidium* in Teluk Ketapang also resulted in a high value of the AEI (95.8), indicating greater hypoxic conditions in Teluk Ketapang. The AEI was lowest (75.1) in the Pantai Acheh sampling site, indicating a lower influence of hypoxia at this site (Carnahan *et al.* 2009; Sen Gupta 2003).

There was no correlation between the measured physical parameters or micronutrients (other than nitrate, r = 0.214; 0.207) and the occurrence of the two major genera, *Ammonia* and *Elphidium* (Table 3). Other studies have shown that *Ammonia* species tend to dominate the foraminiferal assemblage in coastal areas under the influence of anthropogenic stressors (Martinez-Colon & Hallock 2010; Alve 1995). The dominance by members of the stress tolerant group (*Ammonia* and *Elphidium*) indicates that Teluk Aling was under greater stress compared to other study sites; Teluk Bahang was the second most impacted site, followed by Pantai Acheh and Teluk Ketapang. The highest AEI value was recorded in Teluk Bahang suggesting greater exposure to hypoxic conditions, possibly associated with an increased input of organic matter from fisheries activities (including floating-cage culture). Therefore, the conditions in Teluk Bahang were unfavourable to most foraminiferal species except those of the stress tolerant group, such as *Ammonia* spp., *Ammobaculites* spp. and *Elphidium* spp. The foraminiferal assemblages and distribution at all study sites showed no correlation with the measured physical and chemical environmental parameters. A slight correlation between nitrate with *Ammonia* spp. and *Elphidium* spp. was too low to effect the distribution of foraminifera.

Table 3: Pearson's correlation (*r* values) of physical and chemical properties of seawater with species abundance.

Parameter	Species	
	Ammonia	*Elphidium*
Total suspended solid	–0.058	–0.087
Nitrite	–0.052	-0.043
Nitrate	*0.214	*0.207
Ammonia	–0.093	0.079
Orthophosphate	0.053	0.066
Temperature	–0.115	0.042
Salinity	0.049	–0.148
Dissolved oxygen	0.135	0.116
pH	0.004	–0.142

Notes: N=144, *significant at $p<0.05$

CONCLUSION

The study showed that two closely situated sites, Teluk Bahang and Teluk Aling, are most likely to suffer greater environmental stress. The dominant species at Teluk Aling were all members of the stress tolerant group, while Teluk Bahang was influenced by hypoxic conditions. It was not possible to conclusively determine the most polluted site because the distribution of nutrients between stations was within the normal range for a marine system. The domination of *Ammonia* in the species assemblages indicates that all sites were subject to pollution. However, the type of pollution is yet to be determined. Pollutants, such as heavy-metal or total organic carbon, could influence the assemblage patterns of foraminifera in Pulau Pinang coastal waters. Further studies of foraminiferal distribution and assemblages in relation to such factors should be undertaken.

ACKNOWLEDGEMENT

This study was funded by the Research University Grant of Universiti Sains Malaysia (PPANTAI/1001/815052). We thank CEMACS staffs for help in sample and data collection. We would also like to extend our gratitude to Prof. P. Convey for his helpful comments on the manuscript.

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Appendix 1: Malaysia Marine Water Quality Criteria and Standard.

Parameter	Class 1	Class 2	Class 3	Class 4
Beneficial uses	Preservation, marine protected areas, marine parks	Marine life, fisheries, coral reefs, recreational and mariculture	Ports, oil and gas fields	Mangrove estuarine and river-mouth water
Dissolved oxygen (mg/l)	>80% saturation	5	3	4
Ammonia (mg/l)	0.035	0.070	0.320	0.070
Nitrite (mg/l)	0.010	0.055	1.000	0.055
Nitrate (mg/l)	0.010	0.060	1.000	0.060
Phosphate (mg/l)	0.005	0.075	0.670	0.075
Total suspended solid (mg/l)	25 mg/l or ≤ 10% increase in seasonal average, whichever is lower	50 mg/l (25 mg/l) or ≤ 10% increase in seasonal average, whichever is lower	100 mg/l or ≤ 10% increase in seasonal average, whichever is lower	100 mg/l or ≤ 30 % increase in seasonal average, whichever is lower

Source: Department of Environment Malaysia (2010).