DISTRIBUTION AND ABUNDANCE OF BENTHIC FORAMINIFERA IN THE COASTAL WATERS AROUND PENANG NATIONAL PARK

By

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Thesis submitted in fulfillment of the requirements for the degree of

Master of Science

MAY 2013

ACKNOWLEDGEMENT

In the name of Allah, the beneficent the merciful

Firstly, I would like to extend my heartfelt gratitude to my supervisor, Dr. Khairun Yahya for her continuous guidance, patience and encouragement throughout my graduate career. I am deeply indebted to Mr. Omar Ahmad, Dr. Anita and Professor Norenburg for their knowledge, advice and comments. I would also like to acknowledge Mr. Abdul Latif Omar and Mr. Rajindran A/L Suppiah and other CEMACS's lab assistance, for helping me out during field sampling. Without them this research would not have been possible. Special thanks and appreciation goes to my laboratory members, Ms. Alianie Mustaffa and Ms. Nurul Ruhayu for their encouragement, assistance and guidance in field as well as laboratory work.

The funding of this study was provided by the Research University Grant (1001/PPANTAI/815052) of Universiti Sains Malaysia. My greatest appreciation is to Universiti Sains Malaysia (USM) and Centre for Marine and Coastal Studies (CEMACS) for the facilities and support in this study.

I dedicate this thesis to my beloved family who has been a source of encouragement and motivation to me throughout my life.

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TABURAN DAN KEPADATAN FORAMINIFERA BENTIK DI PESISIRAN PANTAI SEKITAR TAMAN NEGARA PULAU PINANG

ABSTRAK

Satu kajian mengenai taburan dan kelimpahan Foraminifera bentik telah dijalankan di sekitar perairan Taman Negara Pulau Pinang, Malaysia. Empat lokasi (Teluk Bahang, Teluk Aling, Teluk Ketapang dan Pantai Acheh) telah dipilih berdasarkan tahap aktiviti antropogenik. Sebanyak 192 sampel tanah telah dikutip dua bulan sekali antara bulan Oktober 2010 dan September 2011. Semua sampel tanah, sampel air dan parameter persekitaran telah diambil di sepanjang transet dengan selaan 200 m, bermula dari zon sub pasang surut sehingga jarak 1200 m dari pantai. Himpunan Foraminifera merangkumi 14 genera iaitu *Ammonia, Elphidium, Ammobaculites, Nonionoides, Bolivina, Asterorotalia, Reophax, Eggerella, Textularia, Quinqueloculina, Astacolus, Lagena, Fissurina* dan *Hopkinsina* yang telah dikenalpasti. Kumpulan yang mempunyai toleransi terhadap tekanan iaitu *Ammonia* (56.35%) dan *Elphidium* (9.11%) mendominasi himpunan Foraminifera bentik di setiap lokasi. Sementara itu, kumpulan lain (seperti miliolids kecil dan agglutinat) yang hadir <5% dianggap sebagai spesies nadir. Indeks diversiti menunjukkan bahawa Pantai Acheh mempunyai himpunan Foramininifera dengan kepelbagaian spesies tertinggi (H’ = 0.57) diikuti oleh Teluk Ketapang (H’ = 0.47), Teluk Bahang (H’ = 0.43) dan Teluk Aling (H’ = 0.35). Himpunan spesies juga menunjukkan bahawa kesan antropogenik terhadap Foraminifera berkurang apabila lebih jauh dari kawasan pantai. Aplikasi indeks FORAM (FI = 1.0 ~ 2.0) dan indeks

Ammonia-*Elphidium* (AEI = 85 ~ 100) mencadangkan bahawa keadaan tertekan di sepanjang lokasi penyempelan. Tambahan pula, kesan antropogenik yang lebih hebat boleh diperhatikan berhampiran dengan kawasan pantai terutamanya di Teluk Bahang dan Teluk Aling. Pencemaran bahan organik daripada aktiviti akuakultur di Teluk Bahang menyebabkan saiz test *Ammonia* secara signifikannya lebih besar. Analisis kluster mengelaskan semua stesen kepada empat kumpulan, setiap satunya dipengaruhi oleh tahap tekanan antropogenik yang berbeza. Kumpulan A (pada jarak 200m di Teluk Bahang dan Teluk Aling) secara signifikannya menunjukan kuantiti bahan organik yang tinggi (17.14%, $p < 0.05$, ANOVA satu hala), keadaan hipoksik yang kuat (AEI=98, $p < 0.05$, ANOVA satu hala) dan jumlah pH yang rendah (8.37, $p < 0.05$, ANOVA satu hala). Kumpulan ini mempunyai kelimpahan Foraminifera yang empat puluh kali ganda lebih tinggi tetapi mempunyai diversiti yang lebih rendah. Kumpulan B merangkumi stesen yang terletak lebih jauh daripada kawasan pantai dan menunjukkan kandungan bahan organik yang rendah secara signifikan (9.67%, $p < 0.05$, ANOVA satu hala). Kumpulan C mewakili kawasan pinggiran yang bercirikan substrat berlumpur dengan jumlah pepejal terampai yang tinggi secara signifikan (166.03 mg/L, $p < 0.05$, ANOVA satu hala). Kumpulan D menunjukkan ciri-ciri kepadatan yang rendah dan kepelbagaian spesies yang rendah. Secara keseluruhan, taburan ruangan parameter *in situ* (suhu = 29.97 ± 0.05 °C, kemasinan = 29.52 ± 0.08 ‰, oksigen terlarut = 5.21 ± 0.08 mg/L dan pH = 8.43 ± 0.01) dan nutrien terpilih (NO_2, NO_3, NH_4 and PO_4) tidak menunjukan perbezaan yang signifikan (ANOVA dua hala, $p < 0.05$). Sementara itu, kualiti enapan dan bahan organik mempunyai perbezaan yang signifikan di antara stesen dan transek (ANOVA dua hala, $p < 0.05$). Ujian kolerasi Pearson menunjukkan terdapat korelasi kuat antara kepadatan Foraminifera dengan kualiti enapan (pasir kasar, r=0.48; pasir sederhana, r=0.57; pasir halus, r=0.55; pasir sangat halus, r=0.66; kelodak dan tanah liat, r=-0.58, $p < 0.01$). Taburan ruangan Foraminifera dengan jelas dipengaruhi oleh persekitaran enapan dan bahan organik. Oleh itu, walaupun kualiti air tidak menunjukan tanda-tanda pencemaran, kajian teliti Foraminifera membuktikan sebaliknya. Secara keseluruhan, kajian ini menyimpulkan bahawa himpunan Foraminifera berubah sebagai tindak balas terhadap kehadiran stresor antropogenik yang tenggelam dan terkumpul di dasar laut. Oleh yang demikian, Foraminifera telah terbukti sebagai penunjuk biologi yang sangat baik dan murah di sekitar perairan Malaysia.

DISTRIBUTION AND ABUNDANCE OF BENTHIC FORAMINIFERA IN THE COASTAL WATERS AROUND PENANG NATIONAL PARK

ABSTRACT

A study on the distribution and abundance of benthic Foraminifera was conducted along the coastal waters of Penang National Park, Malaysia. Four selected sites (i.e Teluk Bahang, Teluk Aling, Teluk Ketapang and Pantai Acheh) were chosen based on the degree of anthropogenic activities. A total of 192 sediment samples were collected bimonthly between October 2010 and September 2011. Bulk sediments samples, water samples and environmental parameters were collected along the transect at 200 m intervals from the subtidal zone and extending up to 1200 m offshore. Foraminiferal assemblages comprised of 14 genera which include *Ammonia*, *Elphidium*, *Ammobaculites*, *Nonionoides*, *Bolivina*, *Asterorotalia*, *Reophax*, *Eggerella*, *Textularia*, *Quinqueloculina*, *Astacolus*, *Lagena*, *Fissurina* and *Hopkinsina* were identified. The stress-tolerant taxa, *Ammonia* (56.35 %) and *Elphidium* (9.11 %) dominated the assemblage at all sites. Meanwhile, the other functional groups (i.e. other smaller miliolids and agglutinated) which occurred <5% were considered as rare or accidental species. Diversity indices showed that Pantai Acheh has a diverse assemblage (H' = 0.57) followed by Teluk Ketapang (H' = 0.47), Teluk Bahang (H' = 0.43) and Teluk Aling (H'= 0.35). Species assemblage indicated the anthropogenic effect on Foraminifera reduced with increase distance from the shore. Application of FORAM index (FI = 1.0 ~ 2.0) and *Ammonia*-

Elphidium index (AEI = 85 ~ 100) suggested a stressed condition along the study sites. In addition, a greater effect from anthropogenic stressor was observed at area closer to the shore especially in Teluk Bahang and Teluk Aling. Organic matter pollution from aquaculture activity in Teluk Bahang resulted in significantly larger test size of *Ammonia*. Cluster analysis classified the stations into four groups, each influenced by different degree of anthropogenic stressors. Group A (i.e 200 m at Teluk Bahang and Teluk Aling) was characterized by significantly high organic matter (17.14%, one-way ANOVA, $p< 0.05$), strong hypoxic condition (AEI= 98, one-way ANOVA, $p< 0.05$) and low pH value (8.37, one-way ANOVA, $p< 0.05$). This group has forty times higher foraminiferal abundance but relatively low in diversity. Group B consisted of stations situated further away from the shore and showed significantly low organic matter content (9.67%, one-way ANOVA, $p< 0.05$). Group C represented the marginal environmental condition with muddy substrate and significantly high total suspended solids (166.03 mg/L, one-way ANOVA, $p< 0.05$). Group D is characterized by low mean abundance and low diversity. Overall, the spatial distribution of *in situ* parameters (temperature = 29.97 ± 0.05 °C, salinity = 29.52 ± 0.08 ‰, dissolved oxygen = 5.21 ± 0.08 mg/L and pH = 8.43 ± 0.01) and selected nutrients (NO_2, NO_3, NH_4 and PO_4) showed no significant difference (two-way ANOVA, $p< 0.05$). Meanwhile, the sediment quality and organic matter were significantly different between stations and transects (two-way ANOVA, $p< 0.05$). The Pearson's correlation test indicated a strong correlation between foraminiferal density and sediment quality (coarse sand, r=0.48; medium sand, r=0.57; fine sand, r=0.55; very fine sand, r=0.66; silt and clay, r=-0.58, $p< 0.01$). The spatial distribution of Foraminifera was clearly associated with benthic sedimentary environment and organic matter. Therefore, although water quality indicated no sign of pollution, details study on Foraminifera revealed otherwise. Overall, this study concludes that foraminiferal assemblages changed in response to the presence of anthropogenic stressor that sink and accumulated on the sea bottom. Hence, Foraminifera was proven to be an excellent and cheap bio-indicator in Malaysian coastal waters.

1.0 INTRODUCTION

The coastal zones which include mangrove forest, estuaries, lagoons and coastal plains are areas where terrestrial and marine ecosystems interact. These areas face various stressor either natural (e.g temperature and salinity changes) or human derived stressor (such as siltation) and causes changes to the environment. Hence, the worldwide urbanization in the coastal zones had contributed many human-derived contaminants. The marginal marine ecosystems act as natural sink for the pollutant whereas the sediments trap and accumulate pollutant from the water column above. Over the time, the levels of pollutants accumulated create inhabitable condition for certain benthic faunas especially those with low tolerance level. The accumulation of pollutants interrupts the food web and causes deterioration of the aquatic ecosystem.

The Strait of Malacca is known as the busiest route on west coast of Peninsular Malaysia. Penang Island is one of the islands situated at the northern part of the Malacca Strait. The island is divided into two parts; the South West Penang Island and North East Penang Island. The island experiences tropical climates with an average rainfall of 2500 mm (Malaysian Meteorological Department, 2010). There are two monsoon seasons that have pronounced effect on Penang Island. The North East monsoon brings precipitate rain to Peninsular Malaysia in December and February. The South East Monsoon is known as dry seasons and occurs between June and August (Chuah et al., 2000).

By year 2011, Penang state was reported to have the highest population density in Malaysia in which 2 457 people per sq km were recorded on the island while 1on the main land the density is 1056 people per sq km. More than 80% of the total population in Penang Island live in the coastal areas. Due to the limited land area in

Penang Island (292 km^2) and fast growing population, many coastal land reclamation projects have been carried out to meet the demand. These have started as early as 1970s. As a result of poor planning and rapid development, Penang Island is now on the edge of losing its natural heritage (Chan et al., 2003; Hong & Chan, 2010).

Thus in 2003, Penang National Park which was formerly known as Pantai Acheh Reserved Forest is gazetted under the National Park Act of 1980. Penang National Park hosts unique ecosystems including meromictic lake, mangrove swamp, sandy beaches and rocky beaches (Hong & Chan, 2010). Sandy beaches in Penang National Park have long served as nesting area for Green Turtle (*Chelonia mydas*) and Olive Ridley Turtle (*Lepidochelys olivacea*) (Sarahaizad et al., 2012). The presence of rich biodiversity both in flora and fauna in Penang National Park has made conservation work more essential.

The main issue faces by Penang Island is the damages of its natural diversities due to the rapid development. Siltation from construction, poorly managed ecotourism and fishing activities are among the causes that contribute to this problem. Hence, despite the conservation efforts that have been made, coastal waters around Penang National Park are still on threat as marine pollution could not be stop due to the boundless characteristics of the ocean.

In order to promote better management of land use and coastal waters, it is important to distinguish the present condition of sediment and water quality around Penang National Park. A good bio-indicator, the benthic organisms for instance, would make a good tool for such monitoring. This includes the prominent benthic macrofauna and meiofauna. In this study, benthic Foraminifera are chosen to be the monitoring tool as they are proven to be an excellent indicator for sediment quality, heavy metal pollution, organic pollution and water quality (Carnahan, 2005; Hallock et al., 2003; Sen Gupta, 2003 and Alve, 1995).

Foraminifera are single-celled organisms that consist of cytoplasm with one or more nuclei (Murray, 1979). Foraminifera have existed as fossil and they are still living in the modern ocean now. The presence of Foraminifera has been recorded as early as the Cambarian era. It was during Phanerozoic era, that Foraminifera evolve and conquer various marine environments and some fresh water biota (Goldstein, 2003). The only reason that makes dating possible in Foraminifera is because they have shell like structure, known as test. The presence of test which encloses the soft part of Foraminifera, distinguish this group from other living amoeboid protists (Phleger, 1960). Most forams possess test which is made from calcium carbonate. Some with chitinous test and others with agglutinated sand grains test (Phleger, 1960).

Another special feature of Foraminifera is the presence of pseudopodium which involves with basic functions such as feeding, movement and mating (Goldstein, 2003).

So far, over 40000 species of Foraminifera have been described (Cortés et al., 2009). Many of the species belong to the benthic groups while a smaller group belong to the planktonic groups. The planktonic groups reside in the water column and recorded higher rate of movement. On the other hand, benthic groups reside within the sediment on the seafloor and have lower rate of movement (Murray, 2006; Bellier et al., 2010). Identification of Foraminifera is based on several morphological features. The principle types of chamber arrangement, aperture and test structure are widely used as keys to classification.

Foraminifera are ubiquitous; they have been recorded on various continental shelves and slopes (Sen Gupta, 2003). The distribution of Foraminifera is mainly affected by several microhabitat factors. One of the factors is the combination between physical, chemical and biological conditions that allows certain species to successfully survive the ecology while inhabitable to others (Jorissen, 2003).

The Foraminifera has various nutritional modes (Bellier et al., 2010). Therefore they have successfully dominated most of the marginal and marine habitat. The Foraminifera's feeding modes include deposit feeding, carnivore, parasitism, suspension feeding, grazing, symbiosis and some direct uptake of dissolved organic carbon (DOC). Foraminifera use their pseudopodial net to trap suspended food particles and extract food from substrates (Murray, 1979).

Locomotion in forams depends on the pseudopodia. Foraminifera normally have their pseudopodial net spreads over the substrate and their test aperture facing the substrate (Murray, 1979).

Foraminifera undergo alteration of sexual and asexual generations (Goldstein, 2003) and grow by increasing their size or by adding new chamber (Goldstein, 2003). Foraminifera play an important role in the trophic level. They serve as food source to selected shrimps, molluscs and deposit eating invertebrates (Murray, 1979).

They also hold a significant importance as marine heterotrophic protest (Sen Gupta, 2003). The evolution of Foraminifera, especially those related to paleoceanographic construction, has received a great attention for the past decade (Pawlowski et al., 2003). Foraminifera are known for their excellent fossil records, which allow the study of evolutionary history of the early ocean (Phleger, 1960).

Until recently, Foraminifera have become a famous indicator for pollution monitoring. Firstly, the presence of shell-like-structure (test) enables Foraminifera to be preserved, hence making the study of the present and past possible (Scott et al., 2001; Carnahan, 2005). Secondly, the sampling of Foraminifera is cost effective and by it leaves negligible impacts towards the ecosystem (Alve, 1995). Thirdly, since Foraminifera occur in high density, small sample is enough to satisfy the statistical requirement. Finally, the assemblage of Foraminifera is very specific and changes according to their environment (Alve, 1995; Culver & Buzas, 1995). Hence, many researchers utilise Foraminifera as indicator in coral reef, subtidal area, estuaries, salt marshes and mangroves (Scott et al., 2001; Sen Gupta, 2003; Murray, 2006).

Since the assemblage of Foraminifera shifts according to its immediate environment, many authors have proposed the use of a Foraminifera index. Many of these indices compare the density of highly tolerant taxa with sensitive taxa. The *Ammonia-Elphidium* index was proposed by Sen Gupta (1996) where he uses this index to represent the presence of oxygen within the sediment. Another index is the FORAM index (Hallock et al., 2003). This index serves as a monitoring tool that represents the water quality as well as sediment quality at a particular area. In 2012, Hallock wrote a review on this index, looking at its problems, advantages and its applicability. She mentioned that this index has been used successfully in areas which formerly suspected to require some alterations in the calculations (Hallock, 2012).

Study on Foraminifera in Malaysian waters has started from 2000 by Razarudin. Later in 2007, several researchers give focus on Foraminifera distribution in mangrove area. These include studies done by Mohd Lokman et al., (2007) and Wan Nurzalia (2011). However, the application of Foraminifera as pollution indicator only takes place in Setiu, Terengganu (Culver et al., 2012). So far, there was no study on Foraminifera conducted in the vicinity of coastal waters around Penang

Island. Thus, it will be such an interesting study to explore the application of Foraminifera as a monitoring tool and to determine the actual condition of coastal area surrounding Penang National Park. Moreover, this research will also make a good baseline study for both, future and present time.

This study used physical and chemical parameters together with foraminiferal assemblage to determine the present health condition of the coastal waters and sediment quality around Penang National Park.

Objectives:

The aims of this study are:

1) to determine the distribution and composition of benthic Foraminifera;
2) to assess the state of water quality and sediment quality around the Penang National Park; and
3) to recognize the possibility in utilising Foraminifera as bio-indicator as an early pollution indicator.

2.0 LITERATURE REVIEW

2.1 Systematic of Foraminifera

When Foraminifera was first discovered in 1700, they were regarded as Cephalopods. Many naturalists in the early days considered Foraminifera as *Nautilus* (Sen Gupta, 2003). Up to the early nineteenth century, the identification of Foraminifera was based on the aspect of test morphology, particularly the chamber arrangement. In 1852, d'Orbigny's classification changes the way we look at Foraminifera today (Sen Gupta, 2003). D'Orbigny concluded that, Foraminifera are unicellular cells and they differ from those found in cephalopods. He classified Foraminifera within the Class Sarcodina (Sen Gupta, 2003). Carpenter et al., (1862) focused on wall structure for foraminiferal classification. Joseph A. Cushman, who was one of the famous Foraminifera taxonomists, started a new classification method which included the morphology, geological history and regions of distribution (Cushman, 1928). Important taxonomic work done by Cushman in 1920s'-1940s' was widely accepted and had influenced the classification of Foraminifera until today (Sen Gupta, 2003; Murray, 2006).

Two decades after Cushman's works, Loeblich & Tappan (1964) introduced a better classification technique by comparing the wall composition and its structure (Figure 2.1). Recent classification by Lee (1990a) has promoted Foraminifera as a class instead of an order. Sen Gupta (2003) summarized the recent classification of Foraminifera in his book; Modern Foraminifera. Currently, this study refers to the most recent systematic classification of Foraminifera as proposed by Sen Gupta (2003).

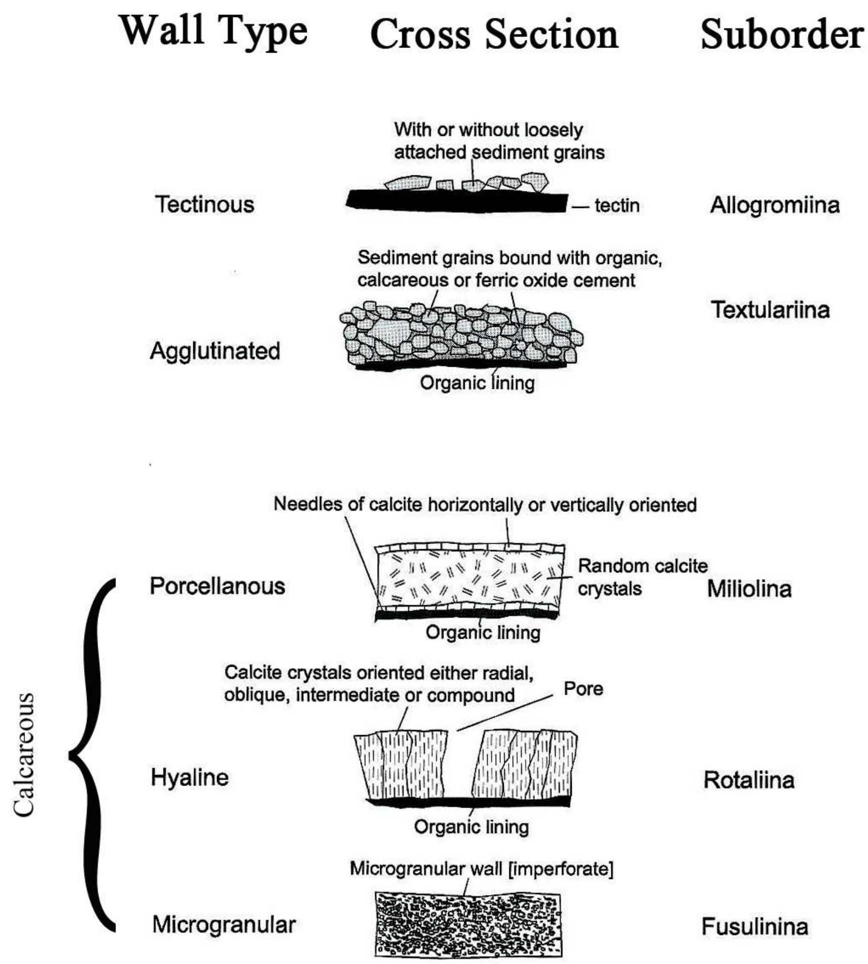

Figure 2.1 Types of wall composition and structure used in taxonomic work (Scott et. al, 2001)

Modern classification places Foraminifera under the kingdom of Protoctista, phylum Granuloreticulosa and class Foraminifera. There are altogether 16 orders with more than 4000 living species identified (Bellier et al., 2010).

2.2 Morphology and anatomy of benthic Foraminifera

Foraminifera are also known as the hole bearers, made up from cytoplasm, nuclei and most of them, test. The test comes in various forms and types of wall composition with obvious soft parts, the reticulate pseudopodia (Murray, 1979). The wall's composition and structure is an important feature for classification and identification purposes (Murray, 1979; Cushman, 1928; Sen Gupta, 2003). The simplest test form is in Allogromiidae (Cushman, 1928). These single celled protists accomplish their essential life functions with the help of pseudopodia that may split and rejoin (Goldstein, 2003).

2.2.1 General morphology for classification

Foraminifera's simplest test consists of a single chamber while more complex form can be made up of numerous chambers that are arranged according to growth pattern (Murray, 1979). The test's shapes range from coiled to elongate or even a cylindrical spiral. Primitive and modern foraminifera can be distinguished based on their shapes. More primitive group in foraminifera tend to be uncoiled compared with the recent group like Rotaliidae (Cushman, 1928). The basic morphology of test are; chambers, suture, umbilicus, aperture, rental process, keel and tubercle. However, not all species possess the entire characteristic mentioned. Figure 2.2 & 2.3 shows a basic diagram of general feature on Foraminifera's test and the pseudopodia. Figure 2.4 shows a general morphology used in species identification.

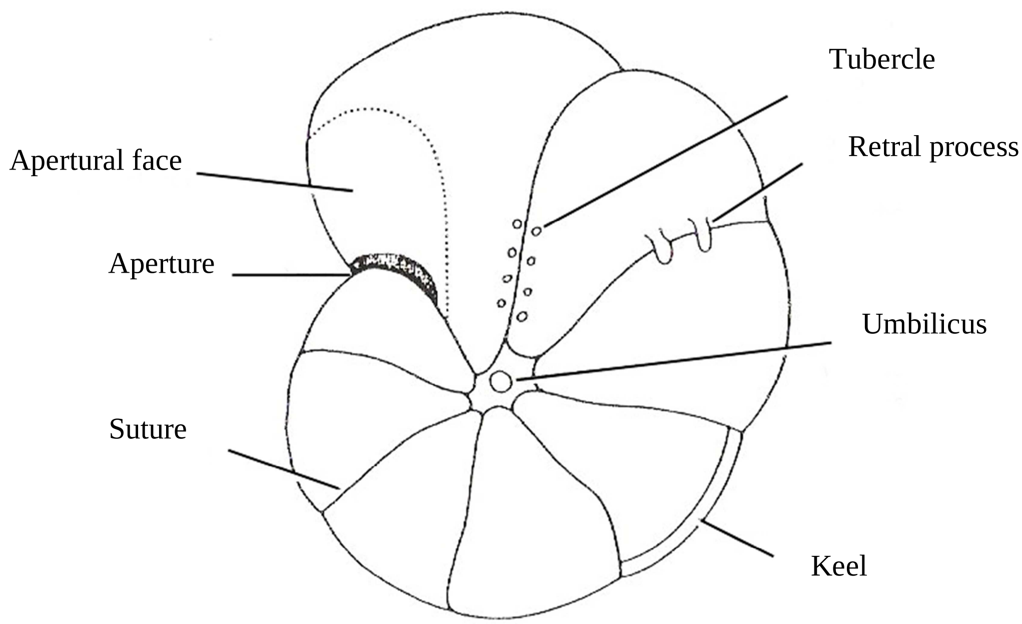

Figure 2.2 General Foraminifera test morphology (Murray, 1979).

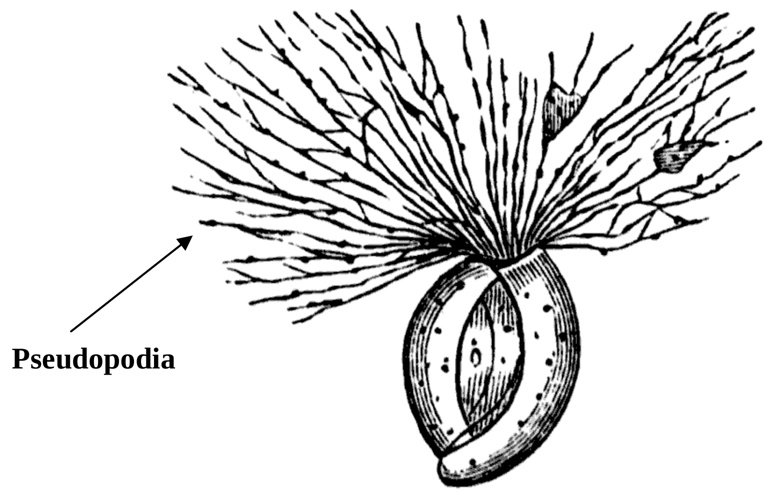

Figure 2.3 Reticulate pseudopodia used for feeding, mating and locomotion (Goldstein, 2003)

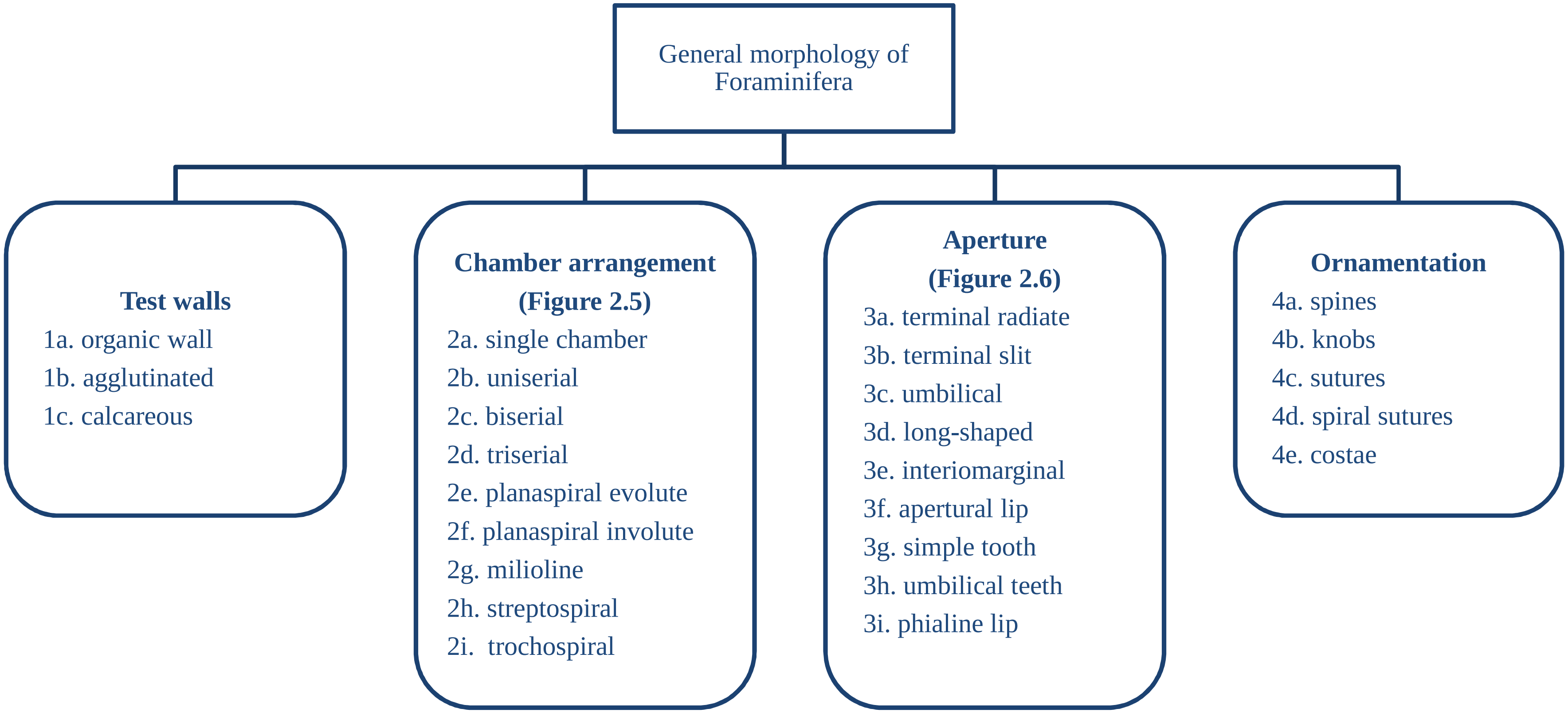

Figure 2.4 Diagram on general morphology of Foraminifera according to Cushman (1928) & Sen Gupta (2003).

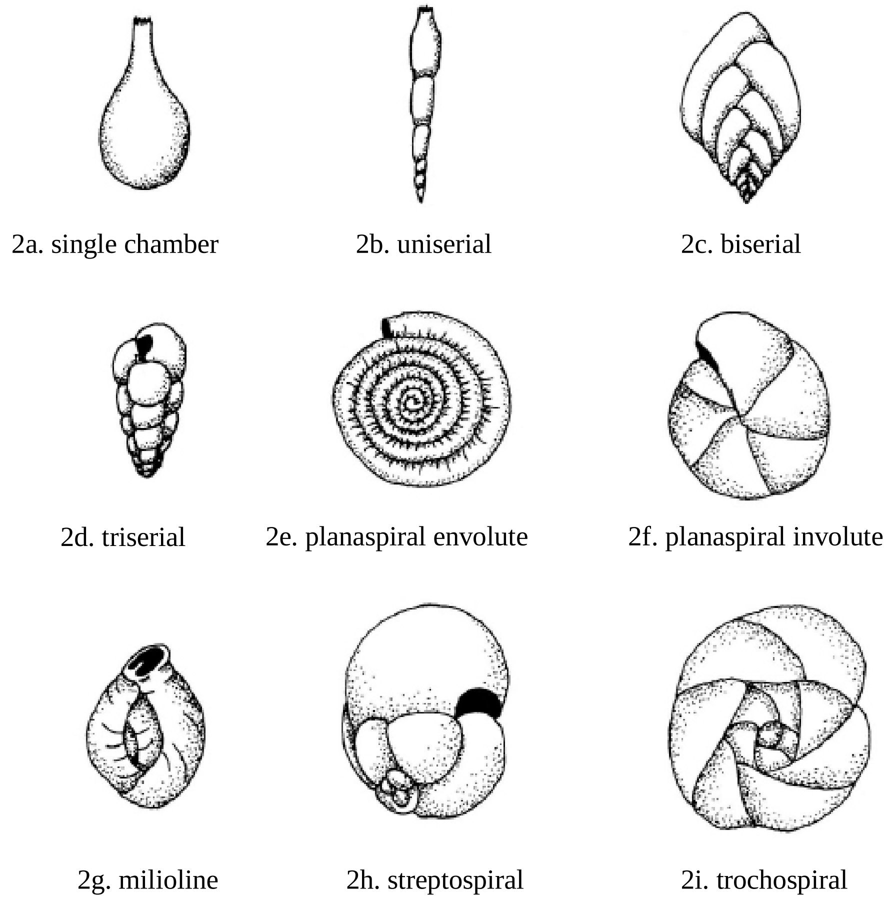

Figure 2.5 Chamber arrangement used in identification (Sen Gupta, 2003; Loeblich & Tappan, 1988)

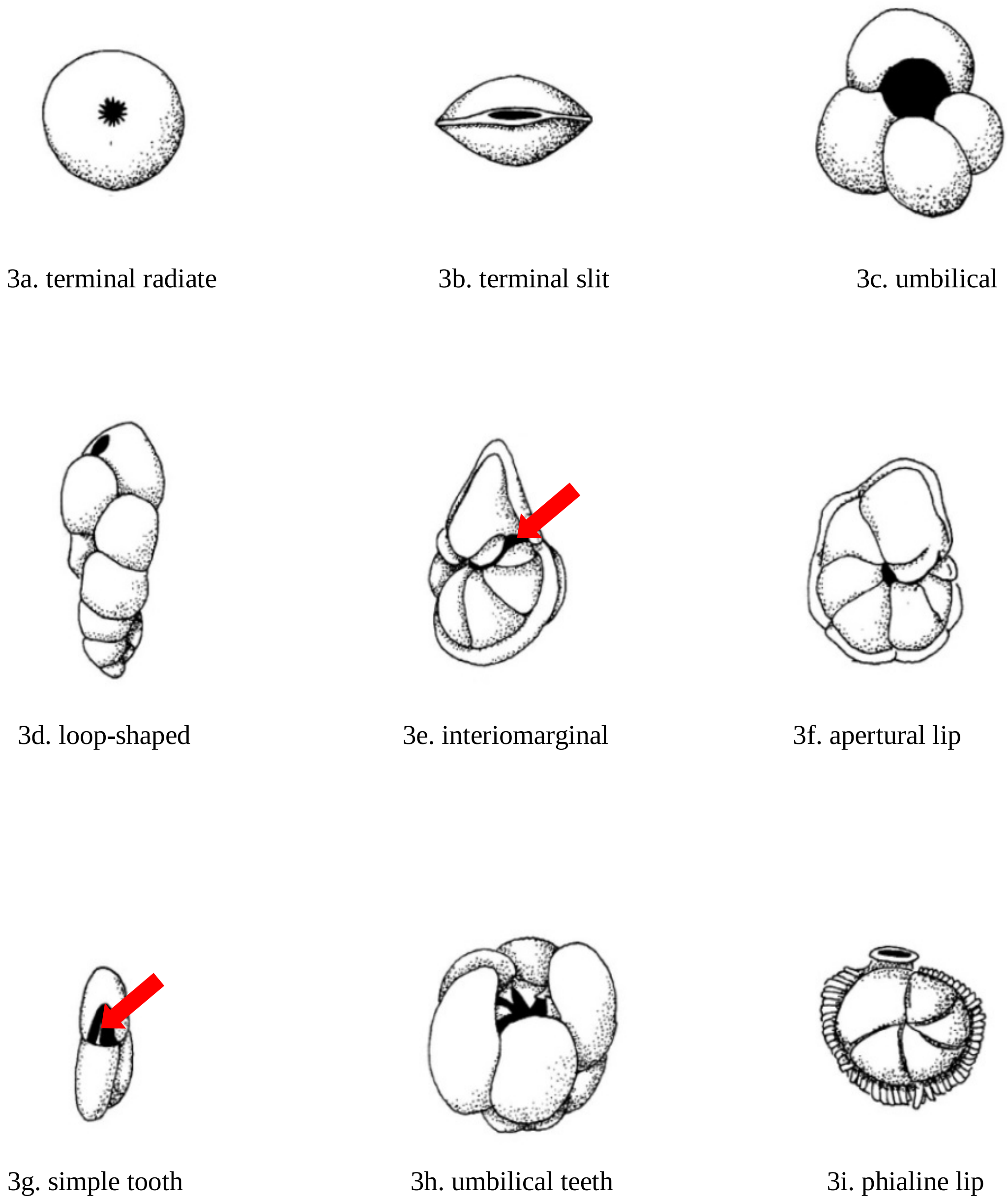

Figure 2.6 Types of aperture in Foraminifera that are used in identification (Sen Gupta, 2003; Loeblich & Tappan 1988). *Red arrow indicates the aperture opening*

2.2.2 Test wall composition

The test of forams can be classified into groups based on the materials that made up the test's wall. The major groups are; 1) organic-walled test group. It builds up its test with the secretion of organic materials, 2) agglutinated test group. It makes its test by agglutinating particles from its immediate environment (Sen Gupta, 2003), 3) calcareous test group refers to forams that has its test wall made up from secreted calcium carbonate and 4) siliceous test refers to forams that has its test wall made of silica.

The agglutinated test of forams might contain a wide range of foreign agglutinated particles such as sand grains, sponge spicules and mica plates. They are cemented together during test constructions (Bellier et al., 2010; Goldstein, 2003; Cushman 1928). Certain species in this group use whichever particles that are available, while others may be selective (sponge spicules, quartz grains or mica flakes) when constructing their test (Cushman, 1928; Sen Gupta, 2003; Goldstein, 2003; Bellier et al., 2010).

2.2.3 Chambers arrangement

The number of chambers present in forams and their form of arrangements are of great diversity. Below are common types of chambers arrangement of benthic forams along Penang coastal waters. The simplest form of chamber arrangement is the single chambered test that consists of spherical or tubular chamber (as shown in Fig 2.4 2a). Single series chamber that is added in straight line or slight curved alignment is uniserial and double linear series chamber is biserial. On the other hand, triple linear series chamber is triserial and multiserial if more than three chambers are arranged together in a linear series. The planaspiral test has its chambers arranged in spiral within a single plane. This type of chamber arrangement may make the test looks similar on both sides. The evolute planaspiral (Fig 2.4 2e) has visible whorls while involute planaspiral (Fig 2.4 2f) has only the last whorl is visible. The trochospiral chamber arrangement (Fig 2.4 2i) is almost similar to the planaspiral but in trochospiral test, the dorsal's and ventral's face are different. However, in the miliolids group, the curved chambers are arranged in series where each successive chamber is placed at an angel up to 180° from the previous one (Fig 2.4 2g). Numerous other types of chamber arrangement may also present in Foraminifera.

2.3 Habitat and ecology of benthic Foraminifera.

2.3.1 Distribution and diversity

There are two main groups of Foraminifera. First, is the highly diverse benthic group and second, is the planktonic group (Sen Gupta, 2003; Murray, 2006). The distributions of planktonic groups are confined to open water settings (Bellier et al., 2010). They are usually found floating in near-surface waters to depth of several hundred meters. Benthic Foraminifera on the other hand, which are a more sessile group may be found on the surface of the sediment, within the sediment or found attached to substrates (Murray, 2006). They occupy in all marine habitats including marginal environment (lagoons, estuaries, deltas, mangroves and saltmarshes), coastal water and deep sea (Scott et al., 2001). However, it is obvious that many species prefered relatively shallow waters, where there will be enough light penetration and food supply (Bellier et al., 2010). Therefore, higher diversity of Foraminifera was discovered on continental shelf, especially in reef environments (Scott et. al, 2001; Murray, 2006; Bellier et al., 2010).

The distributions of Foraminifera species were determined by environmental factors such as oxygen level, organic matter content, salinity and temperature. The agglutinated Foraminifera species preferred area with low temperature and salinity (Scott et al., 2001). The larger carbonate secreting species on the other hand chose to live in area with high as well as stable temperature, salinity and pH (coral reef environment).

Benthic Foraminifera’s species that inhabit marginal environment (e.g. mangrove) are characterized with high tolerances towards alternation of salinity, temperature and pH. Typical Foraminifera that inhibit the mangrove environment largely possess agglutinated and hyaline test (e.g. *Ammonia, Quienquloculina, Ammotium, Arenoparrella, Cribrononion, Elphidium*) (Sohrabi-Mollayousefy et al., 2006; Murray, 2006; Javaux & Scott, 2003; Scott et al., 2001). A study done by Biswas (1976) on foraminiferal assemblage in Sumatra mangrove indicated the presences of common species belong to agglutinated forms.

Nearshore environment with shallow water condition (1 m – 20 m) favours the distribution from the order of Rotaliida, Buliminida and Textulariida (Murray, 2006, Phleger, 1960). According to Sen Gupta (2003) typical intertidal communities are includes the calcareous species such as *Ammonia beccarii* and *Elphidium williamsoni*. In many shallow near shore settings, several significant factors that may influence the communities are types of substrate, current, salinity, pore-water oxygen content and wave action. Coastal waters with high organic matter and low oxygen content seem to favour less number of species. These species are usually known either as stress-tolerant taxa or opportunistic taxa (Hallock, 2003; Carnahan, 2005). Therefore, *Ammonia* and *Elphidium* (both stress-tolerant taxa) are usually found to dominate the assemblages in polluted coastal environment (Alve, 1995; Scott et al., 2001).

Symbiont-bearing Foraminifera are known to host various types of algae. This group of Foraminifera is usually larger in size and prefers places that receive enough sunlight. Due to this, the symbiont-bearing Foraminifera exhibit high diversity at tropical regions especially in coral reef ecosystem (Hallock, 2003). As larger symbiont-bearing Foraminifera prefer more stable environment (Murray, 2006), any subtle changes (i.e. nutrient loading, increase in temperature) may cause serious threat to its existence. Consequently, as proposes by Hallock et al. (2003) symbiont-bearing Foraminifera will make a good indicator for the reef vitality

2.3.2 Nutrition

Foraminifera practise various types of nutrition modes which includes grazing, carnivory, herbivory, direct uptake of dissolved organic carbon (DOC), omnivorous, passive suspension feeding, parasitism, resource partitioning and symbiosis (Goldstein, 2003; Murray, 2006).

Herbivory group of Foraminifera is divided into two; 1) passive herbivore - they have restricted movement and only feed on food availability around the sites of attachment and 2) active herbivore - they use reticulopodia to move and collect food particles (Murray, 2006). Herbivorous Foraminifera feed on algae, diatoms and bacteria that are abundant at the euphotic zone. Carnivorous feeding mode can be found in both benthic and planktonic groups (Goldstein, 2003). Omivorous group is also common in benthic Foraminifera. They feed on both animals and plants that are easily available for this kind of group (Murray, 2006).

Foraminifera which are passive suspension feeder are usually either epifaunal or sessile. They attach to hard substrate and filter food particles as water current pass through them (Murray, 2006).

Some species of free-living Foraminifera practice parasitism nutrition mode. This group usually infests on other Foraminifera, mollusc, sponges or stone coral (Goldstein, 2003).

Apart from that, symbiosis nutrition mode occurs in the symbiont-bearing Foraminifera where by larger Foraminifera host autotrophic endosymbiotic algae (Murray, 2006). This mode of feeding is more common in larger tropical Foraminifera (Hallock, 2003). Hallock (2003) lists three potential benefits of endosymbiosis to Foraminifera; 1) energy from photosynthesis, 2) enhancement of test calcification and 3) uptake of host waste metabolites by algae.

2.3.3 Reproduction

Generally, Foraminifera are characterized with a complex life cycle known as the alternation of generations i.e. alternation between haploid and diploid generations (Goldstein, 2003). However, not all species perform the same life cycle. In some species, alternation of generation reproduction is known to be obligatory while others may be facultative (Goldstein, 2003). The Foraminifera are known as gamont during haploid phase and agamont during diploid phase

2.4 Significant of benthic Foraminifera

Benthic foraminiferal assemblage has various significant usage and application. Among these are biostratigraphy (Culver & Buzas, 2003; Afzal et al., 2005), paleoecology (Culver, 1996) and paleoceanography study (Ta et al., 2001; Horton et al., 2007). Moreover, Foraminifera are highly utilised as proxy for anthropogenic pollution (Burone et al., 2007; Carnahan et al., 2009; Martinez-Colon & Hallock, 2010; Buosi et al., 2010), coral reef condition (Hallock et al., 2003) and other environmental changes (Mendes et al., 2004).

In the early days, the applications of Foramnifera were formerly associated with paleontology and oil exploration. It was about three decades ago, scientists had started using forams in pollution monitoring study. A case study in Chesapeake Bay showed that the abundance of *Ammonia* has significantly increased between 1680 and 1970 (Murray, 2006). Scientist believed that the increased of *Ammonia* is due to hypoxic condition brought by anthropogenic activities. Alve (1995) had done an extensive review on Foraminifera as indicators in marginal environment, in which she compared the characteristic of foraminiferal assemblages with the types of pollutant. She founds that the ability of different species to withstand different types of pollution, made Foraminifera as excellent proxies of pulp (paper), chemical, heavy metal, oil, thermal and aquaculture originated pollutants. Study by Frontalini and Coccioni (2008) confirmed the suitability of benthic Foraminifera as indicator for heavy metal pollution in marine coastal settings. Test deformation (Figure 2.7) in Foraminifera species is typical at sites that are affected with heavy metal pollution. Similar results are obtained from a research done by Carnahan (2005) in Biscayne Bay. *Ammonia beccarii* and *Elphidium excavatum* are two common species confirmed to be associated with pollution (Murray, 2001).

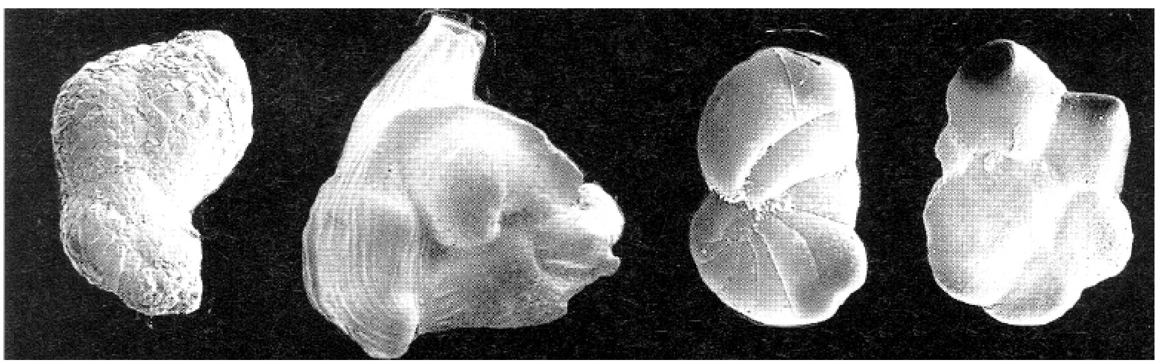

Figure 2.7 Examples of test deformation and abnormalities in Foraminifera (modified from Sen Gupta, 2003)

The symbiont-bearing groups are Foraminifera that perform symbiosis with the algae found in coral reef area. Several authors utilize the symbiont-bearing Foraminifera to monitor water quality (Uthicke & Nobes, 2008; Uthicke et al., 2010; Narayan & Pandolfi, 2010) while others use this group to indicate the health of coral reef (Hallock et. al, 2003; Suhartati, 2010). Hallock et al. (2003) has suggested an application of Foraminifera in Reef Assessment and Monitoring (FORAM) Index to monitor the condition of coral reef and environment suitability for the continuation of reef growth. This index also provides a measurement of the water quality at the monitoring area. As Foraminifera index shifts according to their immediate environment, Hallock et al. (2003) divides them into functional groups. Table 2.1 shows the functional groups and the genera classified under them. Symbiont-bearing groups are reef-associated Foraminifera and they live side by side with symbiotic algae. The stress-tolerance taxa on the other hand are an opportunistic group. They may tolerate larger environmental changes. Hence, more symbiont-bearing taxa over stressed-tolerant taxa indicate better water quality.

In biostratigraphy and palaecology study, researchers utilize the modern foraminiferal assemblage as analogues of the past in an attempt to understand the past environmental conditions (Murray, 2006; Friedrich, 2010; Ta et al., 2001). Preservation of their test in marine sediment over the years has created a timeline. For example, foraminiferal test near Mekong River are used in carbon dating in an attempt to understand the sea level changes since the late Pleistocene (Ta et al., 2001). One research in the Gulf of Mexico has employed Foraminifera as a tool in dating the age of the Gulf (Arz et al., 2004).

In palaeoceanography study, Foraminifera play a role as indicator of sea level changes. Foraminifera offer accurate zonation that enables us to detect even small sea-level changes (Scott et al., 2001). Besides that, coastal Foraminifera were also used to interpret seismic events and tsunami occurrence by looking at species assemblages in the sediment. (Scott et al., 2001; Hawkes et al., 2007)

Table 2.1 FORAM index functional groups, genera and their distribution. (Modified from Hallock et al., 2003 and Carnahan, 2005).

Functional Group	**Order**	**Family**	**Genera**	**Distribution**
Symbiont-bearing	Rotaliida	Amphisteginidae	*Amphistegina*	Circumtropical
		Calcarinidae	5 genera	Indo-Pacific
		Nummulitidae	*Heterostegina*	Circumtropical
	Miliolida	Alveolinidae	*Alveolinella*	Indo-Pacific
			Borelis	Circumtropical
		Peneroplidae	Several genera	Circumtropical
		Soritidae	*Sorites*	Circumtropical
			Amphisorus	Circumtropical
			Marginopora	Indo-Pacific
Stress-tolerant	Trochamminida	Trochamminidae	Several genera	Cosmopolitan
	Textulariida	Lituolidae	Several genera	Cosmopolitan
	Buliminida	Bolivinidae	Several genera	Cosmopolitan
		Buliminidae	Several genera	Cosmopolitan
	Rotaliida	Rotaliidae	*Ammonia*	Cosmopolitan
		Elphidiidae	*Elphdium*	Cosmopolitan
Other Small Taxa	Miliolida	Most execpt larger taxa noted above		Cosmopolitan
	Rotaliida	Most except those noted above		Cosmopolitan
	Other	Most		Cosmopolitan
	Textulariida	Textulariidae	*Textularia*	Cosmopolitan
		Astrohizidae	*Bigenerina*	Cosmopolitan

Oxygen is one of the limiting factors towards benthic foraminifera in shallow region (Scott et al., 2001) thus benthic Foraminifera make an excellent indicator of sediments hypoxic condition (Bernhard et al., 1997). Certain species of forams are also known as the opportunistic species. They may strive better in oxygen depleted environment compare to others. Therefore, suggestion in using *Ammonia – Elphidium* Index is very applicable in monitoring the bottom water oxygen concentration (Sen Gupta, 2003).

The ability of Foraminifera to indicate changes makes it as a popular tool in ocean monitoring. The availability of various indices related to Foraminifera makes them easy to be employed at most study sites.

2.5 Past studies on Foraminifera.

The discovery of Foraminifera dated back to the eighteenth century when the invention of microscope takes place. A drawing of *Elphidium* by Leeuwenhoek proves the discovery of Foraminifera as early as 1700. However, the name ‘Foraminifera’ was not yet introduced back then. Most authors have mistaken Foraminifera with mollusk, cephalopods and even worm (Sen Gupta, 2003; Murray, 2006).

During the nineteenth century, works that have been done were more focused on classifying these shelled protists. A famous researcher, d’Orbigny (1826) classified Foraminifera within the class Cephalopodes. He named the order Foraminifera (hole bearing) after the discovery of hole on the test (Sen Gupta, 2003; Lipps et al., 2011). Another distinguish taxonomic work was carried out by Brady (1884), in which he examined samples from the Challenger expedition (Sen Gupta, 2003). Other major contributors in the nineteenth century include work from Williamson and Carpenter (Murray, 2006; Lipps et al., 2011).

There were increases of ecological works as well as acknowledged classification on Foraminifera throughout the twentieth century. Authors that contributed to taxonomic work during that time were Cushman (1928), Loeblich & Tappan (1964) and Lee (1990a). The ecological work on Foraminifera started in 1935 by Rhumber (Murray, 2006). Since then, growing interest in Foraminifera reproduction mode, habitat, nutrition and growth, had led to the increase of ecological works done by other researchers. According to Sen Gupta (2003), the research in Foraminifera ecology were intensified due to their ability in providing clues to the understanding of geological changes in the past. Early works on significant use of benthic Foraminifera as proxy indicator were initiated by Resig (1960) and Watkins (1961) in the early 1960s’ (Alve, 1995). In late