DISTRIBUTION AND ABUNDANCE OF BENTHIC MOLLUSCS IN COASTAL WATERS OF NORTHWESTERN PENANG ISLAND

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Appendix 8: Alianie M. (2012). Study on the Distribution, Abundance and Composition of Macrobenthic (Mollusc) along Penang National Park Coastal Water. In: *6th PPSKH Postgraduate Biocolloquium*, 14 and 15 February 2012. School of Biological Sciences, Universiti Sains Malaysia, Penang, Malaysia.

TABURAN DAN KELIMPAHAN MOLUSKA BENTIK DI PERAIRAN BARAT DAYA PULAU PINANG

ABSTRAK

Kajian ini dijalankan dari Oktober 2010 sehingga September 2011 di empat tapak pensampelan—Teluk Bahang, Teluk Aling, Teluk Ketapang, dan Pantai Acheh. Di setiap tapak, sampel moluska bentik, sedimen, dan parameter kualiti air diambil setiap 2 bulan, pada selang 200 m dengan enam titik pensampelan. Sejumlah 21 famili, 21 genera, dan 25 spesies moluska bentik telah direkodkan dengan kelimpahan purata adalah 631.6 moluska/m^2. Spesies dominan yang dijumpai dalam kajian ini adalah *Sacella bellula*, *Nucula* sp., *Timoclea* sp., *Vaceuchelus* sp., *Ethaliella* sp., *Ringicula propiquans*, *Retusa* sp., dan *Lucidesta* sp. Kepelbagaian spesies (*H'* = 1.58) dan dominasi spesies (*D* = 0.74) tertinggi direkodkan di Pantai Acheh; kesamarataan spesies tertinggi direkodkan di Teluk Aling (E=0.50); jumlah kelimpahan tertinggi (35,757.3 moluska/m^2) dicatatkan di Teluk Bahang; dan kandungan bahan organik tertinggi (16.4%) direkodkan pada jarak 200 m. Parameter kualiti air yang diukur tidak mencatatkan perbezaan signifikan di antara 4 tapak kajian (ANOVA, $p > 0.05$). Nilai purata bagi parameter kualiti air adalah seperti berikut; nitrit, 0.015 ± 0.001 mg/L; nitrat, 0.01 ± 0.003 mg/L; ammonia, 0.02 ± 0.003 mg/L; ortofosfat, 0.12 ± 0.005 mg/L; jumlah pepejal terampai (TSS), 138.66 ± 6.38 mg/L; oksigen telarut, 5.21 ± 0.08 mg/L; pH, 8.57 ± 0.01; saliniti, 29.52 ± 0.08‰, dan suhu, 29.97 ± 0.05°C. Analisis kluster menggunakan cara Ward (Tukey's test, $p < 0.05$) memperlihatkan 3 kumpulan utama berdasarkan taburan saiz partikel, kandungan bahan organik, nilai pH, kepekatan ammonia, serta taburan dan kelimpahan moluska bentik. Kumpulan 1 terdiri dariTeluk Bahang (600-1200 m), Teluk Aling (200 m dan 600-1000 m), dan Teluk Ketapang (200-1200 m)—dicirikan

berdasarkan kandungan bahan organik beserta kelimpahan moluska bentik yang rendah. Kumpulan ini telah dibahagikan kepada dua kumpulan kecil (Kumpulan 1A dan kumpulan 1B). Kumpulan 1A merangkumi jarak terjauh di Teluk Ketapang (800 m - 1200 m), dan dicirikan dengan perbandingan suhu yang tinggi, pH yang tinggi dan bahan organik yang tinggi, tetapi kandungan oksigen terlarut yang rendah, berbanding Kumpulan 1B. Kumpulan 2 terdiri dari Pantai Acheh (200-1200 m) dan Teluk Aling (400 m dan 1200 m) —dicirikan dengan perbandingan bahan organik, serta kandungan lumpur dan tanah liat yang tinggi, tetapi kandungan ammonia yang rendah. Kumpulan 3 terdiri dari kawasan berpasir di Teluk Bahang (200-400 m)—dicirikan dengan kelimpahan moluska bentik yang tinggi. Secara keseluruhannya, hasil kajian ini mendapati taburan dan kelimpahan moluska bentik adalah bergantung kepada taburan saiz partikel, kandungan bahan organik dan aktiviti antropogen.

DISTRIBUTION AND ABUNDANCE OF BENTHIC MOLLUSCS IN COASTAL WATERS OF NORTHWESTERN PENANG ISLAND

ABSTRACT

The study was surveyed from October 2010 to September 2011 at four sampling sites—Teluk Bahang, Teluk Aling, Teluk Ketapang, and Pantai Acheh. At each site, benthic molluscs, sediments, and water quality parameters were sampled every 2 months, at intervals of 200 m with 6 sampling points. A total of 21 families, 21 genera, and 25 species were recorded with mean abundance of 613.6 molluscs/m^2. The dominant species found in the present study were *Sacella bellula*, *Nucula* sp., *Timoclea* sp., *Vaceuchelus* sp., *Ethaliella* sp., *Ringicula propiquans*, *Retusa* sp., and *Lucidesta* sp. The highest species diversity (*H*' = 1.58) and species dominance (*D* = 0.74) were recorded at Pantai Acheh; the highest species evenness was recorded at Teluk Aling (E=0.50); the highest total abundance (35,757.3 molluscs/m^2) was observed at Teluk Bahang; and the highest organic matter (16.43%) was recorded at 200 m distance. The measured water quality parameters did not differ significantly among the 4 sampling sites (ANOVA, $p > 0.05$). The following mean values for water quality parameter were determined: nitrite, 0.015 ± 0.001 mg/L; nitrate, 0.01 ± 0.003 mg/L; ammonia, 0.02 ± 0.003 mg/L; orthophosphate, 0.12 ± 0.005 mg/L; total suspended solids (TSS), 138.66 ± 6.38 mg/L; dissolved oxygen, 5.21 ± 0.08 mg/L; pH, 8.57 ± 0.01; salinity, 29.52 ± 0.08‰, and temperature, 29.97 ± 0.05°C. Cluster analysis with Ward's method (Tukey's test, $p < 0.05$) revealed the presence of 3 main groups based on particle size distribution, organic matter content, pH value, ammonia concentration, and distribution and abundance of benthic molluscs. Group 1 consisted of Teluk Bahang (600–1200 m), Teluk Aling (200 m and 600–1000 m),

and Teluk Ketapang (200–1200 m) —characterized by low organic matter and low abundance of molluscs. This group was further divided into 2 subgroups (Group 1A and Group 1B). Group 1A included the furthest stations of Teluk Ketapang (800–1200 m), and was characterized by relatively high temperature, high pH, and high organic matter, but low dissolved oxygen, compared to Group 1B. Group 2 included Pantai Acheh (200–1200 m) and Teluk Aling (400 m and 1200 m) —characterized by relatively high organic matter, and high silt and clay, but low in ammonia concentration. Group 3 comprised a sandy area in Teluk Bahang (200–400 m)—characterized by a high abundance of benthic molluscs. Taken together, these results indicate that the abundance and distribution of benthic molluscs is dependent on particle size distribution, organic matter content and anthropogenic activities.

CHAPTER 1.0-INTRODUCTION

The term benthic is derived from the Greek word "βένθος", which means "bottom of the sea". Benthic organisms are bottom-living animals, generally dominated by invertebrates, and are usually classified into 3 types—epifauna, infauna, and demersal. Epifauna refers to an animal living on the sediment surface or attached to the substrate, whereas infauna refers to an organism living beneath the sediment. Meanwhile, demersal usually refers to fish families that swim on the bottom level, feeding on epifauna and infauna creatures.

In the kingdom Animalia, Mollusca is the second largest phylum after Arthropoda. It includes a vast number of species, among which at least 100,000 mollusc species have been identified (Feldkamp, 2002: Bruyne, 2003: Kenneth, 2007). The phylum Mollusca consists of 7 classes—Polyplacophora, Aplacopora, Monoplacopora, Gastropoda, Bivalvia, Scaphopoda, and Cephalopoda (Pechenik, 2000).

All molluscs except Aplacopora and Cephalopoda possess a shell to protect their bodily tissue and organs. The delicate body part known as the mantle is also responsible for producing the shell, by secreting conchiolin (Bruyne, 2003: Kenneth, 2007). Most molluscs have a separate sex, but a few are hermaphrodites. Molluscs usually lay eggs (oviparous) in an egg carcass or directly into the water; they seldom carry embryos internally (ovoviviparous) (Bruyne, 2003).

Molluscs vary with respect to their mode of feeding. Gastropods are equipped with an odontophore and radula, with which they graze on their prey. Certain molluscs such as bivalves lack a radula, but possess siphons to draw in a stream of water containing food particles. On the other hand, detritivores utilize organic matter as a food source.

Marine molluscs occur worldwide, in temperate, arctic, and tropical regions. Penang, Malaysia is situated in the sub-region of Southeast Asia, and is well known for its tropical climate. Malaysia's coastal waters are generally defined as Indo-Pacific in zoogeographical area, and constitute the largest area among the remaining 15 regions (Bruyne, 2003).

Studies of benthic molluscs in Malaysia are scarce. The earliest investigation on marine molluscs—conducted in 1981 by Purchon, Way and Morris (Purchon and Purchon, 1981: Way and Purchon, 1981: Morrris and Purchon, 1981)—focused on the distribution of molluscs in Peninsular Malaysia. Most previous studies on coastal waters have focused on the health status of molluscs and other benthic fauna, because of their key role in habitat structure and trophic dynamics (Valiela et al., 1992: Nixon et al., 1996).

Benthic communities were previously considered relatively unimportant, because they appeared barren, unpopulated, and unproductive (Onate-Pacalioga, 1994). Today, benthic communities are known to participate in detritus food chains throughout some highly productive areas, such as seagrass beds, and therefore the significance of soft-bottom communities has been rewarded much attention (Onate-Pacalioga, 1994). Molluscs play an important role in the food chain, by representing a nutrient source for higher trophic levels of the food web. The abundance of benthic molluscs has been shown to correlate with fish availability (Zahoor et al., 2010).

Global studies are focusing on the role of benthic as environmental indicators (Thompson et al., 2003), based on their predictable response to many kinds of natural and human-induced disturbances (Thompson et al., 2003: Venturini et al., 2004). Furthermore, the composition and abundance of benthic molluscs over a period of time may determine the health status of an ecosystem (Zahoor et al., 2010).

Benthic molluscs living on or within sediments have been shown indirectly to influence the psychochemical nature of the sediment and bottom water (Cuomo and Zinn 1997: Covich et al., 1999). The molluscs trigger acceleration of detritus decomposition and other major ecological processes, including release of nutrients into the aquatic environment as a result of feeding activities and excretion of waste (Covich et al., 1999). Rapid uptake of these nutrients by bacteria and plants results in accelerated microbial activity and enhanced plant growth (Ingham et al., 1985). The increment of bacterial and plant biomass provides an abundant food source for a range of benthic mollusc assemblages. The food web continues, because the subsequent phase of benthic fauna serves as a food source for larger organisms. In most cases, the presence or absence of benthic organisms is positively correlated with the prevalence of larger organisms (Cuomo and Zinn, 1997: Covich et al., 1999).

Benthic molluscs are being increasingly studied, because they are omnipresent, relatively sedentary, and reflect site-specific conditions. For example, they respond to changes in water quality occurring at the time of sampling, and also to variations occurring over a longer time period (Roldan, 2003). Furthermore, many species of molluscs show low tolerance to small physicochemical variations (Seto and Sato, 2003). This is because of their sedimentary living condition, whereby they accumulate contaminants and respond rapidly to any environmental changes caused by sediment pollutants (Blanchet et al., 2007). Thus, they can be used as biological indicators to prevent further contamination, which could spread to larger, less-sensitive organisms.

Benthic molluscs, especially bivalves, have frequently been used in heavy metal studies (Mohd. et al., 2007: Halina et al., 2010). Bivalves are able to accumulate pollutants from their surrounding area, because of their nature as filter feeders. The level of pollutant accumulated in the tissues has been used to investigate the degree of habitat pollution (Al-Madfa et al., 1998: AbdAllah and Moustafa, 2002).

Smaller molluscs generally accumulate higher quantities of heavy metals than do larger molluscs (Fowler and Benayoun, 1976: Strong and Luoma, 1981: Gault et al., 1983). This is because metabolic rates of smaller molluscs are higher than those of larger molluscs. Furthermore, the regulatory uptake and excretion of larger organisms may explain why smaller molluscs are more effective for heavy metal studies (Boyden, 1974).

The diversity of benthic communities also reflects water quality conditions, with a high diversity generally indicating high water quality (Hynes, 1984). Evaluation of benthic communities is therefore frequently used in biomonitoring, to assess the ongoing quality of the ecosystem (Phillips and Rainbow, 1994: Bockelmann et al., 2004).

The distribution of benthic communities is important for maintaining population structures of many organisms, and is considered to involve interspecific relationships between abundance and distribution. Thus, the relationship between abundance and occupancy is one of the most extensively studied patterns in macroecology (Brown 1984: Gaston 1996: Gaston et al., 2000: Blackburn et al., 2006).

In the present study, the impacts of human activities on benthic communities were considered (Warwick, 1993). Human activities can trigger land runoff, waste contaminants, and sediment disturbances, which potentially have a greater influence on shallow-water benthic habitats than on deep-water regions (Holland et al., 1987: Malone, 1992: Dauer et al., 1992).

The most severe threat to marine diversity is the loss of coastal habitats (Gray, 1997). Habitat disturbance is most affected by commercial fishing (Dayton et al., 1995). Trawls and dredges have an impact on many species that live on or close to the seafloor. Other possible disturbances include habitat modification, such as land reclamation (Auster et al., 1996), turbidity caused by boats (Bilota et al., 2008), changes in sedimentation pattern (Churchill, 1989), and benthic algal production and nutrient cycling (Mayer et al., 1987).

In the present study, the distribution and abundance of marine benthic molluscs was surveyed in the tropical coastal waters of Penang Island. Since 2001, Penang has been actively involved in land reclamation, mostly in the northern part of the island. The largest land reclamation project is in Bandar Tanjung Pinang, which covers 240.63 hectares.

1.1 Objectives

The objectives of the study were as follows:

(1) to record the diversities of benthic molluscs in the coastal waters of northwestern Penang Island;

(2) to study the abundance of benthic molluscs with regards to spatial and temporal distribution patterns;

CHAPTER 2.0-LITERATURE REVIEW

2.1 Class of benthic molluscs

Molluscs are geographically distributed all over the world, in highlands, lakes, rivers, estuaries and oceans. They can be found in abundance on land as well as in the aquatic ecosystem. To date, the number of mollusc species present is debatable. Based on the literature, it is more than 100,000 species molluscs have been recorded (Feldkamp, 2002: Bruyne, 2003: Kenneth, 2007). This makes Mollusca the second largest phylum after Arthropoda (Kenneth, 2007) which constituted more than 1 million species (Campbell and Reece, 2004). However, in marine ecosystem Mollusca is the largest phylum (Gosliner et al., 1996: Bouchet et al., 2002).

Molluscs consist of seven classes which are Polyplacophora, Aplacopora, Monoplacopora, Gastropoda, Bivalvia, Scaphopoda, and Cephalopoda. Benthic molluscs on the other hand were usually inhabited by 3 main classes (gastropods, bivalves, and scaphopods) as recorded in most research found regarding benthos studies (Ong and Krishnan, 1995: Pisut and Cejka, 2002: Poirier et al., 2010: Pawar and Prabhakar, 2012).

2.2 Morphology of benthic molluscs

2.2.1 Bivalvia

Bivalves are mainly characterized by bilateral symmetry, with 2 calcified valves of variable size and shape (rounded, oval, oviform, etc.). The dorsal part of the bivalve is known as a hinge; here, the elastic ligament structure is situated and functions to open and close the valves. This crucial action is aided by the adductor muscle, which is fixed at the anterior and posterior ends within the valves. The area where adductor muscle lies is visible through the imprinted muscle scars. The uppermost part of the dorsal area is the umbo, which points either forwards (prosogyrate) or backwards (opisthogyrate). In some species of bivalves, lunules, denticles (teeth), and escutcheon are present close to the umbones. Arrays of teeth may also be present at the internal lower margin of the valves.

Bivalves possess no head, and the body is usually covered by a mantle. Pallial sinus is situated at the ventral margin of the shell, where the siphons are kept when the bivalve retracts inside itself. The exterior of the valves (the periostracum) varies considerably among different species and may be smooth or glossy, with riblets, visible concentric lines, or even nodules. Figure 2.1 shows the morphological structure of a bivalve.

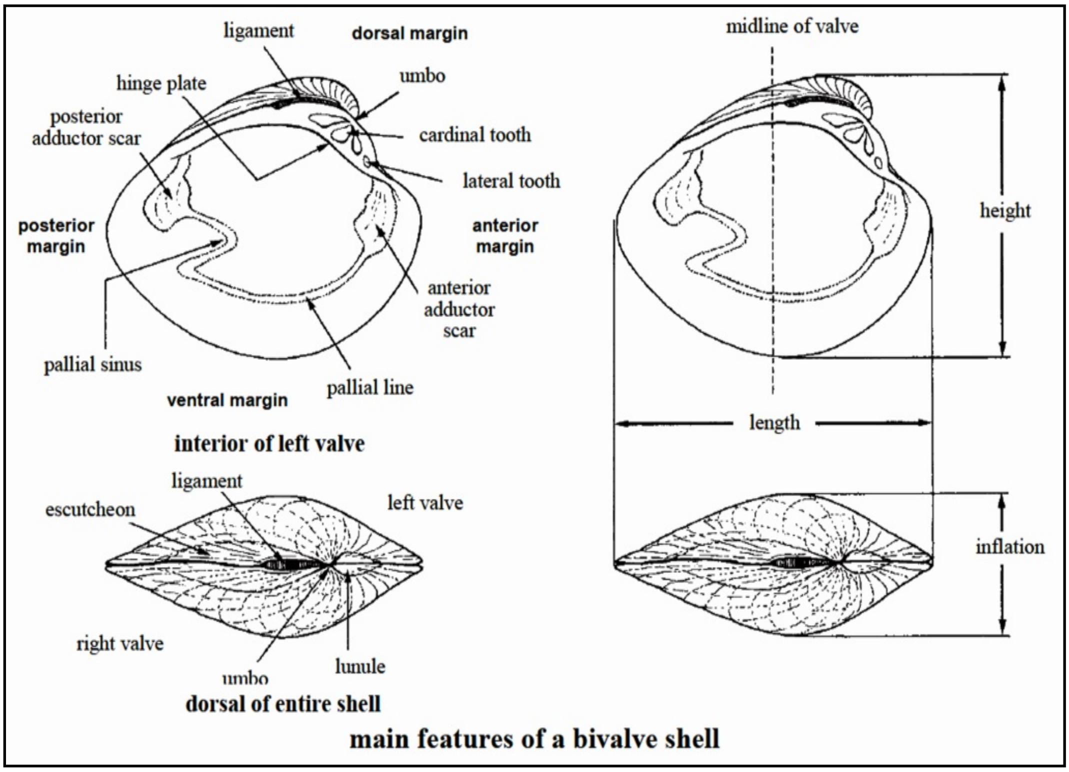

Figure 2.1: Morphological structure of a bivalve (Carpenter and Niem, 1998).

2.2.2 Gastropoda

Gastropods have a single shell known as a conch, which is present in various shapes and sizes. The body is divided into 4 areas—the head, foot, visceral mass, and mantle. The taxonomy of the gastropods mainly focuses on their highly variable shell morphology. The main body of a gastropod may be spiral with a few whorls, with an apex at the top. The continuous line between the whorls is known as suture. Gastropods possess either a corneous or a calcerous opening known as an operculum, which seals the shell. However, some species may not seal themselves, because they have a wide aperture, comprising a posterior canal (notch) or siphonal canal at the anterior end. Immediately adjacent to the aperture is the columella, which may thicken (columellar callus) or have riblets (columellar folds). The inner and outer lips are located ventrally along the aperture, while the umbilicus (a small hole) may be present, usually close to the inner lip. The inner lip is usually sculptured (spiral or axial), showing the growth marks of the shell, but may also have a smooth appearance. The periostracum of the body whorl varies among species, and may be smooth or glossy, with nodules, thorns, riblets, etc. Figure 2.2 shows the morphological structure of a gastropod.

2.2.3 Scaphopoda

Scaphopods comprise a small group of species, with shells resembling an elephant tusk (Figure 2.3). The body is elongated body, curved slightly at the anterior, and globose or slender at the posterior. Concentric rings and ribs may be present along the ventral axis, or the body may be smooth and glossy. The anterior part may seal off with a blunt or pointed shape; however, in certain species, a small hole may be visible.

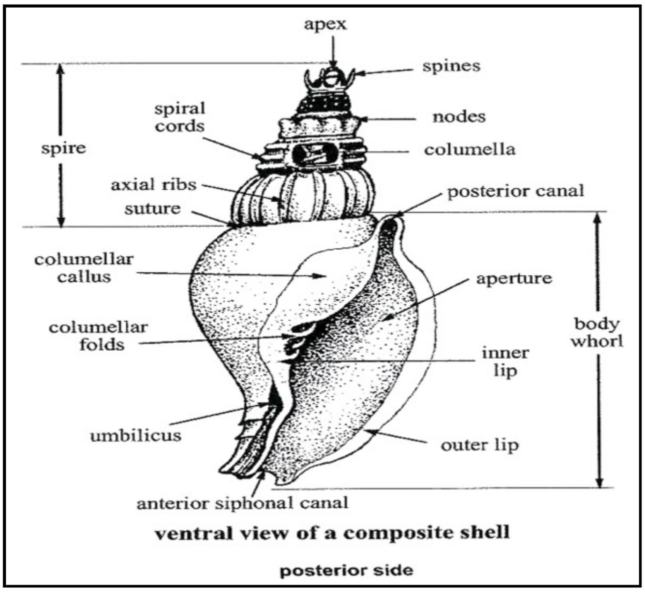

Figure 2.2: Morphological structure of a gastropod (Carpenter and Niem, 1998).

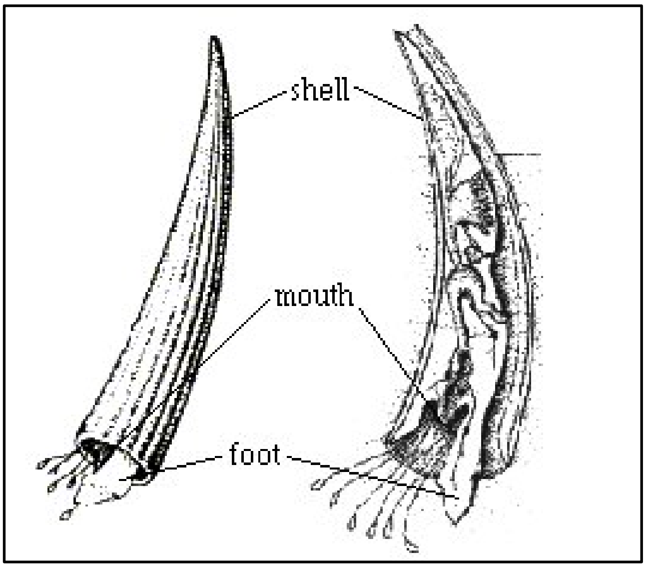

Figure 2.3: Morphological structure of a scaphopoda (University Carlifornia Museum of Paleontology, 2006).

2.3 Effective instruments in benthic studies

Many studies have been conducted regarding molluscs as functional organisms in the environment both in fresh water and in the marine environment. Most of the studies usually used grab instruments to sample the fauna. The use of Ponar grab 6× 6 inches was favored in most of the studies as the most reliable grab tool in benthic studies. The downward force generated by its weight (10 kg) enables the benthic sampling at various sediment constitutions and reduces bow wave during grab descent (Panis et al., 1995). Comparative study by Elliot and Drake (1981) on seven grabs found that the Ponar grabs are the most versatile instruments for quantitative studies.

2.4 Morphological studies of molluscs

Morphological studies have been conducted mostly focusing on mollusc taxonomy to identify the fauna in closely related species taxa. The most accurate method for identification of species is via molecular study (Carvalho et al., 2001) because it allows precise species determination. Another method is the classical method of examining taxonomy through morphological characterization, and this method is currently being widely used. However morphological identification is a labor intensive practice (Ferraro and Cole, 1990) and requires an expert who is familiar with the native fauna; however, this method is the cheaper than molecular analysis.

Furthermore, the process of sorting and identification is time consuming, especially when it involves closely related species within the genus, in which case, identification is prone to inaccuracy and misidentifications (Warwick, 1988). Troschel started the morphological studies focusing on tooth arrangement in 1836, which was the pioneer study in examining mollusc radula arrays (Sollas, 1907). However most of the studies conducted later on focused on mollusc diet rather than taxonomic classification.

The studies on mollusc tooth morphology were less popular back in early 19th century, and most of the studies focused on the feeding habits in specific molluscs by examining their gastrointestinal tract. There are well-known mollusc families such as Conidae, Muricidae, Mitridae, Fasciolariidae, and Vasidae, and their diets are highly specific and mostly consist of other benthic organisms (Kohn, 1959, 1968: Kohn and Nybakken, 1975: Taylor and Lewis, 1995: Taylor, 1976, 1984a, 1984b, 1993).

The focus of Taylor and Lewis' research (1995) was Indo-Pacific Fasciolariidae; their study emphasized on tooth morphology, which had rarely been attempted before. They also suggested that the arrangement of mollusc radula influences the feeding habits of molluscs, and this theory was supported by the findings of three other studies (Kool, 1987: Nybakken, 1990: Taylor, 1993). Nybakken (1990) showed a correlation between tooth morphology and prey type preferences. Taylor (1993) studied Mitridae and suggested that tooth morphology of comb-like radula were indicative of sipunculans-feeders, and this finding was strengthened by the results of Kool (1987), who studied another mollusc family, namely, Muricidae (comb-like radula).

2.5 Taxonomic level of benthic molluscs in ecological studies

Gray et al. (1988) pointed out that there is a considerable degree of redundancy in species data and concluded that aggregation into higher taxonomic levels (species > genus > family > orders > class) would reduce this problem, preventing natural variables from masking the effects of pollution. On the other hand, levels higher than family has given useful results in multivariate ordinations in some studies (Somerfield and Clarke, 1995: Olsgard et al., 1997, 1998: Venturini et al., 2004).

According to Warwick's (1988) suggestion, the effects of pollution are detectable at coarser taxonomic groups because natural variability affects community structure mainly by species replacement. Many other studies provided the best evidence to date for the taxonomic resolution of higher taxa in pollution studies, especially regarding family-level identification (Somerfield and Clarke, 1995: Olsgard et al., 1997: Olsgard et al., 1998: Ferraro and Cole, 1990: Thompson et al., 2003: Gesteira et al., 2003: Dauvin et al., 2003). These studies demonstrated the equivalency of pollution assessments at the species to family level for several macrobenthic data sets, suggesting that identification to the level of family may be satisfactory in many common monitoring surveys.

However, small numbers of species per genera and per family have been observed in several previous studies by Warwick (1988), Ferraro and Cole (1990), Gesteira et al. (2003), and Guzma´n and Carrasco (2005). They found that multivariate analysis at the genus and family level data is no less effective for identifying sample groups than ordination of the species level data.

Some studies of taxonomic sufficiency by Gesteira et al. (2003), Narayanaswamy et al. (2003), and Thompson et al. (2003) showed that the use of higher taxonomic level could still help determine the responsive group of benthic community towards stress factors in their studies in shallow marine environments.

2.6 Studies of mollusc compositions

Meanwhile, many studies have been carried out on species richness, species distribution, and species diversity (Kohn and Leviten, 1976: Bouchet, 2006: Elizabeth et al., 2003) because each continent holds several different species.

A checklist by Mohammed and Al-Khayat (1994) prepared on the basis of benthic molluscs study in the Qatari coast of the Arabian coastal waters. A total number of 70 species was found in various types of sediment colonization. In that study, of all the identified species, 24 species were considered rare; 21 species, uncommon; 11 species, common; and 14 species, very common. The results from this species richness study can be used for future reference as baseline information for a monitoring program to maintain the health status of the environment.

Spatial patterns of benthic diversity have been evaluated in West Antarctica by Troncoso and Aldea (2008). The research focused on the effects of latitude and longitude on species distribution, which resulted in identification of 134 species from 54 sites. Molluscs were spatially distributed in an extensive region of 500–2200 km from the South Shetland Island to the Bellishausen Sea. The mollusc distribution was highly variable and being the main phylum found.

Patella ferruginea is known as the most endangered species in the Mediterranean region and is used as food, fishing bait, and collector item (Ramos, 1998). In 2004, Guerra et al. reported that species in undisturbed areas showed higher diversity and more abundance than species in disturbed areas.

James et al. (1996) conducted a comparative study pertaining to the patterns of interspecific variation in the sizes, shapes, boundaries, and internal structures of geographic ranges. In his study, he proposed the characteristics that appear to reflect the influences of environmental limiting factors on dispersal within genera, families, orders, and classes are range size that often varies by several orders of magnitude. These variations are associated with body size, population density, dispersal mode, latitude, elevation, and depth.

2.7 Mollusc studies in tropical coastal waters

In 1978, Clarke conducted a study on polymorphism in marine molluscs. In this study, he compared samples from three regions (temperate, arctic, and tropical) and found that tropical molluscs highly differed in interspecific (between different species) and intraspecific (within a species) morphological characteristics compared with the molluscs from the other two regions. Natural selection and biome maturation were said to be responsible for these morphological trends.

The robustness of species in tropical country made Tan and Clements (2008) start baseline taxonomic research in Singapore focusing on Neritid (a euryhaline species) to avoid any misidentification of this species in the future.

Barnes (2003) researched in the mangrove area in Sulawesi revealed that horn shells were the dominant species in the region. There were three main species observed, two of which were horn shells—*Terebralia sulcata* and *Terebralia palustris*—and one was a mud-creeper species—*Cerithium coralium*. The numbers of *T. sulcata* and *T. palustris* were found to be inversely correlated with that of *C. coralium*. However there was no obvious intraspecies stress on the feeding rate because fecal production by *T. sulcata* was not significant.

A baseline study in a pristine mangrove area in Sematan, Sarawak forest, was conducted by Elizabeth et al. (2003), who identified 44 molluscan species, and their abundance was positively correlated with small trees and negatively correlated with the type and number of mangroves associated.

The recent increase in human population and needs, as well as social and economic development, has adversely affected mollusc communities. In the Jakarta Bay, an important study was conducted by Van Der Meij et al. (2009) in the year 2005, in which they compared the composition of molluscs dating back to the year 1937–1938 with recent data. They found that in recent times, species number had decreased. Seventy years ago, Jakarta Bay was inhabited by 171 species of molluscs, while in 2005; this region housed only 58 species. Ninety-six species of molluscs were lost while 17 new species were observed in 2005. The shift and loss in the number of species in the Jakarta Bay region could be attributable to anthropogenic factor such as land reclamation and contamination, man-made objects, oil pollution, and domestic and industrial sewage (Sutamihardja, 1985: Willoughby et al., 1997: Uneputty and Evans, 1997a, 1997b: Rees et al., 1999).

2.8 Mollusc as a bioindicator

Molluscs are known to be important fauna in the environment because they act as indicators of heavy metal pollutants (Luoma et al., 1992: Maher et al., 1997: Halina et al., 2010). Further, inadaptable species have been adversely affected through numerous anthropogenic activities, thereby jeopardizing the abundance and species diversity (Thrush et al., 1998: Rovere et al., 2009).

Molluscs are being cited as vital for other organisms because they became substrates for attachment for some species such as nemerteans and amphipods. Crooks and Khim (1999) showed that *Musculista senhousia* indirectly affect the assemblage of small fauna because of its nature to form a dense mat that can increase infauna density and species richness of an ecosystem. A study by Gutie'rrez et al. (2003) emphasized on the importance of mollusc shells for attachment of epibionts, shelter for prey species, controlling transport of solute and particles in the benthic community, and as physical or physiological stress towards the ecosystem.

Benthic macro-inverterbrates are commonly used as bio-indicators in the trophics and mollusc is one of the communities. In studies by Nkwoji et al. (2010) and Balogun et al. (2011), molluscs are the most sampled taxa among all other taxa in the tropical regions. This trend was also seen in the study by Bouchet et al. (2002) in which they examined the species richness in tropical marine environment. They identified 2,738 species from 12,7652 specimens of macrofauna, and this study yield is the highest recorded among all other Indo-Pacific sites (Bouchet et al., 2002). High number of mollusc species indicated that the ecosystem was in good condition, and this finding was supported by the results of another comparative study conducted by Balogun et al. (2011) in the same tropical coastal water; this study focused on the sensitivity of molluscs towards pollutants.

Another benthic survey was conducted by Kohn and Leviten on marine molluscs in the shallow waters of the Mexico coastal waters in 1976, with a yield of 316 species of molluscs (i.e., 193 gastropods species, 114 bivalve, and four scaphopod species); approximately three-fourths of the samples collected were already empty shells. His study suggested that the pattern of assemblage was due to aggressive bioturbation and not due to the effect of wave and currents.

The study by Bhattacharya et al. (2003) revealed that selenium accumulation is more precise and observable in bivalve than in zooplankton, macroalgae, and seagrass. The study was designed to provide baseline data for future environment quality assessment programs. Another study by Kurochkin et al. (2010) focused on the effect of cadmium on the mitochondria of molluscs and the mechanism of cadmium in mitochondrial dysfunction of the marine mollusc *Crassostrea virginica*.

The efficiency of gills in accumulation of heavy metals in bivalve molluscs was evaluated by Zhang et al. (1990) and Fowler and Benayoun (1976). The benthic bivalves can directly accumulate selenium from sediment particles, as shown by Luoma et al. (1992) in natural habitat and experimentally proven by Chapman (2005) and Maher et al. (1997). *Anadara trapezia*, a filter-feeding bivalve, can be used as a bio-indicator for selenium metal because the nature of *A. trapezia* (filter feeder organism) makes the organism capable of retaining heavy metal in its body, thereby making it an important bio-indicator fauna.

2.9 Benthic molluscs and habitat modifications

Apart from the commercial value of molluscs, their community structure could be affected by human activities. Thrush et al. (1998) suggested that the used of fishing gears was expected to change sea floor habitat, which could indirectly change species population. They reached this conclusion when abundance and diversity of species previously found in the study area were found to be affected.

Most of the studies on benthic communities focused on the effects of environmental disturbances. Studies by Lu (2005) focused on the effect of petroleum and showed that it had a negative effect on the species number, abundance, and diversity of the macrobenthic community in Singaporean coastal water.

A study by Rudling (1976) and Jacob et al. (2009) indicated that petroleum hydrocarbon is toxic to benthos and that petroleum hydrocarbons are persistent in sediments and had harmful effects on the behavior of bivalves (Hartwick et al., 1982). Studies by Berge (1990) and Lu (1999) showed that lower densities and species numbers of bivalves could be found in defaunated sediment contaminated with petroleum hydrocarbons. Meanwhile, in experimental studies by Olsgard and Gray (1995), contamination of oil-based drill-cuttings in Norway was found to reduce key components of the benthic communities, and the impact remained several years after cessation of drill-cutting discharge.

Some studies have been conducted on the responses of macrobenthic community to dredged sediment disposal (Johnson and Frid, 1995: Harvey et al., 1998: Boyd et al., 2003: and Simonini et al., 2005). However, the effects of contaminants in the dredged sediment on recolonization and succession of macrobenthos are poorly known, especially in tropical and sub-tropical areas.

In 2007, Lu and Wu showed that there was no significant effect of contamination on the abundance, species number, diversity, and distribution of molluscs, and this was true even after eleven months. Thus, Lu and Wu (2007) concluded that recovery from the effects of dredged, industrial-contaminated sediments in sub-tropical waters may be faster than that in temperate regions. However, significant differences between the industrial-contaminated and the control communities in terms of species composition still existed after fourteen months of study. This obviously shows that industrial wastes with a variety of contaminants may have a relatively long-term impact on species compared with contamination with a singly contaminant.

A study by Harvey et al. (1998) in Canada showed that more than two years were required for macrobenthic community structure to be restored to an undisturbed condition at dredged sediment disposal sites. Clear signs of recovery from the effects of colliery waste dumping were detected seven years after cessation of dumping in England (Johnson and Frid, 1995).

A comparative study was carried out by Sugden et al. (2008) on the interaction between nutrient availability and disturbance frequency in non-mature and mature molluscs. This study revealed that the non-mature bivalve communities were affected at the end of the experimental period, while the mature bivalve communities were affected at the middle of the experimental period. The abundance of the non-mature bivalve and mature mollusc communities decreased as disturbance frequency increased. However, species richness was not affected, and the size of the molluscs (surface area through their gills) is believed to play an important role in this. Therefore, Sugden et al. (2008) suggested that communities at an older successional stage, which are heavily dominated by one or two species, are less stable than those at younger successional stages where a number of species are still competing for dominance (Sutherland and Karlson, 1977), and the older communities will suffer more damage for a given level of disturbance (Sousa, 1980).

The study by Halina et al. (2010) showed that the population of the bivalve *Anodonta cygnea* decreases when exposed to different kinds of pollutants for one year. The study demonstrated the reliability of using *A. cygnea* as biomarkers for assessing both long-term and or accidental environmental pollution loads. However, another study by Guerlet et al. (2007) revealed that certain molluscs such as opportunist species that enable adaptation to the polluted environment did not show any changes in response to the pollutants.

Carla et al. (2007) conducted a study in Guanabara Bay, one of the most polluted environments of the southern Brazilian coastline. The severe impact of heavy discharge by both industrial and domestic waste from the Rio de Janeiro metropolitan area on the distribution of molluscs was investigated in that study. The mollusc distribution varied significantly in space and time and was probably influenced by the organic enrichment effects of hypoxia and altered redox conditions coupled with the prevailing patterns of circulation.

2.10 Effects of global warming on benthic molluscs

A study by Andersson et al. (2007) on both seawater chemistry and sediment mineral composition in Devil's Hole, Bermuda, showed that Mg-calcite minerals preferentially dissolved under conditions of elevated pCO2 in the natural environment. Andersson et al. (2007) estimated that if the rate of calcification was suppressed by 40% by the end of the 21st century, which has been proposed as a result of rising seawater pCO2 and decreasing surface seawater carbonate saturation state, net accumulation of carbonate material on coral reefs and in other carbonate dominated ecosystems will, at some point in time within the next century or two, become negative. Coralline algae and benthic invertebrates will probably respond more quickly to ocean acidification.

A recent laboratory study by O'Donnell et al. (2009) showed that planktonic larval stage had a negative impact on marine invertebrate populations. Consequences of CO_2 and temperature decrease the capability of larvae stage into the adult stage. These factors have a strong potential to disrupt marine invertebrate community compositions in the future.

CHAPTER 3.0-MATERIALS AND METHODS

3.1 Field sampling

3.1.1 Sampling sites

The present study was conducted at the northwestern part of Penang Island. Four sampling sites—Teluk Bahang, Teluk Aling, Teluk Ketapang, and Pantai Acheh—were selected, based on the degree of human activity (Figure 3.1). All of the sampling sites are located within Penang National Park, which covers approximately 1,265 hectares (Rosnidah, 1998: Roswandi, 1998). Teluk Bahang is a fishing village, within which a few settlements have inadequate sewage systems. Therefore, discharge from the village may have an impact on benthic assemblages. Teluk Aling is home to the Centre for Marine and Coastal Studies (CEMACS). Teluk Ketapang has no specific human activity, and was therefore assumed to be less disturbed by human activities. Pantai Acheh is a mangrove area with extensive mudflats, through which the Pinang River flows. The location of each sampling site was recorded with the global positioning system (GPS) (Garmin GPSmap 60CSx, Garmin Int. Corp., Olathe, KS). The abbreviations and approximate GPS coordinates of each sampling site are listed in Table 3.1.

Table 3.1: Abbreviations and GPS coordinates of the 4 sampling sites.

Sampling site	Abbreviation	GPS coordinate
Teluk Bahang	TB	N 05’ 47.1”, E 100’ 20.8”
Teluk Aling	TA	N 05’ 47.7”, E 100’ 19.8”
Teluk Ketapang	TK	N 05’ 39.6”, E 100’ 15.8”
Pantai Acheh	PA	N 05’ 46.2”, E 100’ 16.6”

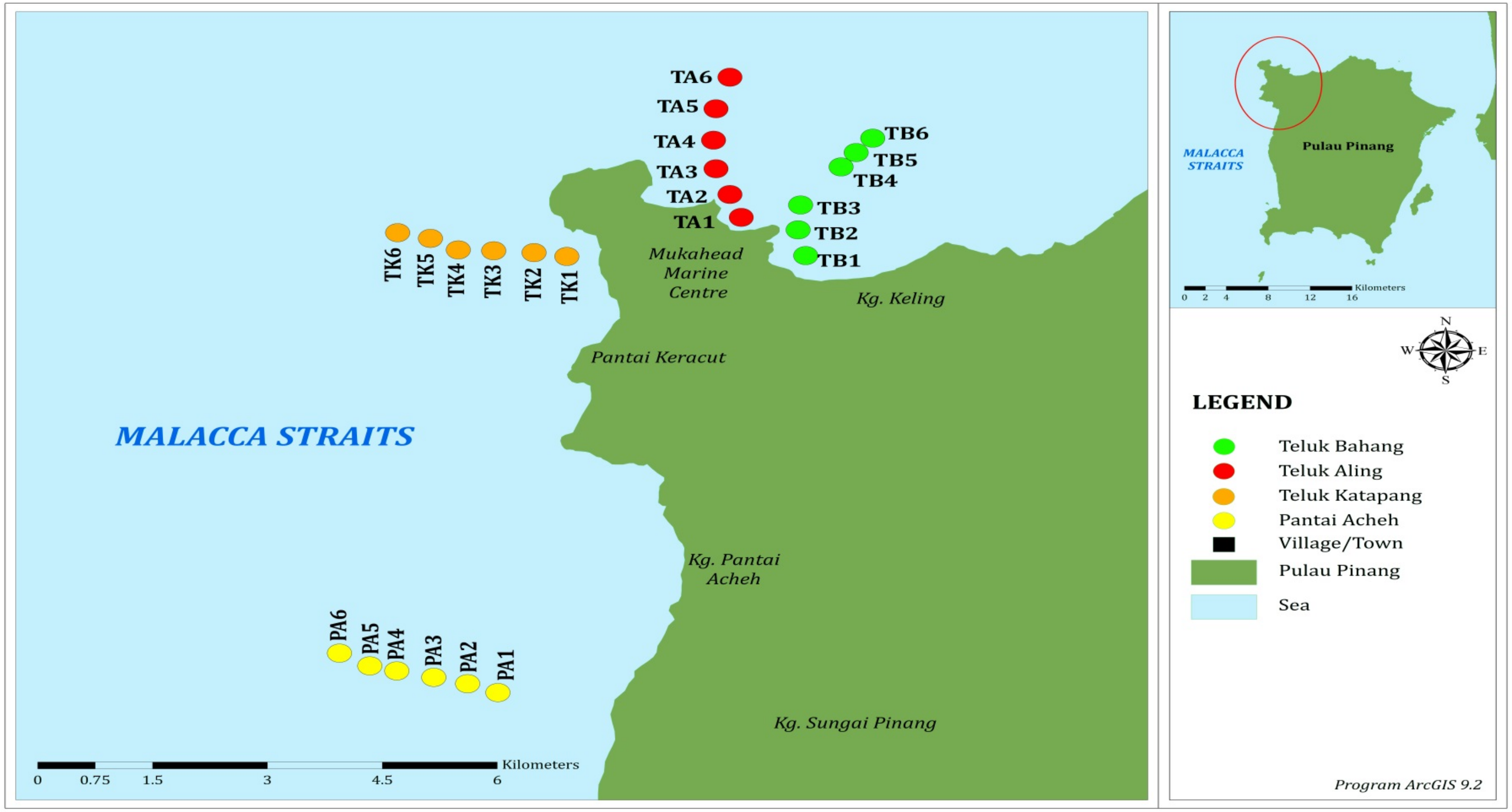

Figure 3.1: Location of 4 study sites. TB, Teluk Bahang: TA, Teluk Aling: TK, Teluk Ketapang: PA, Pantai Acheh; 1=200 m: 2=400 m: 3= 600 m: 4= 800 m: 5=1000 m: and 6=1200 m. (Scales shown are not the exact distance between the sampling points)

3.1.2 Sampling method

Samples were collected every 2 months during the spring low tide, by using a CEMACS III research boat. At each site, samples were collected from 6 sampling points—located at 200 m intervals. The first sample point was located 200 m from the shoreline, and the final one was located 1200 m from the shoreline. The sampling point abbreviations and distances from the shoreline are listed in Table 3.2.

Table 3.2: Sampling point abbreviations and distances from the shoreline. The data shown are applicable to all of the sampling sites.

Stations	Distance from the shore
Station 1	200 m
Station 2	400 m
Station 3	600 m
Station 4	800 m
Station 5	1000 m
Station 6	1200 m

At every sampling point, a hand-operated 152 mm × 152 mm (6 inch × 6 inch) Ponar grab (Wildco, Cat. No 1728) was lowered into the seabed to grab the benthic sample. Each sample collection was made in triplicate. The benthic molluscs in the sediment were passed through a 0.5-mm sieve (considered to be the ideal size for sampling macrofaunal organisms; Rumorh, 1999). The retained organisms were placed in 200 mm × 250 mm plastic bags. The samples were then preserved in 10% formalin