MOLLUSC ASSEMBLAGES IN RELATION TO HABITAT CHARACTERISTICS IN MANGROVES OF PENANG ISLAND

NOR SYUHAIDAH MOHAMMAD ZEE HOOD

UNIVERSITI SAINS MALAYSIA

2017

MOLLUSC ASSEMBLAGES IN RELATION TO HABITAT CHARACTERISTICS IN MANGROVES OF PENANG ISLAND

by

NOR SYUHAIDAH MOHAMMAD ZEE HOOD

Thesis submitted in fulfilment of the requirements for the degree of Master of Science

November 2017

ACKNOWLEDGEMENT

Alhamdulillah, fullest gratitude to the Almighty for His blessings, the faith and courage given, I was able to complete my master project. I would like to thank Ministry of Higher Education for supporting my research study through MyBrain15 scheme and research grant ‘Sustainability and Productivity of Mangrove System’.

First of all I would like to express my deep appreciation to my supervisor, Dr. Shuhaida Shuib and my co-supervisor, Prof. Madya Dr. Khairun Yahya for their guidance and support during supervising my master project. Special appreciation dedicated to Prof. Dr. Shabdin Mohd Long from Universiti Malaysia Sarawak, Dr. Tan Koh Siang and Mr. Tan Siong Kiat from National University of Singapore (NUS) for their willingness to help me identify the mollusc species. I am so grateful to have had assistance from these academics to help in my project.

I am thankful to Hannah Rahim, Lisa Shafiera and Amelia for their help during the field sampling and assistance to complete this project. I wish to thank Noor Hazwani and Syazreen Sophia whom are instrumental in giving their technical inputs, peer reviews and assisting to the completion of this thesis. My appreciation also goes to all my postgraduate mates, Aimie Nadzirah Malik, Asmimie Asmawarnie Azizan, Amni Nabilah Mat Adam, Diyanah Ismail, Nur Afiqah Abdul Rahim, Nur Hidayu Syuhada, and Syakirah Aina that always share their knowledge and laughter with me.

I dedicate this thesis to my parents and family which always give all the supports and love that I needed the most especially during hard times. Lastly I would like to thank everyone who has helped me during making my master project until complete whether direct or indirect help. Thank you very much.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS AND SYMBOLS

cm	centimetre
e.g.	for example
et al.	and others
i.e.	that is
h	hour
ha	hectare
g	gram
ind.	individual
km	kilometre
L	litre
min	minutes
mL	millilitre
mm	millimetre
m^2	square metre
n	number
s	second
^0C	degree celcius
µm	micrometre
%	percentage
ρ	rho

HIMPUNAN MOLUSKA BERHUBUNG KAIT DENGAN CIRI-CIRI HABITAT DI HUTAN PAYA BAKAU DI PULAU PINANG

ABSTRAK

Moluska memainkan peranan penting dalam mengekalkan fungsi ekosistem bakau kerana kemampuan mereka untuk menguraikan bahan detritus dan organik untuk kitaran nutrien. Walau bagaimanapun, tekanan alam sekitar daripada aktiviti antropogenik mengancam moluska ini kerana mereka merupakan antara fauna pertama yang akan menerima kesan daripada bahan-bahan pencemaran. Sebagai akibat, kemerosotan kepelbagaian biologi moluska akan berlaku dan selanjutnya boleh menyebabkan kehilangan beberapa spesies yang belum pernah direkodkan lagi. Oleh itu, adalah penting untuk mengkaji taburan moluska dan hubungannya dengan ciri-ciri habitat hutan bakau. Disebabkan corak taburan moluska didapati tidak sekata dalam persekitaran bakau, corak komposisi himpunan moluska merentasi skala ruang dan masa telah dikaji di hutan paya bakau tropika Pulau Pinang dari bulan April 2015 hingga Januari 2016. Kajian ini bertujuan untuk menilai kesan skala ruang (meter ke kilometer) kepada hubungan antara moluska dan ciri-ciri habitat bakau yang terdiri daripada kepadatan pneumatofor, bahan organik, bahan detrital dan saiz butiran sedimen. Reka bentuk persampelan berhierarki telah digunakan dalam kajian ini. Kepelbagaian spesies moluska disampel serentak dengan ciri-ciri habitat merentasi Masa ($n = 5$), Hutan ($n = 3$), Ketinggian pasang surut air laut ($n = 2$) dan Kawasan ($n = 3$) dengan Plot ($n = 3$) sebagai replikat. Sampel moluska dan ciri-ciri habitat dikumpulkan daripada sedimen yang diambil daripada subsampel kuadrat bersaiz 0.25 x 0.25 m. Dua puluh lima spesies moluska, yang terdiri daripada 21 gastropod dan 4 spesies bivalvia telah direkodkan sepanjang kajian ini, kebanyakan corak taburan didominasi oleh gastropod *Assiminea brevicula*. Analisis multivariat mendedahkan komposisi himpunan moluska berbeza secara ketara pada Masa x Hutan (PERMANOVA, Ti x Fo, $P < 0.05$) dan pada Hutan x Ketinggian (PERMANOVA, Fo x He, $P < 0.05$). Komposisi himpunan moluska mempunyai perbezaan yang tinggi di dalam setiap hutan (SIMPER analisis dengan peratus purata persamaan kurang 50%) yang kebanyakannya disumbangkan oleh *Assiminea brevicula*. Analisis SIMPER juga mendedahkan perbezaan tinggi komposisi himpunan moluska antara hutan terutamanya Pulau Betong. Berdasarkan keputusan ini, jelas menunjukkan komposisi himpunan moluska dipengaruhi oleh skala masa dan ruang. Penemuan ini juga mendedahkan komposisi himpunan moluska dipengaruhi oleh pelbagai kombinasi ciri-ciri habitat yang berbeza pada masa, hutan dan ketinggian pasang surut yang berlainan. Corak moluska dipengaruhi oleh ciri-ciri sedimen (saiz butiran sedimen dan bahan organik) walaupun ada diantaranya tidak menunjukkan hubungan yang ketara. Ini mendedahkan bahawa taburan moluska dalam hutan paya bakau Pulau Pinang adalah kompleks merentasi pelbagai skala masa dan ruang dengan pengaruh ciri-ciri habitat. Penemuan ini dapat menyumbangkan maklumat yang berguna berkenaan status moluska di Pulau Pinang dan boleh juga menyumbang kepada senarai terkini biodiversiti moluska di ekosistem paya bakau di Malaysia.

MOLLUSC ASSEMBLAGES IN RELATION TO HABITAT CHARACTERISTICS IN MANGROVES OF PENANG ISLAND

ABSTRACT

Molluscs play an important role in maintaining ecosystem function of mangroves due to their ability to decompose the detrital and organic material for nutrient cycling. However, environmental stress from anthropogenic activities are threatening mollusc assemblages as they will be among the first fauna to be impacted by contaminants in the sediment. As such, decline of mollusc diversity will occur and we may lose some of the species that have not even been recorded yet. Therefore, this study is important to determine the distribution of mollusc and its relation to habitat characteristics in mangroves. As mollusc distribution patterns are patchy in the mangrove environment, patterns of mollusc assemblage compositions across spatiotemporal scales were studied in the tropical mangroves of Penang Island from April 2015 to January 2016. This study aimed to assess the effects of multiple spatial scales ranging from m to km across different sampling times on the relationships between mollusc assemblages and mangrove habitat characteristics comprising pneumatophore densities, organic matter, detrital matter and sediment particle size. A hierarchical sampling design was used in this study, with mollusc abundance and diversity collected simultaneously with habitat characteristics at different Times (n=5), Forests (n=3), Heights (n=2) and Site (n=3) with Plots (n=3) as replicates. Mollusc samples and habitat characteristics were collected from scraped sediments from subsamples of 0.25 x 0.25 m quadrats. Twenty-five mollusc species, comprising 21 gastropod and 4 bivalve species were recorded throughout this study, with patterns of species dominated by gastropod *Assiminea brevicula*. Multivariate analysis revealed mollusc assemblage composition were significantly different at Time x Forest (PERMANOVA, Ti x Fo, P<0.05) and at Forest x Height (PERMANOVA, Fo x He, P <0.05). There were high variation of mollusc assemblage composition within each forest (SIMPER analysis with average similarity percentage less than 50%) contributed majorly by *Assiminea brevicula*. SIMPER analysis also revealed high differences of mollusc assemblage composition between forests especially Pulau Betong. Based on these results, it is clear that mollusc assemblage compositons were influenced by time and space scales. Findings also revealed mollusc assemblage compositions were influenced by different combinations of habitat characteristics across different times, forests and intertidal heights. Mollusc patterns were influenced by sediment characteristics (particle size and organic matter) although some of the correlations were not significantly correlated. It is revealed that mollusc distribution in mangrove of Penang Island is complex across variable spatiotemporal scale with influence of habitat characteristics. Thus, findings from this study provide useful information on mollusc status in Penang Island and is a timely contributions to the biodiversity list of molluscs in mangroves of Malaysia.

CHAPTER 1 INTRODUCTION

1.1 Background study

Molluscs are among the most diverse invertebrates in aspect of body form and species (Gosling, 2003) and are present in various biogeographic regions and ecosystems of the world (Benkendorff, 2010; Oehlmann and Schulte-Oehlmann, 2003). Gastropoda and Bivalvia constitutes a major part of phylum Mollusca in marine and freshwater ecosystems (Gosling, 2003). Out of the seven molluscan classes, 80% of the species are represented by Gastropoda and another 15% by Bivalvia (Oehlmann and Schulte-Oehlmann, 2003) while other classes are relatively minor (Benkendorff, 2010).

In terms of ecosystem goods and services, gastropods and bivalves are used as food for protein sources, medicines, dyes (Cardon, 2010) and shells for decorative and ornamental purposes (Benkendorff, 2010). Ecological studies of marine gastropods and bivalves (Ashton *et al*., 2003; Mustaffa *et* al., 2013; Sasekumar and Chong, 1998; Skilleter and Warren, 2000; Wong and Arshad, 2011) have revealed the importance of bivalves and gastropods in the coastal and marine environment.

The presence of these classes in marine ecosystems is crucial as a reflection of the current status of marine ecosystem health (Oehlmann and Schulte-Oehlmann, 2003). This is due to their lifestyle that almost sedentary and directly contact with substrate medium (Oehlmann and Schulte-Oehlmann, 2003), which the pollutants may be adsorbed and deposited on the bed substrate (Yujun *et al*., 2008). These pollutants are generally come from many sources such as ocean-based (for example, oil waste from offshore platforms or ships), or from land-based such as urbanization, industrial and agricultural runoff (Hammer *et al*., 2012) that will end up in coastal environment.

Coastal areas provide many goods and services for human population (Martinez *et al*., 2007). In the early 2000, human population density living in coastal area was nearly 100 people per km^2 compared to inland area which was 38 people per km^2 (Agardy *et al*., 2005). Coastal and marine ecosystems not only provide human with protein sources (Rönnbäck, 1999; Beveridge *et al*., 2013), but also in terms of transportation, recreation and other socio economy activities such as aquaculture and tourism (Creel, 2003).

Mangroves, for example, are among the most productive ecosystems valued for its ecological and socio economic resources (Bouillon *et al*., 2008; Pereira *et al*., 2016). Mangroves support fisheries sector by providing nursery and breeding ground for the juveniles of many commercial species (Jusoff and Taha, 2009; Samidurai *et al*., 2012; Skilleter and Warren, 2000) comprised of groupers, snappers, penaeid shrimps, mud crabs and edible molluscs such as oysters, cockles and mussels (Walters *et al.*, 2008).

Despite many crucial functions of mangroves (Himberg, 2016), these ecosystems are underestimated (Krauss *et al*., 2008; Zakaria and Rajpar, 2015) and often perceived as muddy and stinky wastelands. Direct or indirect exploitation of mangrove ecosystems (Beaumont *et al*., 2007) may harm this ecosystem if it is being utilized unsustainably (Chong, 2006). Subsequently, loss of the goods and services provided by mangroves as a result of disintegrating ecosystem functions are harmful to the livelihoods of dependent communities and may lead to decline in mangrove faunal diversity (Polidoro *et al*., 2010) .

Over the past two decades, approximately one-third of mangroves was lost worldwide (Penha-Lopes *et al*., 2010; Rajpar and Zakaria, 2014) due to anthropogenic activities (Aldrie and Latiff, 2006). Large areas of mangrove forests have been cleared for the purpose of aquaculture, agriculture and urban development activities in Peninsular Malaysia (Aldrie and Latiff, 2006) resulting in the simplification of mangrove habitat complexity (St. Pierre and Kovalenko, 2014). It was estimated that mangrove forest in Peninsular Malaysia reduced by one percentage per year since in 1990's for expanding the sector of aquaculture, agriculture, urban and industrial area as in Malaysia economic planning (Hamdan *et al*., 2012).

As a result, the macrofauna population in mangrove ecosystems were negatively affected by these activities (Rajpar and Zakaria, 2014). This anthropogenic activities such as land reclamation and mangrove conversion (Mazlan *et al*., 2005) may cause erosion, high sedimentation, destruction of mangrove roots and pneumatophores, and the loss of epiphytic algae mostly utilized by the macrobenthic organisms (Skilleter and Warren, 2000).

Macrobenthos regulate mangrove ecosystem functions (Alongi, 2002) along with other microbenthic organisms such as bacteria and fungi (Sahoo and Dhal, 2009). Macrobenthic helps in nutrient cycling in mangrove ecosystems (Penha-Lopes *et al*., 2010; Reef *et al*., 2010) as they are primary consumer of mangrove detritus and organic matter (Prajapati and Dharaiya, 2014) and aid in bioturbation of mangrove sediment through burrowing activities (Lee, 1999; Orvain and Sauriau, 2002). In addition, their selective feedings such as those conducted by invertebrates which are filter feeders and grazers may prevent algal bloom and eutrophication event (Worm and Lotze, 2006). Thus, information on macro faunal assemblage is important to help us conserve mangrove environment.

Molluscs are the most conspicuous and dominant group of macrobenthos in mangrove environment with major ecological roles (Bouchet *et al*., 2002; Kabir *et* *al*., 2014). As a result, the decline in mollusc diversity may cause negative consequences to the entire mangrove systems (Oehlmann and Schulte-Oehlmann, 2003). The information on mollusc distribution in tropical regions are limited despite the significant role of this macrofauna in mangroves.

Mangrove molluscs facilitates the process of organic matter breakdown into waste materials that are bioavailable and contain high nutritive value for other higher level consumers (Samidurai *et al*., 2012). The vital roles played by gastropods and bivalves in ecosystem functioning of mangrove could serve as bioindicators and reflect the health of this ecosystem (Irma and Sofyatuddin, 2012; Macintosh *et al.*, 2002a). For example, dominant gastropods from family Assimineidae and Littorinidae are often used as indicators to assess the status of mangrove ecosystem health (Macintosh *et al*., 2002b).

Mollusc abundance and diversity are associated with microhabitats, formed by networks of aerial roots of mangrove (Kathiresan and Bingham, 2001; Nagelkerken *et al*., 2008). Mangrove physical structure not only provide higher chances for the survival of macrofauna (Lee, 2008), but also protect them from harsh environmental stress and predation, and provide greater availability of food (Kathiresan and Bingham, 2001). This habitat characteristics may influence the pattern of bivalves and gastropod assemblages in terms of abundance and species richness in tropical mangrove forests (Thivakaran and Sawale, 2016).

Gastropod species, which are primarily grazers and deposit-feeders, decreased in number in response to the reduction of pneumatophore density (Skilleter and Warren, 2000). Thus, changes in mangrove physical structures, either by natural phenomena (Schaeffer-Novelli *et al*., 2016) or by anthropogenic activities

(Rodrigues *et al*., 2016) will subsequently influence pattern of abundance and species richness of mangrove associated molluscs (Skilleter and Warren, 2000).

Low counts of mollusc diversity in subtropical estuarine area indicated influences of anthropogenic pollutants as a result from effluents of sewage and wastewater desalination plants, solid waste from construction industries and from other human activities such as urbanization and land reclamation (Youssef *et al*., 2016). In tropical regions, similar cases were documented, suggesting human pressure on coastal ecosystem was greatly increased due to continuous increase of coastal population particularly in Asia (Nordhaus *et al*., 2009).

1.2 Problem Statement

This unsustainable and destructive development trend can also be observed in Penang, as mangroves are lost due to built-up areas mainly for urbanization (Mohammed *et al.*, 2015). Although many assessment on bivalves and gastropods on coastal area such as in sandy and rocky shores (Ahmad *et al*., 2011; Gholizadeh, 2015), subtidal coastal areas (Mustaffa *et al*., 2013), and seagrass beds (Shau-Hwai *et al*., 2007) have been performed, yet, study on mangrove mollusc is lagging behind. In fact, this limited information of mollusc records in Penang mangrove may further cause danger to mollusc biodiversity as there might be a decline occurring at present, and loss of species and associated functions may not be detected until extinction occurs and efforts of rehabilitation and restoration will be unsuccessful.

1.3 Research objectives

To address the issue of lack of information on diversity of bivalves and gastropods in mangroves, this study was conducted:

a. To identify the influence of spatial and temporal scales on abundance and species richness of mangrove bivalves and gastropods in Penang Island.

b. To determine the relationship between mollusc assemblage compositions with habitat characteristics in mangroves.

1.4 Hypothesis

There are two principal hypotheses in this study:

a. Mollusc assemblage compositions in mangrove of Penang Island will vary across spatial and temporal scales.

b. The pattern of mollusc assemblage compositions in mangrove of Penang Island will significantly be influenced by habitat characteristics.

CHAPTER 2 LITERATURE REVIEW

2.1 Mangroves

Mangroves are unique vegetation that occur within latitude of 30˚N and 30˚S, in the intertidal region (Figure 2.1) (Giri *et al*., 2011). Mangroves rarely occur outside the range of 20^{o}C isotherm because of their intolerance to frost (Hogarth, 2007). As such, mangrove species number tend to decline as approaching this temperature limit (Hogarth, 2007).

Mangroves located between the land-sea interface, and exist as actual solid physical structures capable of stabilizing and protecting shorelines (Hamdan *et al.*, 2012; Kathiresan and Bingham, 2001; Penha-Lopes *et al*., 2010) from cyclones, storms, flooding and coastal erosion, simultaneously becoming natural barriers that shield coastal communities (Walters, 2003). Mangroves therefore are important habitats for both aquatic as well as terrestrial fauna (Hamdan *et al*., 2012).

Mangroves are socio-economic commodities used by humans, even more so in the past few decades. Mangrove ecosystems support the fisheries sectors directly and indirectly (Walters *et al*., 2008), providing nursery grounds for the larvae and juvenile of many fishes as well as shellfishes (Manson *et al*., 2005; Walters *et al*., 2008), supply of food to fishes, prawns, crabs and other aquatic organisms, and as refuge for juvenile fish and other prey from predators (Chong, 2006). Mangroves also provide good sources of timber and wood for jetty, poles used for fishing traps, firewood, charcoal, tannin and medicine, and as a foundation of resources used in aquaculture and agriculture sectors (Alongi, 2002; Ewel *et al*., 1998; Pattanaik *et al*., 2008).

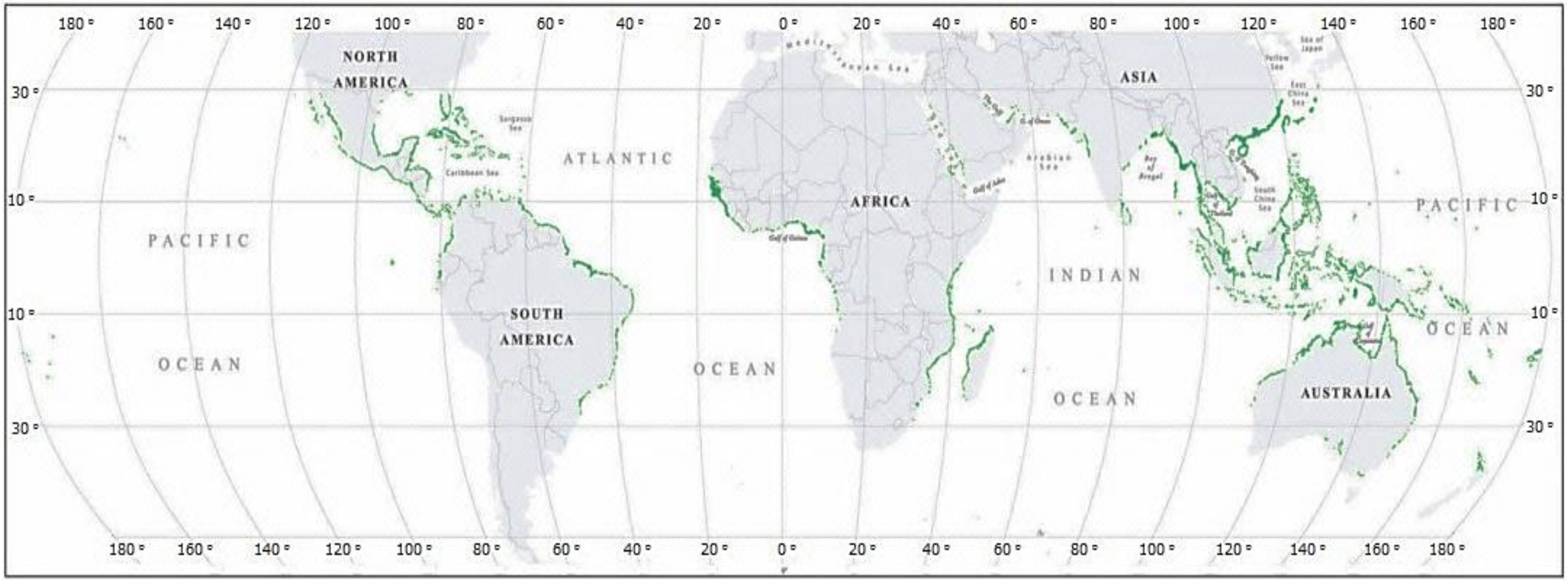

Figure 2.1: Distribution of mangrove forests at global scale with reference of earth latitude and longitude by Giri *et al*. (2011).

Despite the ecological and socio-economic value of mangroves, this ecosystem is under great pressure from various anthropogenic activities. Destruction in mangroves are significantly correlated with human population density (Alongi, 2002). The decline of mangrove forest areas are caused by shortage of viable land space, therefore mangroves are cut down to accommodate the expansion of activities such as agriculture and aquaculture (Hamdan *et al*., 2012).

2.2 Disturbances in mangrove

An alarming 35% reduction of mangrove forests was estimated to have occurred globally since the 1980's (Valiela *et al*., 2001). In a period of 2 decades, mangroves area cover were reduced by 19.42% (25, 637.89 ha) from 1990 to 2010 in Peninsular Malaysia (Hamdan *et al*., 2012). Based on this estimation, mangrove forest cover in Peninsular Malaysia were reduced by approximately one percentage per annum (1,281.90 ha) (Hamdan *et al*., 2012). Alongi (2002) reported that one hectare of mangrove could approximately support 0.45 tonnes of marine fish catch annually. Therefore, if one thousand hectare of mangrove were to disappear, an estimated 450 tonnes of marine fish catch per year could be lost. Consequently, this shows mangrove destruction brings major threats to marine life with deleterious effects on the economy and survival of communities dependent on this resource.

Immediate threats to mangroves involve the direct conversion of mangrove forest for alternative uses such as aquaculture, agriculture, urban and industrial area (Hamdan *et al*., 2012). One of the major driving force behind mangrove conversion to ponds is caused by lack of sustainable, long term plans in estimating the value of an intact mangrove ecosystem (Walters *et al*., 2008). For instance, major loss of mangrove extent in the world was caused by intensive and destructive aquaculture activities (Valiela *et al*., 2001). This activity did not only directly destroy mangroves via deforestation for pond construction, but also caused indirect problems to the adjacent mangrove and coastal environment. Negative impacts comprise of (i) physical disturbances caused by tidal creeks blockage and tidal flow alterations; (ii) chemical disturbances as a result of toxic waste discharge, development of acid sulphate soils and reduction in water quality; and (iii) biological disturbances, such as the alteration of natural food chains which subsequently could cause trophic level changes and trophic cascades (Alongi, 2002).

Although mangrove replanting efforts that have been done, with more than 5 million seedlings covering area of 1819 ha in coastlines of Malaysia (Kamali and Hashim, 2011), there were usually limited to only one or two mangrove species, which caused habitat changes and reduced mangrove ecological functions when compared with established and natural multispecies mangrove forests (Macintosh *et al.*, 2002a).

In fact, reforestation failed in the abandoned pond area even after ten years progression due to acidification of mangrove soil that occurred when the sediment plot was exposed to air after farming (Wolanski *et al*., 2000). Thus, although reforestation could provide a short term solution to mangrove deforestation, replanting mangroves are not to be considered a good replacement for natural mangrove stands. It is impossible to regain the full functions of diverse natural mangrove forests (Lewis, 2005). Aside from mangrove ecosystems, the impacted component would be fauna that live in close association with mangrove sediments, such as molluscs.

2.3 Mangrove associated fauna

Mangroves support faunal assemblages by providing them microhabitats from fine-grained to course-grained sediments, from hard substrates (trunk, twigs, pneumatophores) to soft substrates (leaves, saplings and detritus) (Lee, 2008) and from simple root (pencil-like root) to complex root systems (prop root). Due to these features, mangrove can be a host to a number of fauna (Nagelkerken *et al*., 2008) including infauna (animal live in the sediment), epifauna (animal lives on the sediment) and arboreal fauna (animal lives on tree). All of these fauna play different roles in maintaining mangrove ecosystem functions.

Mangrove sediment provides habitat for many faunal communities such as bacteria, fungi, meiofauna such as nematodes and macrofauna such as polychaetes, mollusc and crabs (Nagelkerken *et al*., 2008). Microorganisms in mangrove sediment are important in sustainably maintaining mangrove productivity for process of recovery as well as conservation (Dos Santos *et al*., 2011). Microbial activities in mangroves involving nutrient transformation, nitrogen fixation, photosynthesis process (Holguin *et al*., 2001) and production of by-products such as bioemulsifiers and antibiotics (Das *et al*., 2006).

Degradation of mangrove vegetation by bacteria and fungi produces detrital material, which then be consumed by detritus feeders like meiofaunal communities (e.g. nematodes, polychaetes) and macrofauna such as polychaetes, mollusc and crabs (Holguin *et al*., 2001). This detritus matter is a fundamental at food web base, in fact, many mangrove associated fauna at higher food web would get benefits from it indirectly by consuming these detritus feeders (Holguin *et al*., 2001).

Crabs and molluscan are major macrofauna in mangrove due to their ubiquitous, high species richness and produce distinct distributional patterns in mangrove environment (Alongi, 2002). The presence of these macrofauna enhancing bioturbation of anoxic mangrove sediment via their burrowing and grazing activities (Alvarez *et al*., 2013; Alongi and Christoffersen, 1992). This will allows anearobic bacteria inside the sediment to perform decomposition process of mangrove debris on the sediment surface that buried by macrofauna (Dos Santos *et al*., 2011).

2.4 General overview of Phylum Mollusca

The word mollusc originates from Latin word, "mollis" meaning soft-bodied (Keen, 1971). Phylum Mollusca's members are among the most diverse invertebrates ranging from simplest to complex, in the aspect of body size, morphology and nervous systems (Hochner and Glanzman, 2016). Phylum Mollusca has been classified into seven classes namely Gastropoda, Bivalvia, Aplacophora, Monoplacophora, Polyplacophora, Scaphopoda and Cephalopoda (Pechenik, 2010). Gastropoda and Bivalvia constituted the major part of class in phylum Mollusca. Out of the seven molluscan classes, 80% is represented by Gastropoda and 15% by Bivalvia (Oehlmann and Schulte-Oehlmann, 2003).

Molluscs are widespread and can be found in various biogeographic regions and ecosystems in the world (Oehlmann and Schulte-Oehlmann, 2003). Some have successfully adapted to breathing on land (Shanmugam and Vairamani, 2008), and diverse assemblages are also found in marine and freshwater environments (Wong and Arshad, 2011). Based on various adaptations to different environmental conditions, molluscs are the most successful phyla in animal kingdom that can tolerate unfavourable environment conditions (Hohagen and Jackson, 2013). For example, a number of mollusc species comprising of gastropods and bivalves from Family Trochidae, Turbinidae, Cypraeidae, Olividae and Conidae were found inhabits the Arabian Gulf that are characterized with very high evaporation resulting in high salinity up to 70-80 PSU (Youssef *et al*., 2016).

2.5 Molluscs in mangrove

Molluscs, comprising bivalves and gastropods are among the most dominant taxonomic group in mangrove forests (Kathiresan and Bingham, 2001). This macrofauna occupy all levels in the food web based on various feeding preferences including detritivory, herbivory, filter-feeding and carnivory (Cannicci *et al*., 2008). Mollusc distribution are influenced by vertical (different heights from the ground) and horizontal (along intertidal area) zones in a mangrove forest (Cannicci *et al*., 2008; Purchon and Purchon, 1981). Bivalves are usually confined to supralittoral fringe zone, while gastropods are widely distributed in mangrove across intertidal zone although some of them are highly zoned (Kabir *et al*., 2014). For example, the Elllobiid gastropods are usually characterized by type of mangrove vegetation for food and refuge during high tide, while gastropod Assimineid are usually widely disperse within a forest (Macnae, 1969; Suzuki *et al.,* 2002). The distribution of mollusc species depends on its adaptability to environmental variables, dispersal patterns and strategies (Kabir *et al*., 2014). The close relationship between mollusc and the mangrove environment also means that the survival of mollusc are dependent on the availability of a diverse array of microhabitats (Cannicci *et al*., 2008).

There are two types of molluscs in mangroves, comprising sessile (i.e. bivalves) and mobile (i.e. gastropods) molluscs. These two categories have their own adaptations in the extreme mangrove environment (e.g. extreme salinity and temperature) which can become unfavourable to mollusc survival. Gastropods are freely moving and could climb up and down the pneumatophores or tree trunks to avoid the tides that can abruptly change the salinity (Vannucci, 2001). For bivalves that are not free-moving, the only way to survive during the extreme environment is by osmoregulation while closing their shells (Chang *et al*., 2016).

2.6 Functions of molluscs in mangrove

Macrofaunal activities could stabilize mangrove structure and functions (Lee, 2008). Mollusc diversity and abundance have been recorded in great numbers in mangroves (Cannicci *et al*., 2008). For instance, high number of molluscan species were recorded compared to crab species at a tropical mangrove in Malaysia (Ashton *et al*., 2003). Due to their abundance and ubiquitous number in mangrove, they play vital roles in maintaining mangrove ecosystem functions (Lee, 1999; Nagelkerken *et al*., 2008; Oehlmann and Schulte-Oehlmann, 2003; Printrakoon and Wells, 2008).

Molluscs also provide important edible sources of protein to humans (Hamli *et al*., 2012). Edible species such as cockles, oysters and gastropods are extensively collected by coastal residents for local consumption (Walters *et al*., 2008). Purchon and Purchon, (1981) found 18 bivalves and 6 gastropods species were marketed from West Malaysia and Singapore coastal waters. Hamli *et al*. (2012) discovered 15 bivalves and 14 gastropod species were sold in local wet market from Sarawak coastal water. Edible mangrove mollusc species that are being consumed by humans are the blood-cockles (bivalves), *Anadara granosa*, and the potamid snails, *Cerithidea obtusa* (Purchon and Purchon, 1981).

In terms of mangrove litter processing, findings from a carbon isotope study revealed consumption of mangrove litter by molluscs were higher compared with sesarmid crabs (Bouillon *et al.*, 2002). These molluscs have been identified to be an important link, facilitating transfer of organic material to the next trophic level, therefore acting as the main contributor of energy transfer in a mangrove food web (Kabir *et al.*, 2014).

Mollusc assemblages are susceptible to contaminants from many anthropogenic sources (Douglas *et al*., 2013). This is because molluscs are in-contact directly to the ambient medium (soil or water) and are exposed to chemical compounds via ingestion of contaminated food, through their respiratory organ and integuments (Oehlmann and Schulte-Oehlmann, 2003). Unlike the other invertebrates (e.g. arthropods) and vertebrates, they have limited ability to excrete contaminants through excretory organs, thus molluscs will respond negatively to more lower concentrations of contaminants, and could act as an early warning system (Oehlmann and Schulte-Oehlmann, 2003). Neritidae, Littorinidae, Potamididae and Assimineidae are gastropod families commonly found in mangroves, and could be possible bioindicator species (Macintosh *et al.*, 2002a).

2.7 Mollusc studies in Malaysian coastal area

Previous studies about molluscs were mainly focused on taxonomy and diversity on different substrates in specific area, except Purchon and Purchon (1981) which performed the mollusc survey extensively. Wong and Arshad (2011) has briefly reviewed a number of studies on marine shelled molluscs in Malaysia. From the effort done by Wong and Arshad (2011) on collection and compilation of scientific writing of marine shelled mollusc in Malaysia, a total of 581 species (384 from class Gastropoda and 206 from class Bivalvia) has been listed and verified by

World Register of Marine Species (WoRMS), SeaLifeBase Portal and The Taiwan Malacofauna Database.

Marine molluscs study in Penang Island were performed by few researchers on different area of interest. Sixteen species of molluscs were found in sandy beach dominated by button snail, *Umbonium vestiarum* (Ahmad *et al.*, 2011). In another study conducted by Mustaffa *et al.* (2013) in the subtidal coastal area of Penang National Park, mollusc species namely *Nuculanidae* sp., *Megastomia* sp. and *Timocea* sp. showed positive correlation with sandy sediment. Overall, they found 25 species of molluscs from 21 families and 25 genera. A total of 14 species of gastropod from 9 families and 12 genera, 8 species of bivalves from 6 families and 8 genera were recorded in sea grass bed in man-made island, Pulau Gazumbo, Penang (Shau-Hwai *et al*., 2007) with most dominant mollusc was represented by *Nassarius livescens* recorded at 18 individual per m^2.

Previous study of mollusc in mangrove forest had performed by several researchers. Faezah and Farah (2011) recorded a total of 426 individuals from 6 families, 6 genera and 10 species from mangrove in Tanjung Dawai, 351 individuals from 5 families, 5 genera and 6 species from mangrove in Pulau Sayak. Unlike other studies that only centred on mollusc diversity only, Ashton *et al*. (2003) studied molluscan diversity in relation with environmental conditions as a baseline ecological data in Sematan mangrove forest, Sarawak. They found 44 molluscan species overall, with highest density represented by *Assiminea brevicula* at 192 individuals in $1m^2$ area. Also, Ashton *et al*. (2003) reported that there was negative correlation between the molluscan abundances and the number of decaying leaves. Hookham *et al*., (2014) also found high density Assimineid snail in mangrove of Sungai Merbok.

Ecological studies concerning the distribution of gastropods and bivalves in mangrove across the West Coast of Malaysia (Purchon and Purchon, 1981), at Kedah (Faezah and Farah, 2011; Hookham *et al.*, 2014), Selangor (Sasekumar and Chong, 1998), and at East Coast of Malaysia in Sabah (Shabdin *et al*., 1998), and Sarawak (Ashton *et al.*, 2003) are to some extent limited, as information related to spatial and temporal distribution of mollusc assemblages was not considered. This missing information is important for conservation and management activities in current situation where number of species is declining due to threats from human activities.

2.8 Spatial and temporal effects

A primary objective in many ecological research is to identify patterns in biodiversity and understand how they are structured (Chang and Marshall, 2016). Biodiversity patterns are structured by variability of heterogeneous effects of space and time (Underwood *et al*., 2000). This spatial variability are usually measured in hierarchy from metres to kilometres (Manson *et al*., 2005; Underwood and Chapman, 1996).

Identification of this heterogeneous effect is essential as organisms might respond differently to abiotic and biotic factors that are highly variable at different scales of space (Morrisey *et al*., 1992; Underwood and Chapman, 1996) and time (Underwood *et al*., 2004). Therefore, spatiotemporal scale should be taken into consideration in ecological study to understand at which scale the interaction occurred (Underwood and Chapman, 1996).

Mollusc abundance was found to be greatly affected by temporal scales as a result of habitat alteration through time in response to season, weather or other abiotic and biotic factors (Matias *et al*., 2010). Higher abundance of mollusc were recorded in rainy season, corresponding to low salinity values (Rodrigues *et al*., 2016). At different times, patchy habitat may have different prey or 'food source' leading to changes in the consumption rate of molluscs (Underwood *et al.*, 2004).

2.9 Habitat complexity

Structural components in mangroves include different sediment types, grain sizes, above-ground root structure, leaf and plant litter (Chong, 2007). It may assist the escape of prey by providing a refuge to which predators could not access (Wilkinson and Feener, 2007) and from harsh environmental conditions such as direct sunlight (Suzuki *et al*., 2002) that may raise sediment temperature. In addition, the accumulation of plant material and detrital matter could also provide food to macrofauna (Daniel and Robertson, 1990). Hence, the macrofaunal community structure could be influenced by physical features of habitat (Bell *et al.*, 2003).

Disturbances in mangrove is linked to negative influences on the abundance and diversity of flora and fauna (Kihia *et al*., 2010; Skilleter and Warren, 2000). Decline in mangrove forest complexity was reported by the occurrence of only homogenous tree species such as *Avicennia marina* or *Ceriops tagal,* replacing other species of mangroves (Kihia, 2014). These structurally modified mangroves may affect the organisms inhabiting mangroves (Skilleter and Warren, 2000). Reduced number of mollusc species and individuals were recorded when structural complexity was reduced (Skilleter and Warren, 2000).

It should be noted however, the influence of habitat complexity is species-specific. For example, the abundance of gastropod *Assiminea brevicula* was not significantly affected by pneumatophore densities, suggesting that this structure did not really help this species in terms of protection from direct sunlight and refuge from predation (Suzuki *et al*., 2002). Conversely, removal of pneumatophores could influence the abundance of other gastropod species through availability of food, such as for detritivorous gastropods *Assiminea tasmanica* and *Salinator solida* (Skilleter and Warren, 2000). The food supply in question are microbes and detritus trapped between the pneumatophores (Skilleter and Warren, 2000). Therefore, it is important to be know the ecology and biology of species so we can pinpoint the relationship between mollusc fauna and habitat complexity.

CHAPTER 3 MATERIALS AND METHODS

3.1 Study area

This study was conducted at mangrove forests at Penang Island. Three sites were chosen, comprising Kuala Sungai Pinang, Pulau Betong, and Gurney Drive (Table 3.1, Figure 3.1).

Table 3.1: List of abbreviations and GPS coordinates of 3 sampling sites.

Study site	Abbreviation	GPS coordinate
Kuala Sungai Pinang	KSP	N 05^0 23.470’, E 100 11.678’
Pulau Betong	PBT	N 05^0 18.471’, E 100 11.756’
Gurney Drive	GDR	N 05^0 26.585’, E 100 18.523’

The first mangrove site, Kuala Sungai Pinang was in the inner part of the Pinang River estuary (Figure 3.1 A). The estuary was categorized by human settlements associated with aquaculture and fishing activities (Colbourne, 2005). In addition to direct untreated effluent from aquaculture ponds, the Kuala Sungai Pinang site is at the receiving end of sewage from human settlements along the Pinang River (Nurul-Ruhayu, 2015). Furthermore, Pinang River is a busy transport hub, being the second entrance to Penang National Park (Nurul-Ruhayu, 2015).

Pulau Betong, the second mangrove site, is in the south-western part of Penang (Figure 3.1 B), in close proximity to a fishing village, boat moorings, and a jetty (Colbourne, 2005). Presence of shrimp ponds was also observed behind mangroves fringing the coastline at this site. Water flows into the mangrove via a small channel originating from Sungai Betong located next to the mangrove. At times, during rainy season, this mangrove area may be subject to flooding due to overflow from the channel.

Mangrove forests at Kuala Sungai Pinang and Pulau Betong are matured and established (Figure 3.2 A and B, respectively). In general, high number of mangrove tree species was noted in Pulau Betong such as *Avicennia* sp., *Rhizophora* sp., *Bruguiera* sp., *Xylocarpus* sp. and mangrove affiliates such as *Acanthus* sp.. Kuala Sungai Pinang was noted with *Avicennia* sp., *Rhizophora* sp. and *Bruguiera* sp.. The mangrove site in Gurney however, is different from these two sites.

Gurney Drive is located in the north-eastern part of Penang Island (Figure 3.1 C). This newly established fringing mangrove is dominated by mangrove *Avicennia* sp. and a few *Rhizophora* sp.. Mangroves at Gurney Drive was the outcome of replanted activities after the tsunami tragedy in 2004. Gurney Drive is in the centre of an urbanized area, therefore mangroves at Gurney Drive is highly exposed to urbanisation, specifically housing, commercial and industrial areas (Figure 3.2 C).

The coastline of Penang Island experienced semidiurnal tides (Mohd Yusoff *et al.*, 2015) with a tidal range of 2 m (Colbourne, 2005). Overall in 2015 to 2016 Penang Island experienced low rainfall (<150 mm) during the first three months, high rainfall from April to November 2015 (225.4 mm – 507.4 mm) and low rainfall started again on December 2015 until April 2016 (Department of Meteorology, 2016).

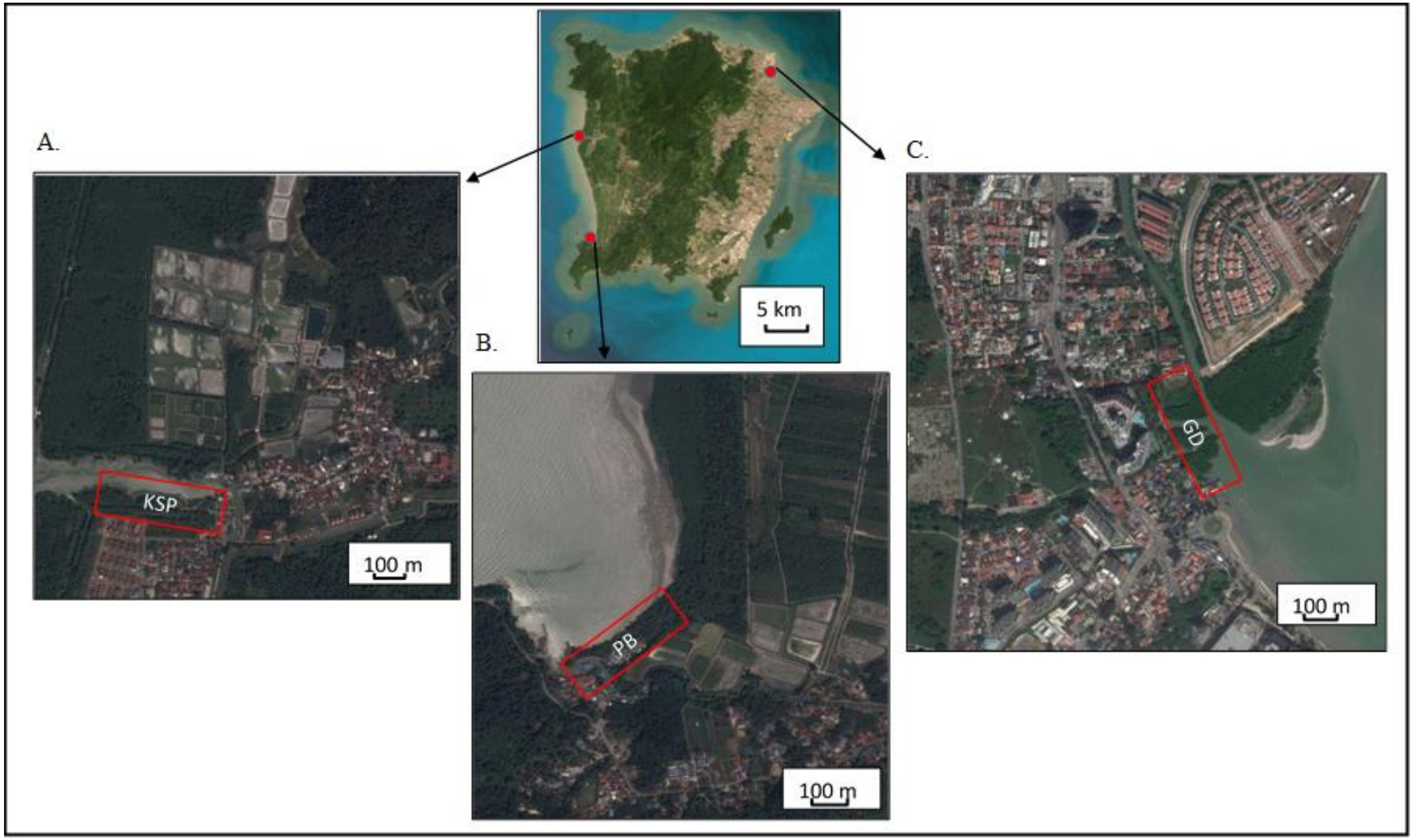

Figure 3.1: Mangrove forests chosen as study sites in the western (A. Kuala Sungai Pinang and B. Pulau Betong) and northeastern (C. Gurney) regions in Penang Island. Figures on the outset of the map marked with circles and indicated by arrows shown were specific locations (coordinates, refer Table 3.1) where sampling was conducted.

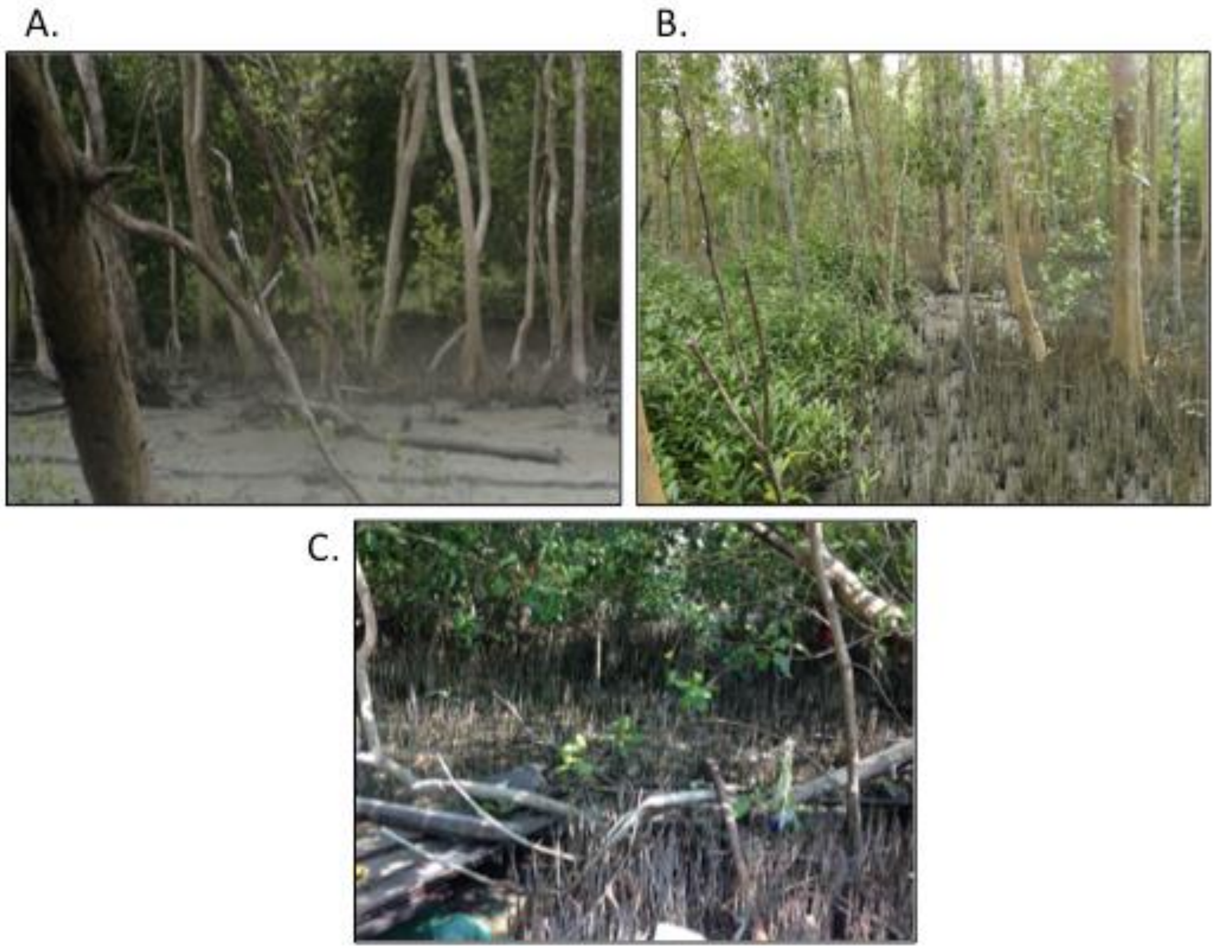

Figure 3.2: Mangrove of Penang Island located in Balik Pulau comprising (A) Kuala Sungai Pinang and (B) Pulau Betong. (C) Mangrove located in Gurney Drive.

3.2 Sampling design

Sampling was conducted bimonthly from April 2015 to January 2016 and consisted of 5 sampling occasions across multiple spatial scales, ranging from centimetre (m) to kilometre (km). Due to the patchy distribution of soft-sediment benthos (Morrisey *et al*., 1992), a detailed sampling design was utilized to consider the potential effect of spatial complexity and temporal heterogeneity. The sampling of bivalves and gastropods was conducted simultaneously with habitat characterization, and included sampling across different time and involving multiple spatial scales, specifically potential variation due to intertidal height and plots within the mangrove forest. Factors in the design included Time (n=5), Forest (n=3), Intertidal Height (n=2), and Station (n=3) with Plots (n=3) as replicates (Figure 3.3). Three subsamples represented by 3 quadrats (0.25 m x 0.25 m) were taken in each Plot and later pooled as a representative sample of one Plot (Figure 3.3).

The time (n=5) represent 5 sampling months:

1. April 2015
2. June 2015
3. August 2015
4. October 2015
5. January 2015