EFFECTS OF STRUCTURAL COMPLEXITY ON THE DISTRIBUTION OF MACROBENTHOS AT SELECTED ARTIFICIAL AND NATURAL SHORELINES IN PENANG ISLAND, MALAYSIA

AMNI NABILAH BINTI MAT ADAM

UNIVERSITI SAINS MALAYSIA

2017

EFFECTS OF STRUCTURAL COMPLEXITY ON THE DISTRIBUTION OF MACROBENTHOS AT SELECTED ARTIFICIAL AND NATURAL SHORELINES IN PENANG ISLAND, MALAYSIA

by

AMNI NABILAH BINTI MAT ADAM

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

December 2017

ACKNOWLEDGEMENT

Praised be to Allah s.w.t for giving me strength along my journey as a Master degree student. I am very grateful this opportunity, to be a part of the Centre Marine and Coastal Studies (CEMACS) team. I will never forget all the experiences which have made me who I am today. Behind my success, there are many people who I would like to thank for helping me realize my thesis. First and foremost, I wish to convey my heartfelt gratitude to my supervisor, Dr. Chee Su Yin, who always gives professional supervision, support and meticulous comments that improved my quality of my work.

I wish to express my sincere appreciation to Miss Sadchatheeswaran from University of Cape Town, who is willing to teach me about the 3D software for completing a part of my thesis. Even though we have never met, but you are an awesome person because you are willing to sacrifice your time to teach me through Skype and emails. Also not forgetting, a million thanks to the following person, Prof. Benny Chan, (National Taiwan University); Dr. Hiroaki Fukumori, (University of Tokyo); Dr. Nur Leena Wong, (Universiti Putra Malaysia); Dr. Chou Loke Ming and Mr. Ng Chin Soon Lionel, (National University of Singapore) for helping me in species confirmation. Special thanks also goes to Dr. Ally Evans (University of Southampton) and Dr. Zarul Hazrin Hashim (Universiti Sains Malaysia) for helping me in statistical analysis.

I also wish to express many thanks to my team members, Marcus and Jean, who always helping me in many aspects especially in sharing new ideas and comments throughout my study. I wish to express my gratitude to my friends, Ummi, Maizatul, Syuhaidah, Zulaikha and Hazwani, who always giving me supports. Thank you to the staff involved at CEMACS which assisting me indirectly in the fieldwork. Deepest appreciation to my family members especially my dad, Mat Adam and my mom, Wan Noraini, for their prayers and words of encouragement throughout the study process, because without them I would not have reached up to this level. Also, I would like to extend my warmest gratitude to my brothers and sisters who always cheer me up when I am stressed. Special thanks also to Ministry of Higher Education for providing me financial support through MyBrain15 scheme along my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

KESAN KERUMITAN STRUKTUR TERHADAP TABURAN MAKROBENTOS PADA PESISIRAN TIRUAN DAN SEMULA JADI DI PULAU PINANG, MALAYSIA

ABSTRAK

Pembangunan pesisiran pantai di pesisir timur Pulau Pinang, Malaysia telah menggantikan garis pantai semula jadi dengan pembinaan struktur pelindung pantai, sekaligus menjejaskan organisma marin yang tinggal di pantai "baru" ini. Habitat tiruan tidak mempunyai banyak retakan dan rekahan seperti habitat semula jadi, tetapi ia mempunyai kelimpahan jurutera ekosistem. Jurutera ekosistem, seperti tiram dan teritip, menyediakan kerumitan seni bina untuk digunakan oleh individu lain. Tujuan kajian ini adalah untuk mengkaji diversiti organisma pasang surut dan hubungan antara kerumitan struktur terhadap organisma ini. Kajian ini telah dijalankan di pantai berbatu Pulau Pinang. Tiga puluh gambar kuadrat dengan dimensi 15 cm x 15 cm telah direkodkan pada setiap bulan bermula Januari 2016 hingga April 2016 di enam kawasan berbeza iaitu tiga kawasan untuk setiap habitat semula jadi dan buatan beserta tiga zon pantai yang berbeza di sepanjang 25 m garis lintang selari dengan garis pantai. Fiziko-kimia parameter air diukur *in-situ* manakala nutrien dan logam berat telah dihantar ke makmal untuk diujikaji. Untuk mengukur kerumitan struktur, purata individu jurutera ekosistem, *Saccostrea cucullata*, *Amphibalanus amphitrite* and *Chthamalus malayensis* telah dikira berdasarkan gambar kuadrat bagi setiap bulan, kawasan dan zon pantai. Kemudian, sampel tersebut dicipta menggunakan Blender 2.74—program pemodelan 3D sumber terbuka. Kerumitan struktur juga diukur menggunakan kaedah isipadu celahan Blender. Sejumlah 31 dan 24 spesies masing-masing direkodkan di habitat semula jadi dan buatan. Kelimpahan makrobenthos direkodkan lebih tinggi pada habitat semula jadi (1648.31 ± 63.09 individu/m^2) berbanding habitat tiruan (995.99 ± 58.52 individu/m^2). Analisis Komponen Utama (PCA) menunjukkan parameter air yang mempengaruhi kelimpahan makrobentos di kedua-dua habitat ialah pH, kromium dan semua nutrien. Perbezaan nilai julat kualiti air di KD berbanding kawasan lain, menyebabkan keadaan yang tidak sesuai untuk organisma. Seterusnya, mengakibatkan kelimpahan makrobentos yang rendah. Kerumitan struktur antara habitat semula jadi dan buatan adalah berbeza secara signifikan. Walau bagaimanapun, semua kawasan tiruan (KD, SQ, EO) juga terdapat perbezaan yang signifikan antara satu sama lain. Sebaliknya, semua kawasan semula jadi (CS, MB, TG) dan satu kawasan tiruan (EO) menunjukkan kerumitan struktur yang sama. Peningkatan kelimpahan spesies ($r = 0.47$) dan kekayaan spesies ($r = 0.50$) dikaitkan dengan peningkatan kerumitan struktur. Habitat semula jadi telah dikenal pasti dapat menyediakan lebih banyak kerumitan struktur berbanding habitat tiruan, secara tidak langsung ia memberi kesan kepada bilangan spesies dan individu-individu yang mendiami pesisiran pantai tersebut. Berdasarkan penemuan ini, pelindung pantai atau pantai berbatu tiruan ini tidak boleh bertindak sebagai pengganti kepada pantai berbatu semula jadi. Cadangan penambahbaikan kerumitan pantai berbatu tiruan turut disediakan supaya biodiversiti pasang surut di pesisiran pantai dapat ditingkatkan.

EFFECTS OF STRUCTURAL COMPLEXITY ON THE DISTRIBUTION OF MACROBENTHOS AT SELECTED ARTIFICIAL AND NATURAL SHORELINES IN PENANG ISLAND, MALAYSIA

ABSTRACT

Coastal development on the east coast of Penang, Malaysia has replaced natural shorelines with built shoreline protection, adversely affecting marine organisms living on these “new” shores. Unlike natural habitats, artificial habitats do not have cracks and crevices, but do have an abundance of ecosystem engineers. Ecosystem engineers, such as oysters and barnacles, provide structural complexity for other individuals to make use of. The aim of this research is to study the diversity of macrobenthos and relationship of structural complexity to these organisms. The study was done on the rocky shores of Penang Island. Thirty quadrats with dimension 15 cm x 15 cm were photographed monthly in six different sites with three sites each for natural and artificial habitat from January 2016 to April 2016 at three different shore levels along a 25 m transect line parallel to shoreline. Physicochemical water parameters were measured *in-situ* while nutrients and heavy metals were sent to the laboratory for testing. To measure structural complexity, the average individual number of ecosystem engineers, *Saccostrea cucullata*, *Amphibalanus amphitrite* and *Chthamalus malayensis* were counted based on quadrat photos. Then, samples were recreated in Blender 2.74—an open source 3D modelling program. The structural complexity was also measured using a Blender interstitial volume method. In total 31 and 24 species were recorded on natural and artificial habitat respectively. High abundance of macrobenthos was recorded on natural (1648.31 ± 63.09 individual/m^2) compared to artificial (995.99 ± 58.52 individual/m^2) habitats. Principal Component Analysis

(PCA) showed water parameters that affected the abundance of macrobenthos on both habitats were pH, chromium and all nutrients. The difference in range values of water quality at KD compared to other sites, caused an unfavourable condition for organisms. Thus, resulting in the low abundance of macrobenthos. The structural complexity between natural and artificial habitats were significantly different. However, all the artificial sites (KD, SQ, EO) were also significantly different from each other. In contrast, all of the natural sites (CS, MB, TG) and one artificial site (EO) demonstrated similar structural complexity. The increase in structural complexity was correlated with the increase of total species abundance ($r = 0.47$) and species richness ($r = 0.50$). Natural habitats are able to provide more structural complexity than artificial habitats, hence affects the number of species and individuals that can make use of the shoreline. Based on these findings, shoreline protection or artificial rocky shores cannot act as surrogates of natural rocky shores. Suggestions to improve the complexity of artificial rocky shores are provided in order to increase intertidal biodiversity along coastlines.

CHAPTER 1

INTRODUCTION

Coastal urbanisation is happening all over the world replacing natural shorelines with built infrastructure—a process termed coastal hardening (Browne & Chapman, 2011). Expansion of coastal areas is given more attention compared to inland development since it provides higher economic value instead of solely providing more living space for human population (Lange, 2014; Wu et al., 2014). This causes dramatic changes along the coastlines as they are still being expanded dramatically from time to time. Urban and industrial development can now be seen occupying the artificial coastlines associated with man-made structures such as ports and marinas.

Penang Island, Malaysia is experiencing monumental changes on its coastlines much of it in the form of land reclamation. It began in the 1800's (City Council of Georgetown, 1966) and still has reclamation projects planned for the future (Yin & Kwang, 2016). Land shortage due to increasing population growth is predominantly the driving force behind reclamation of its coasts. Besides that, the increasing need of infrastructure and urban development also sped up the need for the reclamation. Now, rapid growth of coastal land reclamation is focused on the northeast of Penang Island (Raman et al., 2014; Ramly, 2008). Example of natural shores that have been fortressed with heavy coastal armouring and now become famous seaside in Penang are Karpal Singh Drive and Gurney Drive.

Extensive reclamation projects are causing loss of intertidal organisms especially macrobenthos where natural shoreline is heavily replaced with featureless hard structures (Airoldi et al., 2015; Baek et al., 2014; Wen et al., 2010). These macrobenthos are very important because they act as bio-indicators in environmental condition assessment due to their degree of sensitivity to both physical disturbances and chemical pollutions (Helmuth et al., 2011; Pinedo et al., 2015; Wethey et al., 2011). Unfortunately, for many years the marine habitat has been receiving less attention compared to terrestrial habitat by the responsible authorities albeit a lot of media coverage regarding these issue (Siqueira et al., 2015; Terrado et al., 2016). Low colonization and diversity of intertidal organisms were reported in the areas of coastal defence structures compared to natural shores (Bonnici et al., 2013; Evans et al., 2016).

Artificial hard structures have shown its capabilities in supporting marine benthic communities such as benthic algae, mobile invertebrates and scleractinian corals but they often are not considered as a surrogate habitat for the marine assemblages (Bulleri and Chapman, 2010; Ng et al., 2012). The conclusion was drawn based on several bodies of research where modification on physical shoreline characteristics was made during the earlier construction of artificial structures and physiological ecology of intertidal assemblages having severely changed as adaptations toward the artificial structures including recruitment, roles of prey and predator or even reproductive biology (Bulleri, 2005; Jackson, 2015; Moreira et al., 2006).

Previous studies found that habitat complexity provided on a substratum has effect on the biodiversity of benthic assemblages on natural and artificial habitats (Bulleri & Chapman, 2010). Habitat complexity plays an important roles in structuring the benthic communities and also facilitating higher species richness (Pierre & Kovalenko, 2014). Various terms have been used to describe the habitat complexity such as architectural, structural and topography complexity (Bozec et al., 2015; Meager et al., 2011; Palacios & Zapata, 2014). Different terms are used accordingly depending on the way the habitat complexity is measured. For example, usually on the studies of rocky shores, the physical structures of ecosystem engineers or substrate topography are related to habitat complexity (Arribas et al., 2014; Worden, 2015). Besides that, addition of features such as crevices, cracks and rook pools on natural habitat also increase habitat complexity of the rocky surfaces. Unlike natural habitat, artificial habitat lack these features but they do have ecosystem engineers that able to enhance complexity of their hard surfaces.

Ecosystem engineers include any species that contribute in creating, modifying and maintaining the habitat, thus providing a suitable substrate where they also create additional refuges for macrobenthos (Passarelli et al., 2014; Silva et al., 2015). Some ecosystem engineers such as barnacles, mussels and oysters are commonly used to determine the habitat complexity on rocky shores (Fraser et al., 2014; Walles et al., 2015). Highly abundant species of oysters (*Saccostrea cucullata*) and barnacles (*Amphibalanus amphitrite* and *Chthamalus malayensis*) are the common occurrence of ecosystem engineers in rocky shores of Penang Island. With their high abundance, it is important to study the roles these ecosystem engineers play in the environment and their interaction with other species (Lejart & Hily, 2011; Sadchatheeswaran et al., 2015).

Even though there are extensive literature about the habitat complexity of ecosystem engineers and how they enhance the habitat complexity on rocky surfaces, limited study has been done on determining of volume provided by the ecosystem engineers for other intertidal organisms. In case of this particular study, the term structural complexity was used which refers to structure of the ecosystem engineers as a role in increasing habitat complexity of the substratum. Structural complexity is defined as the maximum amount of volumetric space individual organisms can live in (interstitial gaps) or on (substrate rugosity) (Sadchatheeswaran, 2017). These approaches include 3D, Blender software to measure the interstitial volume (Sadchatheeswaran et al., 2015; Sadchatheeswaran, 2017).

The effects of structural complexity by ecosystem engineers toward the macrobenthos assemblages on natural versus artificial rocky shores in the Asian tropics, especially Malaysia have never been addressed. This study is not only novel in nature but fills the knowledge gap of how the presence or absence of ecosystem engineers can enhance or reduce coastal organisms. Better understanding of structural complexity will allow researchers to make modifications on artificial structures in the future as to improve the diversity of intertidal organisms. This research was conducted to determine the diversity of macrobenthos and its relationship to the structural complexity provided by ecosystem engineers found on the artificial rocky shores (rock revetments on the coastal land reclamation areas) versus natural rocky shores in Penang Island, Malaysia. The following are the main objectives of this study:

1. To determine the abundance, diversity and community composition of macrobenthos on natural and artificial rocky shores.
2. To assess the relationship between structural complexity and macrobenthos assemblages.

CHAPTER 2

LITERATURE REVIEW

2.1 Rocky shores

Rocky shores are an ecosystem located between land and sea and play important roles in providing functions and services. Rocky shores can be defined as intertidal coastal area which dominated by solid rocks (Wyles et al., 2014). It also supports flora and fauna that grow at different zonation.

2.1.1 Ecosystem functions of rocky shores

Ecosystem functions are the natural processes that take place in the communities of various plants and animals. Categories of ecosystem functions include supporting, provisioning and regulating. Rocky shore has the ability to provide habitat support for various marine and terrestrial lives. The habitat canopy-forming of macroalgae on rocky shores indirectly supports diverse assemblages of mobile species (Lilley & Schiel, 2006; Gravem & Morgan, 2015). It is also a crucial habitat for sea otters and chelonians group. Sea otters have strong connection to this habitat because they consume various benthic invertebrates on the rocky shores (Singh et al., 2013). Besides that, the spaces are provided between the rock surfaces are able to act as a shelter and refuge for certain organisms from their predators such as littorinid and nerite snails.

Another category of ecosystem function is provision of food which is mostly from photosynthesis process and predation activity. Producers in the food chain are responsible for photosynthesis process to provide the nutrients and energy for organisms in the higher tropic levels. Apart from food consumption, prey and predator can balance the population of animals and plants. According to Silva et al. (2008), limpets play an important role in controlling the abundance of macroalgae. Removal of limpets can cause alteration in biomass of macroalgae and species composition (Jenkins et al., 2005). Mobile predators such as crabs and fishes then play natural roles in regulating the abundance of these limpet grazers hence balancing the algal growth and grazing activity in the rocky shore ecosystem.

Following that nutrient regulation, a process of balancing nutrients involving biological and chemical nutrient cycling through the organisms and environment is also an ecosystem function. The common nutrients in the ecosystem are ammonia, nitrogen and phosphorus. The source of nitrogen typically comes the excretion of the animals whereby other organisms such as marine plants, macroalgae and microorganisms utilise the nitrogenous waste and convert them to other elements (Pfister et al., 2010).

2.1.2 Ecosystem services of rocky shores

Ecosystem services are the continuation of ecosystem functions that are beneficial to human beings (Schmidt et al., 2011). The examples of ecosystem services are air quality regulation, food provision and cultural services. Regulation services of air quality are mainly from photosynthetic processes by aquatic plants. The plants generate oxygen supply essential to the human respiration process. Both planktonic algae and benthic macroalgae are able to remove gaseous carbon dioxide from the atmosphere and eventually turn carbon dioxide into oxygen that is released back into atmospheric (Johnson et al., 2013). Regulation of air quality simultaneously can maintain our atmospheric air quality then provide us a better life.

In terms of food provision services, the marine molluscs on rocky shore habitats serve as essential seafood resources consumed by humans. The demand of marine food resources is increasing every year proportional to human population growth (Diana, 2009). Marine foods which are rich in protein are one of the main components required for human diets. According to Ab Lah et al. (2017) which stated that mollusc abundance in Malaysia was reduced due to human exploitation as their main diet. Turban snails are very common among the people in tropical Asia region and it has been proven to have good nutritional value compared to other shellfish (Ab Lah et al., 2016).

In addition, rocky shores also provides cultural services which including educational, recreational and aesthetic values (Clough, 2013). Where people can enjoy beautiful scenery of the ocean and marine wildlife in their natural habitat. Hence, rocky ecosystems add value to ecotourism industry. At the same time, people will also be able to learn about iconic native species besides experienced the cultural diversity from different places all over the world.

2.1.3 Zonation

Rocky shores ecosystem also has vertical zonation that inhibit specific organism across the distinct horizontal bands. The zones consist of supratidal zone, intertidal zone and subtidal zone.

<u>Supratidal zone</u>

Supratidal zone is also called splash zones because they are mostly exposed to the air and moisture caused by the splashing or spraying of breaking waves. Organisms living in this zone are very tolerant to thermal stress. In temperate region, studied on the understanding of mechanism of thermal responses in aquatic species are very important due to climate change. A study by Bedulina et al. (2010) shows cellular defense mechanisms in amphipods modifies according to environmental temperature changes. Adding to that, limpets are able to survive at the edges of their thermal window when temperature reach at 35 ºC to 38 ºC (Prusina et al., 2014). In tropics region, grazing snails such as periwinkle snails are often being found on the edges of the supratidal zones looking for food as they graze on the algae.

Intertidal zone

Intertidal rocky shore is the most physically harshest environment on Earth as they are exposed to heavy wave actions and thermal extremes during low tide (Tomanek & Helmuth, 2002). They are often associated with oxygen depletion, heat stress and low food availability especially during the low tides. Special characteristics of intertidal organisms are very important for their adaptions to the specific conditions. For example, bigger body sizes of organisms are able to reduce water loss and having circulation of body fluid prevent themselves from overheating. Species in intertidal zone also responded to different factors such as wave exposure, temperature and slope (Oigman-Pszczol et al., 2004; Raffo et al., 2013). In addition, intertidal zone can be further divided into three zones which are low, middle and high zones. Low zone is mostly covered by primary producer such as macroalgae and seagrass because this zone exposed to air during neap tides then living organisms can get sufficient of light intensity (Oigman-Pszczol et al., 2004).

In the tropical region, common species that can be found at the low zone are seaweed, *Hypnea* sp., *Ulva* sp. and *Sargassum* sp., barnacle, *Amphibalanus* sp., bivalve, *Saccostrea cucullata* and sea cucumber, *Holothuria* sp.. Meanwhile, organisms that live in the middle zone are gastropods such as *Morula* sp., *Cellana toreuma* and *Siphonaria* sp. Besides that, species found at the high zone are barnacle, *Chthamalus* sp., limpet, *Cellana grata* and periwinkle snails, *Nolittorina* sp., *Echinolittorina* sp. and *Littoraria* sp. (Ahmad et al., 2011; Dong & Williams, 2011; Londoño-Cruz et al., 2014).

Whereas in the temperate region, common species that can be found at the low zone include seaweed (*Corallina* sp. and *Sargassum* sp.) and kelp (*Undaria* sp.). Apart from that, gastropods such as *Turbo* sp., *Nucella lamellose* and *Cerithium* sp., are the organisms that can be found at the middle zone. Whereas in the high zone, barnacles such as *Chthamalus montagui*, *Chthamalus fissus* and *Balanus glandula* are found occupying the rock surfaces. Periwinkle snails such as *Littorina sitkana* and *Littorina littorea* can also be found within these barnacles (Harley et al., 2013; Heo et al., 2011; Rahman & Barkati, 2012; Stickle et al., 2017).

<u>Subtidal zone</u>

The subtidal zone is the area below the intertidal zone and is constantly covered by water even during low tide. In temperate countries like France, certain species of subtidal red seaweed can still survive because it is the most stable area in the region that can provide refuge for these seaweed when responding to global changes (Gallon et al., 2014). Echinoderms such as sea cucumbers, sea stars and sea urchins can also found at subtidal zones of temperate regions. These species are well-studied in terms of their settlement and recruitment (Jennings & Hunt, 2010; Scheibling & Robinson, 2008). Besides that, in the tropical region of Northeastern Brazil, a study by Giraldes et al. (2015) found that large decapods species were recorded in subtidal zones compared to intertidal zones due to the presence of coral reefs in these zones.

2.2 Macrobenthos

Macrobenthos are the benthic organisms, either animals or plants, which live in or on sediments and rocks. Animals or plants can be grouped as macrobenthos when their sizes are equal to or more than 0.5 mm (Tagliapietra & Sigovini, 2010). Molluscs, cnidarians, and crustaceans are considered macrobenthos. They also play important roles in the marine ecosystem where they act as food sources to higher tropic level consumers. The distribution of benthos thoroughly depends on the physical structure of substrate, level of substrate's stability, oxygen and nutrient contents (Rak et al., 2011).

Some studies of intertidal organisms have been carried out in northern Straits of Malacca. For example, study of macrogastropod by Siti-Balkhis et al. (2014) on the rocky shores of three islands—Pulau Telor, Pulau Songsong and Pulau Bidan—showed that 15 species were recorded and the common species found were in the families of Littorinidie (*Littorina undulata*, *Littorina scabra*, *Nodilittorina pyramidalis*, and *Nodilittorina biangulata*) and Neritidae (*Nerita articulata*, *Nerita maxima*, *Nerita plicata* and *Nerita polita*). Highest genera and species diversity was recorded at Pulau Songsong compared to Pulau Telor and Pulau Bidan. However, the study recorded lower abundance of gastropods compared to a study by Shau-Hwai et al. (2007) where the sampling sites located at Pulau Gazumbo, an island which is covered by community of seagrasses, which in turn provide more food supply to the gastropod community compared to rocky areas.

Meanwhile, study on the distribution of intertidal organisms had also been carried out in Teluk Aling, Penang where 13 species were observed and the dominant species found was barnacle (Ahmad et al., 2011). The results showed that barnacles have interactions with other organisms because they are able to increase substrate heterogeneity and subsequently provide shelter for other organisms. However, *Morula* sp., the main predator to barnacles, is responsible in reducing the abundance of barnacles. Furthermore, a study by Amir et al. (2013) on the distribution of barnacles which involved different sites in Penang showed that sites with less disturbance have the highest number of barnacles. From the results, it was also found that higher number of empty barnacle shells are recorded at sites nearer to land reclamation. This shows that, the barnacles are able to settle but unable to survive due to habitat disturbance. As a conclusion, the increase in coastal development has threatened the distribution pattern and diversity of intertidal assemblages, which in turn gradually changes the intertidal distribution pattern (Chapman & Blockley, 2009). Overall, there is still lack of publication on the comparison between the distribution and abundance of macrobenthos on natural and artificial rocky shores on Penang Island.

2.3 Water quality

Distribution and abundance of macrobenthos living in the marine ecosystem are often related to water quality (Airoldi et al., 2005). They are mostly influenced by a variety of physicochemical parameters such as dissolved oxygen, pH, salinity and water temperature. Seasonal change affects the physical water quality. A study by Nkwoji and Ajani (2010) showed that the salinity range of typical freshwater is similar to the salinity at marine condition during the dry season, while higher dissolved oxygen being recorded during the wet season compared to dry season. High dissolved oxygen was also recorded during the low water temperature (Onyema et al., 2010)

Nutrient pollution also influenced the macrobenthos communities. They are mostly linked to agriculture activities which use excessive inorganic fertilizers that contain nitrate and phosphate (Howarth et al., 2002; Michalak et al., 2013). This phenomena act as a catalyst for the algae communities to bloom thus causing the deterioration in water quality (Arévalo et al., 2007). Increasing concentration of organic matter from dead algae would then consume more dissolved oxygen resulting in a hypoxic condition in the water column. Consequently, many benthic organisms cannot survive under this condition, while the absence of primary producers exacerbates the situation.

Moreover, coastal areas are well-known as the final recipient of all substances from different sources. This has thus become one global concern, especially the physiologically stress on the benthic assemblages (Fernandez-Leborans & Herrero, 2000). Heavy metal elements such as arsenic, copper, cadmium, mercury and zinc which come from various point and nonpoint sources may accumulate in the coastal ecosystem. Therefore, only few macrobenthos which are more tolerant can survive under these contaminated conditions. Macrobenthos that can react to these condition is regarded as bioindicators. Bivalve species such as *Saccostrea cucullata* and *Perna viridis,* or gastropod *Thais clavigera* are highly potential act as good bioindicators for trace metal elements (Ismail, 2006; Rahman et al., 2016).

2.4 Coastal urbanisation

By 2020, three quarter of the world's population will be living within 60 km of the shorelines (Airoldi et al., 2005; Firth et al., 2014; Povh, 2000; Tian et al., 2016). Malaysia is also experiencing this situation where this prediction has led to the increase in demand of coastal reclamation which is widely known to have negative impacts towards the natural rocky shore ecosystems.

2.4.1 Coastal reclamation

In Malaysia, one of most popular coastal land reclamation areas is in Johor. Transformation of nation's economy together with the rise of urban population and industrial activities have led to growing demands for new lands. According to Sultan et al. (2016), as one of the economic development corridor, Johor experienced rampant coastal development with the construction of a new waterfront city by Iskandar Waterfront Sdn Bhd where 2000 acres of land will be reclaimed. For the beginning, Danga Bay was the prime waterfront introduced by Iskandar Malaysia, Johor. The strategic geographical location of Johor gives it potential to be developed into one of the busiest shipping route in the southern Peninsular Malaysia. As a result, economy of Johor is able to compete and integrate with Singapore which is in line with the a vision of Iskandar Malaysia (Rizzo & Glasson, 2012).

In addition, land reclamation in Malacca projects are focused along the coastline of the Straits of Malacca. The mega project in Malacca located in Klebang include luxury hotels, shopping malls and others commercial buildings (De Witt, 2010). Besides that, massive reclamation project also has been done in Malacca with the creation of Malacca Island (Mustapa, 2005). Malacca Island is the first man-made island which became the new trade and tourism centre in the state of Malacca. The famous attraction, Wildlife Theatre Melaka and Floating Mosque are situated on this island. The next project is to develop the Malacca Island as a maritime hub which is estimated to be completed by 2025.

Apart from the coastal reclamation project in Malacca and Johor, Penang Island also experienced huge coastal development due to economic growth. Penang is a famous destination among tourists as an attractive island with different cultures. A large scale of land reclamation project called Seri Tanjung Pinang (STP) Phase 1 was completed at the northeast part of the island in Tanjung Tokong (Ramly, 2008). The still ongoing project of STP Phase 2 will have the new accessible waterfront, integrated transport system and other facilities to appeal to international investors. Besides that, there are other reclamation projects aiming to transform the current Gurney Drive into seaside promenade and also an upcoming project of three artificial islands at the south coast of Penang Island which can support 300 000 human population.

2.4.2 Impacts of coastal reclamation

Coastal reclamation has caused loss of marine habitat such as estuarine wetlands, mangroves and seagrass beds (Li et al., 2010; Short et al., 2011). China suffered losses of mangrove and coral reef habitats approximately about 69% and 80% respectively (Tian et al., 2016) while in Singapore from 1970 to 2008, lost about 45.7% of seagrass meadow (Yaakub et al., 2014). Besides that, between 1990 to 2010, the loss of mangrove at west coast of Peninsular Malaysia was about 20% due to land conversion for coastal development and agriculture purpose (Ghazali et al., 2016). Still the actual total loss of mangroves due to coastal land reclamation alone was not documented in Malaysia.

In addition, coastal reclamation showed negative effects toward the intertidal organisms in coastal zones (Chapman, 2003). Even though previous studies had shown positive results on the recruitment of intertidal assemblages on artificial structures, their abundance was still not enough to consider artificial structures as a surrogate habitat (Bulleri & Chapman, 2010). This was supported by Moreira et al. (2006) with findings showing there was greater abundance of limpets surviving on the seawalls in Sydney Harbour but their reproductive output and size was reduced. As the community was not able to maintain a continuous growing population ratio, the species have to be persistent—which is challenging for those living in the harsh intertidal environment.

Besides that, coastal reclamation with built infrastructures such as breakwaters, rock revetments, groynes and seawalls also effect the diversity of intertidal organisms (Aguilera, 2017; Perkins et al., 2015). Usually, the engineers and contractors choose to deploy durable material where the material may not be similar to the natural rock (Green et al., 2012). Seawalls are the most common form of coastal defences that are made from concrete but their vertical orientations are not suitable for colonisations of the intertidal organisms, especially organisms which only inhabit at specific shore levels (Chapman, 2003; Chapman, 2006; Loke et al., 2017).

Reclaimed land with construction of hard structures, residential and industrial areas also give high impact on marine water quality. It caused changes in salinity gradient and increase water pollution subsequently leading to algae bloom (Bi et al., 2012). Algae bloom creates hypoxic condition which can kill the aquatic life. In addition, study by De'ath and Fabricius (2010) showed that low water quality with high level of turbidity, sedimentation and nutrient due to coastal development caused low diversity of macroalgae and coral.

2.5 Natural versus artificial rocky shores

There are different factors that contribute to the differences between natural rocky shores and man-made artificial infrastructures (Table 2.1). The main factor is the vertical surface or steep sloping nature of the built artificial structure especially a seawall. Generally, artificial structures have no clear division of vertical zonation (Bulleri et al., 2005). This influences the intertidal assemblages subsequently, which in turn support less habitat for intertidal organisms on the artificial structure (Chapman & Blockley, 2009; Firth et al., 2013; Moschella et al., 2005). Furthermore, vertical artificial structure also interferes water motion, preventing the tidal cycle from reaching the high water mark from 10 meters to only few meters (Chapman, 2003). Hence, the top of the seawall supports less organisms contrast to the high shore level in the natural habitat.

Table 2.1 Natural versus artificial rocky coasts.

	Natural	**Artificial**
Type	Original	Man-made
Substrate	Rock	Breakwater, seawall and rock revetments
Material	Granite and limestone	Granite, concrete, cement and soil
Slope	Gentle slope	Steeper slope
Arrangement of boulders	Loosely packed	Closely packed
Example	 Natural rocky shore	 Rock revetment

At the Sydney Harbour, study results on the diversity of intertidal organism at different heights on the seawalls and natural rocky shores by Chapman (2003) had proven that half of mobile benthic organisms were not found on artificial habitats. Moreover, natural habitats had greater number of rare species compared to artificial habitats. Another study by Chapman (2006) showed that molluscs were able to utilise the created spaces within intertidal boulder-fields as habitats for both artificial and natural habitats especially natural rocky shores.

Apart from that, Moreira (2006) conducted a study comparing the pattern of intertidal assemblages on both artificial habitats of seawalls with different built materials: natural rock (sandstone) and concrete showed that both seawalls shared similar intertidal species. Another study of intertidal assemblages comparing natural rocky shores against artificial habitat of seawall also showed similar results but the study found difference in species abundance between natural and artificial habitats (Lam et al., 2009). Based on both studies, abundance of intertidal organisms is most influenced by the type of habitat compared to the type of material. A study by Cacabelos et al. (2016) also found that intertidal organisms are not directly influenced by the material type of substratum be it locally quarried rock or concrete.

In addition, differences in species community between both habitats are generally due to the presence of natural features such as crevices, pits and rock pools on natural rocky shores. These features contributed to substratum surface heterogeneity on natural rocky shores (Bulleri & Chapman, 2010; Loke & Todd, 2016). Hence, improvement via engineering has been done on artificial structures as to mimic the natural rocky surface such as artificial rock pools. By doing so, the habitat complexity can be increased thus enhancing the intertidal biodiversity (Evans et al., 2016).

2.6 Habitat complexity

2.6.1 Habitat complexity studies

Habitat complexity is important in structuring and maintaining the aquatic assemblages (Frost et al., 2005; Tokeshi & Arakaki, 2012). It also can be explained as a fundamental driver of ecosystem functions (Meager et al., 2011). Increase in habitat complexity, will subsequently increase species diversity and richness (Burlakova et al., 2012; Pierre & Kovalenko, 2014). Habitat complexity is widely used in terrestrial and marine ecosystem studies. In marine habitat, rocky shores play important roles to support different degree of substratum heterogeneity. Rock surfaces are able to provide refuges and shelter for the population of mobile animals.

In terms of the relationship between habitat complexity and species abundance, Kostylev et al. (2005) stated that the complexity of substratum is directly proportional to the number of macrofauna individual. This was proven as they found higher population of *Littorina* sp. within the barnacle community than the mussel community. Even though the mussel community was more complex than barnacles, smaller animals were able to provide more inter-species microhabitats than larger animals. This finding was in contrast of their earlier study where low population of littorinid snails were found on barnacles instead of mussels due to the small spaces provided by barnacles within the community (Kostylev et al., 1997).

In addition, a study on the roles of mollusc's shell production including living shell, shell fragment and also empty shell in an aquatic habitat is important for the capability of its shell to introduce heterogeneity and complexity into benthic environment and thus, maintaining species richness of a landscape at different type of habitats (Gutiérrez et al., 2003). Empty mussels shells create reef-like structures and provide additional substratum habitats (Burlakova et al., 2012). Spatial arrangement of the shells also affects species richness of the benthic assemblages (Karatayev et al., 2002; Bagur et al., 2016).

Recently, interrelated studies focused on the relationship of habitat complexity in structuring the intertidal communities of rocky shores. According to Moschella et al. (2005), reduced habitat heterogeneity on artificial structures caused low benthic diversity in the habitat whereas presence of natural features such as crevices, pits and rook pools on natural habitat consequently increase the benthic diversity. Nonetheless, presence of positive inter-species interactions that involve at least two ecosystem engineers, be it direct or indirect can help in increasing the habitat complexity on both habitats (Passarelli et al., 2014).

2.6.2 Habitat complexity measures

Habitat complexity has been measured using various methods including chain and tape method (Risk, 1972) and water displacement method (Tsuchiya & Nishihira, 1985). However, there has been no fixed method that can provide accurate information on how the complexity affects the benthic communities. Thus, increasing attention has been focused on the concept of fractal dimension that is able to elucidate the complexity of the structure's static geometry (Committo & Rusignuolo, 2000). After the discovery of the fractal method, study of habitat complexity on rocky shores has become more common among the researchers (Johnson et al., 2003; Kostylev et al., 2005; Meager et al., 2011).

Frost et al. (2005) derived fractal dimension using different methods of measure on the surface complexity of intertidal rocky shore namely length of chain, profile gauges and stereo photography. The results showed that stereo photography overestimated surface complexity on the smooth surface while the other two methods were practical to be used. Results showed that fractal dimension could be more precise if more replicates are taken. Study by Gestoso et al. (2013) then made modification on the chain and tape method and called it the bidimensional rugosity index.

Yet, possibly the most effective method to date to reveal habitat complexity developed by Sadchatheeswaran et al. (2015; 2017). A three-dimensional model was created using the program in Blender 2.64—a sofware that supports various 3D pipelines including rendering, animation and game creation. The 3D models comprised of plane, ecosystem engineers which approximately mimic the shape and size of the species involved, rectangular funnel and sphere. Habitat complexity volume was derived by calculating the volume of free spaced in Blender.

2.6 Ecosystem engineers

According to Jones et al. (1997) ecosystem engineers are the organisms that directly or indirectly use the availability resource to others species or change the physical state of the structure. Ecosystem engineers can also be grouped into two types which are autogenic engineers and allogenic engineers. An autogenic engineer is an organism that can change the environment via its own physical structure by using its dead or living tissues. An allogenic engineer is an organism that can change the environment by transforming living and non-living materials into another states. Some studies have focused on ecosystem engineers such as corals (Komyakova et al., 2013), oysters (Lejart & Hily, 2011) and mussels (Sadchatheeswaran et al., 2015) and their roles in providing spaces to other organisms.

Physical ecosystem engineers are able to control physical stresses of the surrounding environment by providing hydro-dynamically benign microhabitat. Subsequently, the abundance and diversity of intertidal assemblages are much higher within biogenic habitats compared to areas lacking these habitat forming organisms (Castilla et al., 2004). Generally, positive effects of ecosystem engineers on other members of assemblages is directly proportional to the most apparent effects of ecosystem engineering (Harley, 2006). Besides that, ecosystem engineers are also able to increase overall species richness (Castilla et al., 2004) and abundance of interacting species (Wonham et al., 2005).

Barnacles are well studied as ecosystem engineers because they are the most abundant animals in the marine habitat. According to Martins et al. (2016) barnacles *Chthamalus stellatus* and *Chthamalus montagui* are widely studied in Europe because they have broad geographic distributions along Europeans coastlines. Besides, barnacles are known as key space occupiers especially on the mid to upper shore levels even though the abundance of barnacles on hard structures is usually low unlike on the natural rocky shores (Bulleri, 2005). A study by Sueiro et al. (2011) found that monolayer of barnacles provided less habitat complexity compared to mussel beds.

Mussels are known to change the habitat in both allogenic and autogenic ways (Jones et al., 1997). For example, zebra mussel beds tend to increase benthic colonization surface area (Lauringson & Kotta, 2016; Zwerschke et al., 2016) and alter the layer of substratum for other species to live on (Gutiérrez et al., 2003). Recent studies showed increased habitat complexity resulted from the invasion of Mediterranean Mussel, *Mytilus galloprovincialis* in the Marcus Island of South Africa (Sadchatheeswaran et al., 2015); and Zebra Mussel, *Dreissena polymorpha* in the Curonion lagoon of the Baltic Sea (Zaiko et al., 2009).

Research studies showed the positive relationship between ecosystem engineers and other organisms because ecosystem engineers act as additional features on the rocky surfaces in providing habitat complexity. In this study, virtual models developed by Sadchatheeswaran et al. (2015) was applied as to measure the structural complexity or volumetric space available for other species to live in or on. The effects of structural complexity with selected engineer species on intertidal organisms will be studied on natural and artificial rocky shores in Penang Island.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study sites

This study was conducted in Penang Island, Malaysia. A total of three sites were located for each natural and artificial rocky shores respectively. Sites for natural rocky shores (Appendix 1) were—Centre for Marine and Coastal Studies (CEMACS), Miami Beach and Tropical Spice Garden while for artificial rocky shores (Appendix 2), they were— Eastern and Oriental hotel, Karpal Singh Drive and Straits Quay, as shown in Figure 3.1. The site names were given according to nearby landmarks. Abbreviation and approximate GPS coordinates of sampling sites are listed in Table 3.1.

Table 3.1 Abbreviation and GPS coordinates of 6 sampling sites.

Habitat	Sites	Abbreviation	GPS coordinate
Natural	Centre for Marine and Coastal Studies	CS	N 05° 28.158’, E 100° 11.887’
	Miami Beach	MB	N 05° 28.831’, E 100° 16.048’
	Tropical Spice Garden	TG	N 05° 27.800’, E 100° 13.700’
Artificial	Eastern and Oriental hotel	EO	N 05° 23.910’, E 100° 19.868’
	Karpal Singh Drive	KD	N 05° 25.447’, E 100° 20.030’
	Straits Quay	SQ	N 05° 27.618’, E 100° 16.048’

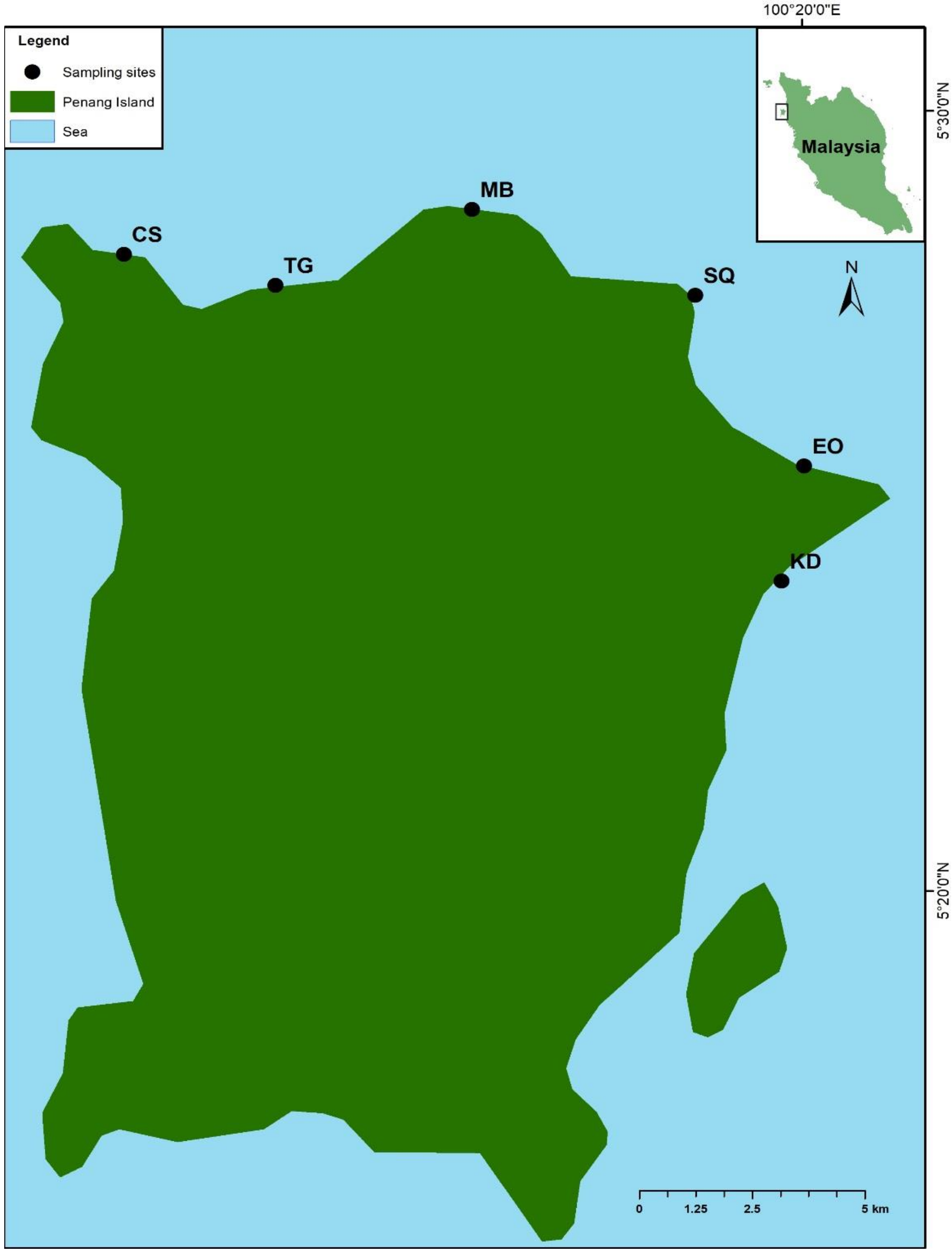

Figure 3.1 Map of Penang Island showing the locations of study sites in natural and artificial shores. Site names are abbreviated as follow: CS-Centre for Marine and Coastal Studies; TG-Tropical Spice Garden; MB-Miami Beach; SQ-Straits Quay; EO-Eastern and Oriental hotel; and KD-Karpal Singh Drive.

All natural sites have natural rocks while artificial sites consist only of rock revetments. CS is located in Penang National Park where there is fishing activity and fish pond nearby CS. MB is located along the coastline in Batu Ferringhi. TG is located at Teluk Bahang. There is no specific human activity on MB and TG apart from favourite spots for picnic. On artificial sites, KD is located at Jelutong. KD has main drainage channels that are connected to nearby residential and commercial buildings. It also has coastal fish ponds nearby the sampling points. SQ is a marina located at Tanjung Tokong while EO is located in Georgetown. The construction of the revetments at EO, KD, and SQ were completed in 2013, 2010 and 2005 respectively (Anandan, pers. obs.).

EO has different arrangement of boulders compared to the other two artificial sites. The boulders at KD and SQ are closely packed together and well-ordered with minimal degree of sloping. When tide water floods the low to middle tidal level, instead of gradually being submerged, the surfaces of the rock revetments were covered almost simultaneously. Thus, this cut short available sampling duration as it was only feasible when tide was lower than 0.7 m, when the low shore levels are accessible.

3.2 Experimental design

Sampling activities were carried out during low tide periods of each month from January to April 2016. The shore was divided vertically into three shore levels: low, middle and high according to tidal water level. A 25 m transect line was laid on each zone parallel to the shorelines. A 15 cm x 15 cm quadrat was used to measure the abundance of macrobenthos across the transect line. In each zone, 30 photographs of