EFFECT OF ARTIFICIAL ENHANCEMENT ON BIODIVERSITY IN MARINE CONCRETE-BASED STRUCTURES

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EFFECT OF ARTIFICIAL ENHANCEMENT ON BIODIVERSITY IN MARINE CONCRETE-BASED STRUCTURES

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
DO	Dissolved oxygen
Eco-engineering	Ecological engineering
nMDS	Non-metric multi-dimensional scaling
PERMANOVA	Permutational analysis of variance
PP	Penang Port
SIMPER	Analysis of similarity
SE	Standard error
SQ	Straits Quay Marina
USM	Universiti Sains Malaysia

LIST OF APPENDICES

KESAN PENAMBAHBAIKAN HABITAT BUATAN KE ATAS BIODIVERSITI PADA STRUKTUR MARIN BERASASKAN KONKRIT

ABSTRAK

Struktur marin berasaskan konkrit seperti tembok laut, pemecah ombak dan struktur lapis lindung telah banyak dibinakan berikut dengan aktiviti pembangunan pesisir pantai. Walaubagaimanapun, struktur tersebut mempunyai nilai ekologi yang rendah disebabkan oleh kekurangan kerumitan struktur. Dalam kajian ini, teknik kejuruteraan ekologi telah diuji untuk mempromosikan biodiversiti dan memulihkan fungsi ekologi struktur marin berasaskan konkrit. Sebanyak tujuh puluh plat konkrit dengan tiga tahap kerumitan: rata, 2.5 cm dan 5.0 cm ketinggian dan penambahan tiram (*Magallana bilineata*), telah dipasang pada tembok laut di Pelabuhan Pulau Pinang dan Straits Quay Marina di Penang. Kepelbagaian bentos adalah dipantau setiap tiga bulan selama satu tahun. Kepelbagaian makrofauna adalah dibandingkan antara setiap kerumitan habitat dengan kawalan. Keputusan mencadangkan manipulasi kerumitan habitat mempunyai kesan yang besar terhadap kelimpahan tanpa menjejaskan kekayaan spesies sementara penambahan tiram mempunyai kesan terhad pada kelimpahan. Sementara itu, plat kawalan menunjukkan kepelbagaian dan struktur komuniti yang sama seperti plat yang lain. Kajian ini memberi gambaran tentang bagaimana struktur komuniti bentos tempatan bertindak balas dengan pelbagai jenis kerumitan habitat dan menggalakkan pemahaman tentang komponen kritikal yang diperlukan untuk mengembalikan biodiversiti yang hilang.

EFFECT OF ARTIFICIAL ENHANCEMENT ON BIODIVERSITY IN MARINE CONCRETE-BASED STRUCTURES

ABSTRACT

Marine concrete-based structures such as seawalls, breakwaters and revetments are progressively built followed by intensified coastal development activities. However, these structures often have low ecological values due to low structural complexity. In the present study, a novel technique of ecological engineering was used to improve the structural complexity of existing seawalls to promote the growth of native biodiversity and potentially rehabilitate ecological function of marine concrete-based structures. Seventy settlement plates with three different degrees of complexities: flat, 2.5 cm and 5.0 cm high ridges, and addition of native oyster seeding (*Magallana bilineata*), were installed at mid-tidal level on seawalls at Penang Port and Straits Quay Marina in Penang. Monitoring of benthic diversity took place trimonthly for one year. Macrofaunal diversity was correlated between each habitat enhancements and that of the control. Results suggested habitat complexity manipulations had greatest effect on abundance without affecting species richness while addition of oyster seeding had limited effect on abundance. Meanwhile, control settlement plate had achieved similar diversity and community structure as in enhanced settlement plates. The study provides an insight on how local benthic and macrofauna communities utilize different habitat complexities and promote an understanding on critical components that are required to bring back lost biodiversity.

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CHAPTER 1

INTRODUCTION

The natural coastal environment consists of a wide range of different habitats, such as coral reef, mangrove forest, salt marsh, beaches, rocky shore, and sand dune, and are valuable natural assets. Globally, coastal environment provides a large segment of ecosystem services such as nutrient cycling, climate regulation, and food production (Barbier et al., 2011). Increased development and shoreline hardening have rapidly removed the ecosystems, replacing them with man-made artificial concrete and steel. Featured with highly homogenous appearance, man-made structures often come with very smooth surfaces, simple in structure (no fissure, opening or groove), extreme pH value, and low porosity (Ansley et al., 2004), which tend to have negative effect on organism survival rate. As coastal organisms make use of crevices and grooves in natural rock surface to prevent themselves from direct sunlight, predation, and desiccation, man-made structures provide very little of this.

To compensate the loss of coastal environment due to shoreline hardening, a new approach that aims to rehabilitate man-made structure toward environmental sustainability is getting more and more important. The technique, termed ecological engineering (eco-engineering) involves several disciplines such as ecology, engineering and technology, allow modification to hard engineered structures to improve overall environmental quality. Such modification including structural complexity, in which introduction of grooves, ridges, pits and holes increase habitat inches of variety macrobenthos. Incorporating eco-engineering techniques into hard engineered structures could create a balance between ecological biodiversity and coastal development expansion. Although restoration of entire ecosystem is impossible, through the innovative design and approach, eco-engineering could modify man-made structures and its environment, not only to combine natural features into artificial environment but also reduce ecological process interruption.

The study makes use of three different types of artificial settlement plates which comprise of flat, 2.5 cm and 5.0 cm height grooves and ridges, and oyster seeding to achieve the first objective: comparison of the macrobenthos community structures between settlement plates and control settlement plate (which represented as seawall). The second objective is to assess the effect of different height enhancements in enhancing macrobenthos diversity on the seawall. Lastly, evaluate the effect of oyster seeding as a habitat-forming species to improve native macrobenthos diversity.

CHAPTER 2

LITERATURE REVIEW

2.1 Coastal population and development resulted in shoreline fortification

Coastal population in the world today is heavy populated. An estimated three billion people or 40% of total human population live within 100 km of the coast (Agardy et al., 2005). The trend of coastal population growth is tremendous, expected that the number will only increase in the future, reaching 50% of world population living in this coastal area by year 2030 (Small and Nicholls, 2003). Many coastal located settlements had grown and developed into great cities, becoming what are known as megacity as the city population continued to expand explosively, going up to 10 million or more residents. Dated to year 2016, the world has 31 classified megacities, where 23 megacities located in the coastal zone (United Nations, 2016).

Asia has the highest population living by the coastal area among all other regions in the world, approximately 461 million people or 73% of total coastal population in the world (United Nations, 2010). Within Asia, Eastern Asia region had the highest coastal population density of 839 people per square kilometres in year 2000. In year 2060 by projection, coastal Asian population would expect to two-fold increase up to 983 million people reside by the coast (Neumann et al., 2015). Despite accounted for majority coastal population in the world and unstoppable growth rate, Asian coastal urbanization scale and rate do not keep up with the pace, produce low level of urbanized cities (Deb, 2017). Nevertheless, most of the rapid urbanized cities within the region are reside in developing countries. As a consequence of rapid growth, densely populated coastal settlement is likely to expose residents to seaward hazards such as greater intrusion of saline waters into coastal aquifers, increased shoreline erosion, intensified flooding, sea level rise and tropical storms (Paskoff, 2009).

The impacts and destructive potential of natural risks associated with climate change are largely driven by social changes, as people and economic activities are increasingly concentrated in coastal cities (Sherbinin et al., 2007). Despite this, there is lack of action in development policy and planning practices relating to the coastal cities, especially Asian coastal cities which are the top of the potential losses due to flooding (UNU-IHDP, 2015). Conflicts between growing coastal settlement, limited land available and increasingly concentrated human activities have force development to take initiative on coastal shoreline, turning these resourceful natural gifts into cold, rigid, impervious surfaces for better protection and security against natural disasters. Such marine concrete-based structures, however, often seen as primary solution that is crucial in protecting coastal properties and life (Rangel-Buitrago et. al., 2018).

The emergence of these concrete-based structures transforming natural landscape into urban marine environment to sustain demands of commercial, residential and tourist activities (Bulleri & Chapman, 2010). As one of the integral parts in urban marine environment, concrete-based structure holds fundamental function in economy, industry, leisure, transportation, and urban planning among urbanized coastal city. Nonetheless, the dominancy of concrete-based structure along the coast have as well alter the principle ecology on the coastline (Gittman et al., 2016). Unlike nature habitat, concrete-based structure acts as a foreign, novel habitat that supports different epibiota and associated assemblages, and thus does not considered as surrogate of natural rocky habitats (Tan et al., 2015). This problem is mainly due to design of the concrete-based structure. Engineered to focus on the functionality solely, concrete-based structure often came in simple shape—a homogenously smooth surface without any texture—which contribute to low habitat complexity (Waltham & Sheaves, 2018).

2.2 Ecological engineering as a novel tool in coastal mitigation to improve biodiversity

In coastal habitat, rapid proliferation of coastal defence structures has become novel ecosystem at the coastline. While removing the hard structure is impossible, restoring the coastal ecosystem is not impossible. Using ecological engineering approach, combining ecological principles with planning, design, and operation of marine concrete-based structures are able to produce multi-functional structures that could bring back ecosystem services (Dafforn et al., 2015).

Ecological engineering defined as: “the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both” (Bergen et al., 2001; Mitsch, 2012). The goal of ecological engineering could be ranged from restoration of entire ecosystem that have been disturbed by anthropogenic effect such as pollution, to the development of new sustainable ecosystem that have both human and ecological values (Mitsch, 2012). It should be distinguished from environmental engineering, which often confuse and make assumption by public, engineers, and ecologists that they are the same.

Environmental engineering is an extension to civil and industrial engineering, make use of biological and nature science knowledge in built environment to prevent and reduce environmental stress (Otti et al., 2018). In contrast, ecological engineering considers the biological behaviour and ecological dynamic in the nature—which is not part of conventional engineering—into designs and management that consistent with ecological principles and thus, sustaining the natural environment (Parrott, 2002; Allen et al., 2003). Such differences can be seen as the purpose of environmental engineering in producing a relatively inert product for its lifespan, but an ecologically engineered structure is expected to change in form and function over time (Allen et al., 2003).

The discipline of ecological engineering must derive on design by the complexity, variability and uncertainly inherent from natural (Bergen et al., 2001). Five principles in ecological engineering are: (1) It is based on self-designing capacity of ecosystems; (2) It can be acid test of ecological theories; (3) It relies on system approaches; (4) It conserves non-renewable energy sources; (5) It supports biological conservation (Mitsch & Jorgensen, 2003).

In order to mitigate loss of ecosystem services from coastal development, an understanding on the marine assemblages and their functional roles in nature and concrete-based structure must be achieved, and thus create suitable habitat enhancement on these artificial ecosystem (Firth et al., 2014).

Marine concrete-based structures generally have fewer abundance and lower diversity from natural rocky shore (Gittman et al., 2016). Many case studies reported species richness, Shannon diversity index and multiple functional groups of the benthic assemblages found on rocky shore were different when compared to seawall, which is typically dominated by hardy or invasive species (Lam et al., 2009; Bulleri et al., 2005; Revinesh & Bijukumar, 2013). The key factor that contributed to the assemblage compositional differences between seawall and natural rocky shore was habitat structural complexity, which is a primary driver in result of lack of primary producer on seawall (which also the main diet to many macrobenthos), exposure to light and wave (Bulleri & Chapman, 2004; Blockey & Chapman, 2006; Lai et al., 2018).

Habitat structural complexity is the term used to define the diversity of structural elements (Taniguchi et al., 2003), which characterised by five different physical aspects: spatial scale, diversity of complexity-generating physical elements, spatial arrangement of elements, sizes of elements, and density of elements (Tokeshi & Arakaki, 2012). Increased in habitat complexity often promote greater species diversity and abundance, because complex habitats are able to provide a wide variety of niches and encourage coexistence (Smith et al., 2014). Marine concrete-based structure, however, have no or very limited structural elements such as pits, grooves, crevices, and crinkles which are otherwise abundant on natural habitat. Without presence of structural element, simple architecture of concrete-based structure provides a large, uniformly flat area available for native colony to grow on has instead favour to the succession of exotic species (Bulleri & Chapman, 2010). The community shift to exotic species on concrete-based structure resulted from the dissimilarity of exotic species and native species, in which earlier have functionally and morphologically advantages over than that of native species, allowing them to create a unique bio niche on the novel habitat of concrete-based structure (Parr et al., 2010; Dijkstra et al., 2017).

The provision of concrete-based substrata as a novel habitat has replaced nature habitat completely, leaving modified man-made environment that lacks number of microhabitats existed in nature habitat, such as cavities, intertidal pools, boulders and shades, of which responsible to provide essential protection for variety of animals from direct sunlight exposure, desiccation, and predation (Scheffers et al., 2013). Nevertheless, as the structures were designed to be permanent and rigid structure, offer almost none of the water retaining feature or under surface microhabitats, thus reducing species diversity (Loke et al., 2017).

The assemblage composition was attracted and affected by the physical complexity characteristics in each habitat, resulted distinctive different in diversity on seawall and natural rocky shore. For instance, Loke et al. (2016) experimented using simple and complex designed of concrete tiles in Singapore demonstrated recruitment of algae as well as macrobenthos were greatly influenced by complex physical features present on the tiles. The higher physical structural complexity can create various microhabitats, which significantly improve the number of species (Loke et al., 2015). At the same time, large structural complexity added onto the seawall could offer a certain degree of protection to juvenile, thus providing a refuge to the organisms (Morris et al., 2017).

Many coastal ecological engineering projects thus focused on increasing microhabitat available on existing marine concrete structures. As such strategy allow ecological enhancement without significant construction works on marine concrete structure which may affects its protection ability. A relatively simple drill-cored artificial rock pools created as to mimic tidal pool on concrete structure in Tywyn, West Wales, United Kingdom was an example of durable and replicable habitat intervention. The artificial rock pools were drilled into horizontal granite surfaces on breakwater, to retaining water on the featureless surface of marine concrete structure (Evans et al., 2016). The addition of artificial rock pools had increased the number of species to the extent that was comparable to that in natural rock pools, attracts rare taxa, mobile animals that were otherwise absent on the breakwater (Moschella et al., 2005; Pister, 2009). The presence of artificial rock pools had hence modified and turning concrete structure as a surrogate intertidal habitat at an affordable cost.

Similar to drill-cored rock pools, artificial engineered habitat “Flowerpots” was designed to promote benthic species living on Sydney Harbour seawalls, Australia have an accidental side effect on fish communities (Morris et al., 2017). Pelagic fish, small-bodied fish, and lower trophic level of fish could have response to artificial flowerpots associated on seawall and react to benthic communities on flowerpots through predative consumption (Chapman & Clynick, 2006; Verges et al., 2011). Similar project of "Vertipool" in Isle of Wight, United Kingdom had likewise created an intertidal pool on seawall to hold water during low tide, reduce stress and increase residential value of hard engineered structure to the coastal benthic assemblages (Hall et al., 2019).

Besides simple intervention like the examples above, a more massive eco-engineered structure invention could design to eventually replace traditional concrete structure unit in the future. Such creativity was tested on Colwyn Bay, United Kingdom in 2012 through precast habitat enhancement unit BIOBLOCK (Firth et al., 2014). One BIOBLOCK is a large 5.4 tonne concrete that functioned as rock armour unit, at the same time consisted of different habitat types such as pits, ledges, and pools all in one BIOBLOCK unit. By providing multiple habitat types, the BIOBLOCK unit would have attracts different colonies that utilized the pits, ledges, and pools as intertidal pools, shelter and adherent surfaces (Hughes et al., 2016). By accumulating available features, the BIOBLOCK is able to support ecosystem services due to diversity of colonization.

Another extensive project of Elliott Bay Seawall in Seattle, Washington, USA was redeveloped aging seawall into brand new marine life corridor of conservation using structural-engineered concrete to recreate artificial tidal zonation on the seawall (Page & Jensen, 2015). The seawall characterized by new habitat features of shelf-like structures protruding from the wall, uneven cobbled surfaces along the wall, "marine mattresses" of mesh bags filled with rocks on the seafloor had successfully recruit greater diversity of organisms especially migrate juvenile salmon species along the shore. In additionally, the new seawall design also included light-penetrated glass panels on the pedestrian sidewalk to let sunlight though to the water below, directing a more natural migration movement of fish (Toft et al., 2007; Munsch et al., 2014). Post sampling after the enhancement had reported increased densities of larval and juvenile fishes, feeding behaviour dependency, and higher taxa richness (Toft et al., 2013). The physical association between seawall and urban management through ecological engineering has showcase the harmony that is achievable to incorporate human use into urban shoreline.

While many trials and intensive ecological engineering works were taking place in temperate countries, Asia countries remained in beginning phase of ecological engineering, often launch in experimental and regional scales (Loke et al., 2016). In highly urbanized coastline of Singapore where seawall and rock revetment are prevalent, ecological engineering approach was undertaking to improve seawall habitat towards coastal ecosystem rehabilitation. Since year 2016, structurally complex tiles with relevant microhabitats and large-scale deployment strategy were carry out on seawalls of Pulau Hantu, Singapore. The concrete tiles deployed on seawalls with different complexity designs were to identify optimal microhabitat size range, variability and structural types that would improve in biodiversity (Loke et al., 2017; Loke et al., 2019).

In present day, worldwide costal ecological engineering is not only to mitigate increasingly pressure on coastal and marine ecosystems, but also combating climate change, sea level rise, and stormier event that occurred more frequent than last century (Cheong et al., 2013). The progressively uncertainty of coastal area have urged coastal manager and planner to abandon single solution such as hard engineering of seawall, but rather turn into hybridization solution such as ecological engineering, to increase the odd of human survivorship. Such innovative approach of “building with nature” developed to integrate both ecological and social dynamics in concrete structure, and hence achieve greater good for all (Korbee et al., 2014). Unfortunately, there is merely 3% of global investment on coastal protection have been oriented on green solutions (McCreless & Beck, 2016).

Although it was considered as a small-scale experiment, the artificial enhancement of seawall proved to be a promising tool in enhancing the physical habitat complexity and thus in turn, improve biodiversity on marine concrete-based structure without compromising the functionality of the structures. There is increasing studies on how artificial enhancement could include into the design of urban marine concrete-based structure, in order to increase ecological values and functions provided by these man-made structures (Firth et al., 2016; Chapman et al., 2018; Strain et al., 2018). Apart from the addition of artificial enhancement, addition of habitat-forming species or ecosystem engineer, is also received an amount of interest.

2.3 Biogenic enhancement as an ecosystem engineer facilitate colonization of other organisms

Ecosystem engineer is a group of habitat-forming species, such as oyster, mussel and barnacle. Essentially, ecosystem engineers are able to create, destroy or modify habitats, alter the abiotic condition such as living space, ambient temperature, sediment accumulation and thereby, affect other organisms in the niche (Crooks, 2009).

It is thus artificial enhancement may fail, as the key limiting factor could not simply be solved by increasing habitat structural complexity alone. Hence it is worthy to include biogenic enhancement, which is more dynamic (Strain et al., 2020). Introduction of biogenic enhancement onto marine concrete-based structures is able to alter unfavourable abiotic conditions surrounding. Taking example from Scyphers et al. (2011) whom constructed artificial oyster reef breakwater, they found that the reef breakwater was able to reduce shoreline retreat by 40% (or more) with higher recruitment of fishes and mobile invertebrates. Strain et al. (2018; 2020) also found that when using native oyster as biogenic enhancement on existing seawall, the oyster facilitating survival of other species, either make use of the interstitial space within the reef or increase feeding frequency on the oyster surface, increase the odds of the species to recruit or survive in the otherwise disadvantageous environment. In addition, ecosystem engineer not only adding physical complexity to the structures using own body components, they themselves are taking part in the ecological processes such as filtration and water quality services, wave energy reduction, attraction for other species (as substrate of settlement or prey item), nutrient recycling and more (Bilkovic & Mitchell, 2013; Manis et al., 2014; Morris et al., 2018).

However, biogenic enhancement has several downsides. As a living component, ecosystem engineers are vulnerable to environmental factor itself. Factors like wave action, impacts from marine debris, temperature changes could seriously impact the growth rate of the ecosystem engineer. Selection of suitable species for biogenic enhancement must be careful examined and tested before large scale deployment or otherwise it may not able to survive long enough for desirable effect to take place (Ng et al., 2015).

More recently, there are studies that incorporated both physical and biogenic enhancements onto seawall to look for interactive effect by adding the two forms of enhancements together. Bradford et al. (2020) in Hong Kong and Strain et al. (2020) in Australia, both had engineering physical complex tiles with native oyster transplantation onto seawall for a duration of 1 year. Species richness and coverage was significantly higher than flat and unseeded tiles, either compared separately or combined both enhancements. This positive result demonstrated physical and biogenic enhancements can be an effective tool in improving native diversity on marine concrete-based structures.

2.4 Eco-engineering in Malaysia

Development in Malaysia is growing fast. Rapid and extensive development and construction in estuaries, coastal wetlands, and lagoons started since 1900s (Ghazali, 2006). The rapid growth of sectors, however, have convert major coastal area into multiple land use infrastructures that served domestic and international markets and put the coast under threats of environmental degradation and depletion (Kalirajan & Singh, 2013).

In recent year, with the increase in public awareness in environment, government gaining interest in identifying nature-based solutions that can be used cost-effectively in coastal defence and as alternative to investing in artificial defences (Ghazali, 2005). Besides traditionally soft engineering approach such as beach nourishment, a relatively more nature-based solution is used for coastal risk mitigation, for example mangrove rehabilitation. Mangrove replanting program was gaining popular in Malaysia, as mangrove is able to attenuate wave energy, reducing wave impacts and strength when reaching the shoreline (Parvathy & Prasad, 2017). Several medium- to large-scale mangrove replanting projects were took place in whole Malaysia, including Perlis, Kedah, Perak, Selangor, and Sabah (Sabah Forestry Department, 2017; Hashim & Shahruzzaman, 2017).

However, many mangrove replantation sites had recorded a high survival initially but high in mortality after the monitoring (Sofawi et al., 2016; Hashim &

Shahruzzaman, 2017). In additionally, mangrove replanted often resulted in mono-species coverage in high density, offer little contribution to coastal protection, fisheries and ecological enhancement (Iftekhar, 2008). In order to engineering mangrove replantation in the right way, mangrove recovery field must be ensured that physical condition of sediments, freshwater supply, and wave exposure are suitable (Motamedi et al., 2014). It is a must to know the right species to plant at the right place, as non-pioneer species may disturb the surrounding environment and fail on colonization (Kamali & Hashim, 2011).

To modify the physical condition into favourable, efforts must be made, or propagules will simply swept away by tides. In Carey Island and Sungai Haji Dorani, Selangor, artificial detached low crested structures and wave breakers were used to shield the propagules from exposed waves and accumulating sediment deposition to the correct elevation (Hashim et al., 2010; Sofawi et al., 2016). The restored area in adjacent to natural occurring mangrove forest allowing natural succession to take place when suitable conditions were achieved.

Another much earlier eco-engineering associated application in Malaysia considered artificial reef deployment. Initially used to enhance coastal fisheries, several artificial reefs were established in Pulau Telur, Pulau Payar, Kedah; and Pulau Aman, Penang in 1975 and 1976 respectively (Latun & Abdullah, 1991).

However, due to lack of scientific research at the time had caused many materials and designs used in artificial reefs ineffectively, such as usage of discarded tyre as artificial reef with polyethylene ropes, which would result in an ecological disaster, became colonized by only filamentous algae, perhaps some hardy sponges, but never blend into natural element of ecosystem (Ramli et al., 2016). It was then artificial reef deployment developed into concrete artificial reefs with small, medium and large sizes to create new habitats at the same time, deterring encroachment of trawlers in nearshore area (Saharuddin et al., 2012). During monitoring, observation was indicated that larger size artificial reefs support more fauna and flora than other sizes, due to presence of space within the large artificial reef unit (Ali & Sulit, 2014). After years of experiment trials, the design and construction of artificial reefs were highlighted, emphasize the importance of eco-engineering enhancement on the structure to achieve expected result.

Coincidentally, almost all eco-engineering projects launched in Malaysia was related to mangrove rehabilitation or underwater artificial reefs, involving the creation of new structure to rehabilitate disturbed environment. But it is not an easy, and not a cheap option to create new structure every time utilized in eco-engineering project. In contrast, infrastructure including harbours, jetties, pilling and other concrete based coastal and marine infrastructures are heavily built along the coastline, is a critical component for urban development and coastal protection. In Penang, large-scale reclamation projects for urban expansion, ports and marine development had led to proliferation of hard engineering structures especially focused in East coast of Penang Island, cover 30% of the coastline (Chee et al., 2017).

Over years shoreline hardening is continued use to fortify our coastline against coastal hazards, but this durable hard engineered structure should not be a lifeless graveyard that replace out our vital natural coastal environment. Ideally, coastal defence structures should have both the function of protection together with ecological benefit. Here the conceptual ecological engineering emerged and interfusion into concrete structure to design a sustainable ecosystem that integrate coastal protection and natural ecology for the greater benefit (Mitsch, 2012). It is aimed to restore ecosystems that have been considerably disturbed by human activities into a sustainable ecosystem.

In facts, the very first ecological engineering project in Penang was established through successful example demonstrated from drill-cored artificial rock pools in United Kingdom.

In Penang, the drill-cored artificial rock pools were able to create tidal pools on rock armour during low tide, provide refugee and attracted small animals to live in which will otherwise thrived on rock armour (Chee et al., 2020). Soon after artificial rock pools project, Penang had received an interest in collaboration on other eco-engineering projects which were World Harbour Project and Flowerpot project originated from Australia. Similar to their original project, World Harbour Project was aimed to create different microhabitats using simple interventions such as grooves, ridges and surface textures. While Flowerpot project created intertidal pools just like drill-cored artificial rock pools, Flowerpot project was installed on vertical breakwater where natural rock pools were not found. One of the objectives was to introduce a habitat that could be utilized by animals, and thus improving the ecological function of a breakwater. Even though these eco-engineering projects were planned to be short-term projects, such solution have already created an interest in varies parties considering the possibility of merging eco-engineering aspect into coastal development.

Time have proved that by using engineering perspective alone in coastal protection is not sufficient, and often catalyse in unforeseen impacts on surrounding ecosystems (Borsje et al., 2011). It is hence the concept of self-designing at the ecosystem core is important to focus on natural energies and biological conservation in order to diverting the problem (Mitsch & Jorgensen, 2003). Ecological engineering interventions of increasing surface complexity, elevations and habitat-forming taxa settings could all brought positive result onto bared hard engineered structure, achieving conservation, rehabilitation, and remediation at the same time (Strain et al., 2018). The advance in coastal eco-engineering is especially crucial in delivering both biology and engineering solutions in the issue of coastal protection, which is able to provide multiple services to maximize economic benefit and adaptation to climatic change (Perkins et al., 2015).

In context of Malaysia, the implementation of ecological engineering is scarce and unorganized (Yeo et al., 2016). Without an appropriate guideline and planning that regulate directly with the provision of ecosystem services, rapid expansion of ungoverned builds has transforming our coastline into high density urban area where both ecosystem and liveliness are left unchecked (Nasongkhla & Sintusingha, 2013). Even though several environment related policies like National Policy on the Environment (NPE), National Landscape Policy (NLP), and National Physical Plan (NPP) implemented, all did not emphasis on environmentally sustainable development, and thus integration between economic and environmental developments should be incorporated in planning stage (Kementerian Sains, Teknologi dan Alam Sekitar, 2002).

Novelty of eco-engineering should not be a hindrance nor discouragement to us. Along with successful example from foreign countries, the application of eco-engineering concept on our coast could be implementable. The urgency of association between marine ecology and coastal engineering is designed to reduce negative ecological impacts during development, promote ecosystem services and introduce multi-functional artificial structures protecting our vital near-shore infrastructures and lives (Dafforn et al., 2015).

CHAPTER 3

MATERIALS AND METHODS

3.1 Experimental sites

In the present study, two experimental sites selected were: a section of seawall at Church Street Pier, Penang Port, Georgetown (5°24’57’’ N, 100°20’39’’) and breakwater in Straits Quay Marina, Tanjong Tokong (5°27’32’’ N, 100°18’53’’ E; Figure 3.1).

Both experimental sites were chosen primarily due to their current status as an active marina/port with workable marine concrete-based structures. Secondly, both sites have ease of access at the time of low tide without the need of addition transport such as boat. Thirdly, both sites offered higher security as restricted public access applied within the private premises. Lastly, the concrete structures in the sites were built vertically, which exclude the possibility of water retention during low tide. This was to ensure no factor other than complexity and oyster seeding (which were the manipulating factors) would have come in play, affecting the result of the experiment which may lead to misinterpretation.

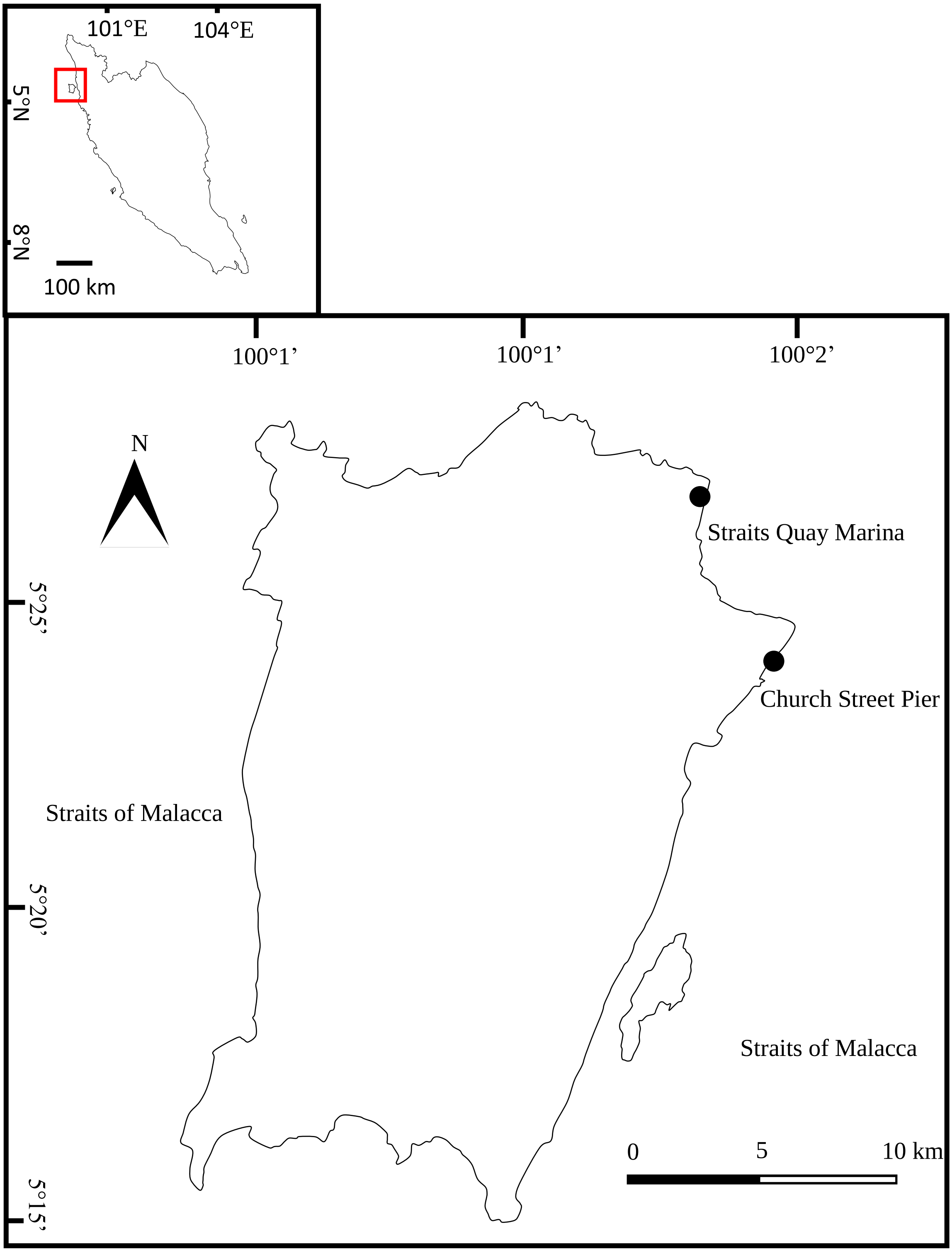

Figure 3.1 Map of Penang Island showing two experimental sites: Penang Port and Straits Quay Marina.

3.1.1 Church Street Pier, Penang Port

Built in year 1897, Church Street Pier is now a heritage pier in George Town waterfront just next to Ferry Terminal, Penang Port (Cheah, 2012). It was closed many years ago, left only abandoned berths visible at the water surface (Figure 3.2). The tidal range in this area is between 0.4 to 2 m height (Karim & Ismail, 2010). During spring low tide, a large area of mudflat can be seen to expose as far as 10 - 50 m from the shoreline. The wave action is generally low to average, and native bivalve attached along the seawall.

Figure 3.2 View of Church Street Pier at Penang Port during high tide and spring low tide.

3.1.2 Straits Quay Marina, Tanjong Tokong

Fully operated in 2010, Straits Quay Marina houses 40 pontoon berths for varies recreational yacht and boats (Figure 3.3). Inside the marina is a basin dredged to approximately 3 m below chart datum, but the depth was greater outside the marina with about 2 m deeper. The maximum tidal range in this area is between 0.8 to 2 m height (Karim & Ismail, 2010). During spring low tide, the seafloor outside of the marina could not be reached and subjected to higher energy wave.

Figure 3.3 Skyview of Straits Quay Marina and side-view of the breakwater.

3.2 Experiment design

The experiment was replicated at two sites: Penang Port (PP) and Straits Quay Marina (SQ). The basis of the experiment was a fully orthogonal experiment design crossing habitat enhancement (of three levels: flat, 2.5 cm, and 5.0 cm height enhancement) with bivalve seeding (two levels: with and without bivalves seeding). Selection of height enhancement was based on previous studies on the effect of cm-scale complexity added onto the seawall (Strain et al., 2018; MacArthur et al. 2019). Additionally, five replicates of control settlement plates had been included to assess the efficacy of the enhancements as such:

1. Flat eco-concrete settlement plate with bivalve seeding (henceforth referred as “flat seeded”)
2. Flat eco-concrete settlement plate without bivalve seeding (henceforth referred as “flat unseeded”)
3. 2.5 cm height enhancement eco-concrete settlement plate with bivalve seeding (henceforth referred as “2.5 cm seeded”)

4. 2.5 cm height enhancements eco-concrete settlement plate without bivalve seeding (henceforth referred as “2.5 cm unseeded”)
5. 5 cm height enhancements eco-concrete settlement plate with bivalve seeding (henceforth referred as “5.0 cm seeded”)
6. 5 cm height enhancement eco-concrete settlement plate without bivalve seeding (henceforth referred as “5.0 cm unseeded”)
7. Flat local manufactured settlement plate without bivalve seeding that represented as new seawall (henceforth referred as “control”)

For treatments 1 to 6 the settlement plates were shipped from Sydney, Australia. These 25 x 25 cm settlement plates were made from eco-concrete with lower surface pH. Treatment 7 acts as control means, was casted and manufactured in School of Housing Building and Planning (HBP), USM with similar dimension as other settlement plates (Figure 3.4).

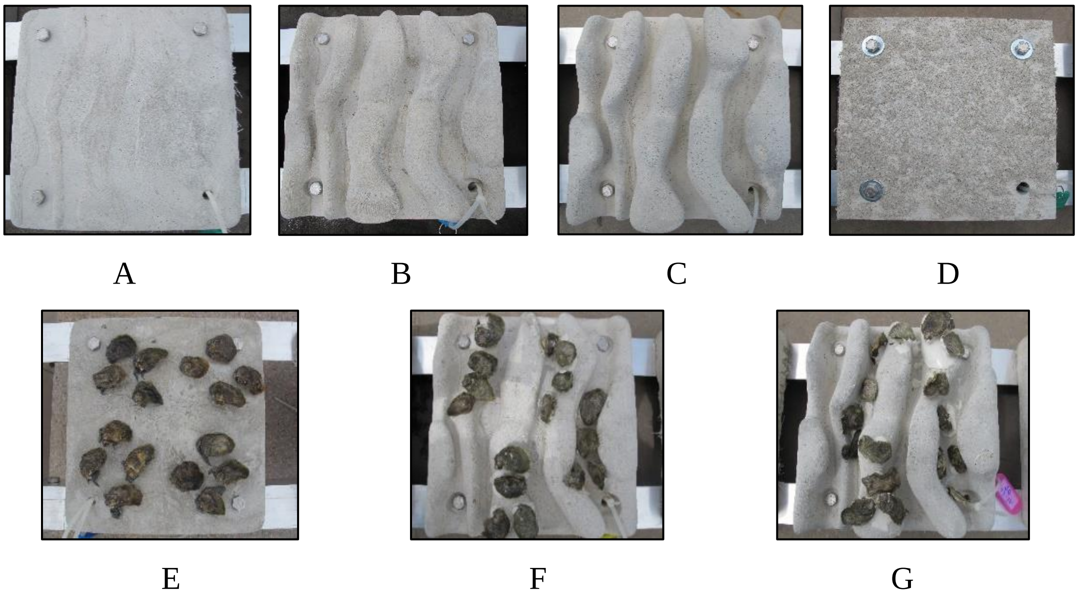

Figure 3.4 Different types of settlement plates used in this study (A) flat; (B) 2.5 cm height; (C) 5.0 cm eco-concrete settlement plates, (D) control (seawall) plate, (E) flat seeded, (F) 2.5 cm seeded and (G) 5.0 cm seeded eco-concrete settlement plates.

The experiment was undertaken on vertical seawall in Penang Port and breakwater of Straits Quay Marina. Settlement plates for seven treatments with five replicates (5 replicates x 7 treatments per site) were deployed at the mid-tidal elevation (which was pre-determined by field surveys on July and August 2016 before the experiment kicked started) and facing open sea to minimize potential point-source of pollution or disturbance such as boat wake.

To prevent damage onto the seawall structures that we were working on, no drill or dynabolt was used to attach the settlement plates on the seawall. Instead, we assembled seven aluminium frameworks of same width (1.5 m) but different lengths (as height adjustment from the top of seawall to desired mid-tidal level was different in each site: 1.5 m and 2.5 m of height in Penang Port and Straits Quay Marina respectively) to hold the settlement plates at the bottom of the framework (Figure 3.5).

A B

Figure 3.5 Aluminium frameworks of different dimension as in (A) Penang Port with 1.5 x 1.5 m and (B) Straits Quay Marina with 2.5 x 1.5 m.

On the bottom of each framework there was five replicates resided, with random combination from six treatments: flat seeded, flat unseeded, 2.5 cm seeded, 2.5 cm unseeded, 5 cm seeded and 5 cm unseeded settlement plates. However, seeded