FISH COMMUNITIES IN ADJACENT SEAGRASS AND CORAL REEFS IN BABI BESAR ISLAND AND TINGGI ISLAND, MALAYSIA

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FACULTY OF SCIENCE
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FISH COMMUNITIES IN ADJACENT SEAGRASS AND CORAL REEFS IN BABI BESAR ISLAND AND TINGGI ISLAND, MALAYSIA

ABSTRACT

Tropical seagrass and coral reefs are highly complex and ecologically- important habitats that provide food and shelter for diverse marine fishes. It has been shown that habitat complexity attributes influence fish community structure in shallow marine habitats. Habitat complexity is defined as heterogeneity and architecture of the habitat, usually described by single-measure variables such as species richness, growth forms, percent cover, biomass, rugosity, substrate cover, canopy height and shoot density. The objectives of this study are (1) to characterise and compare fish communities; (2) to identify the habitat complexity attributes for fish density and species richness; and (3) to identify associations between habitat complexity and fish feeding guilds, in adjacent seagrass and coral reef habitats. Remote Underwater Video Station (RUVS) was used to document fish species and density within 2 x 2m quadrats on seagrass meadows (n=30) and adjacent coral reefs (n=31) in Tinggi Island and Babi Besar Island within the Sultan Iskandar Marine Park in Johor, Malaysia. From 1,098 minutes analyzed footage of RUVS, a total of 136 fish taxa were identified and enumerated from 1429 individuals sampled in the coral reefs, whereas 86 fish taxa were identified from 1005 individuals sampled in the adjacent seagrass meadows. Fish community data showed higher density of juvenile fish utilising the adjacent seagrass habitat as foraging ground. In contrast, coral reefs were mainly inhabited by adult fishes seeking refuge within the highly complex habitat. Additionally, there were 10 species of tropical marine fish identified as utilising both habitats which were mainly invertivores. These findings indicate the potential nursery function of the seagrass habitat and serve as important feeding grounds. To identify fish-

habitat relationship, multiple habitat complexity attributes were assessed for the seagrass meadows (percent cover, canopy height, shoot density, species richness) and coral reefs (percent cover, coral growth forms, substrate percent cover, rugosity, coral genus) using photo quadrat, chain, seagrass core and *in situ* measurement methods. Generalized Linear Models (GLMs) revealed seagrass percent cover and distance to adjacent habitat were important attributes for fish density and species richness in seagrass habitat, with total explained variance of 37% and 34% respectively. In coral reefs, the habitat complexity attribute of live coral cover explained 16% of the total variance in fish density; whereas 14% of the total variance in fish species richness was explained by the rubble percent cover. However, Canonical Correspondence Analysis (CCA) results illustrated no significant correlations between fish feeding guilds and habitat complexity attributes in both seagrass and coral reef habitats. In conclusion, habitat complexity and distance to adjacent habitat were found to be important in structuring fish communities in seagrass and adjacent coral reefs. These outcomes have important implications for fisheries and Marine Protected Area management in conserving the connected habitats of coral reefs and seagrass meadows to ensure the sustainable flow of ecosystem functions and services.
Keywords: habitat complexity attributes; fish-habitat relationships; habitat utilisation; proximity to adjacent habitat; Remote Underwater Video Station

STRUKTUR KOMUNITI IKAN DI RUMPUT LAUT DAN TERUMBU KARANG YANG BERSEBELAHAN DI PULAU BABI BESAR DAN PULAU TINGGI, MALAYSIA

ABSTRAK

Habitat rumput laut dan terumbu karang tropika mempunyai kepentingan ekologi sebagai sumber makanan dan perlindungan kepada pelbagai jenis ikan laut. Sifat-sifat kerumitan habitat mempengaruhi komuniti ikan laut di kawasan cetek. Kerumitan habitat didefinisikan sebagai kepelbagaian dan struktur pembinaan habitat, selalunya dihuraikan oleh pembolehubah yang pengukuran-tunggal seperti kekayaan spesis, bentuk pertumbuhan, liputan, biomass, rugositi, liputan substrat, ketinggian kanopi dan kepadatan tumbuhan. Objektif-objektif kajian ini adalah (1) menghuraikan dan membezakan komuniti ikan; (2) mengenalpastikan sifat kerumitan habitat yang utama untuk densiti dan kekayan spesis ikan; dan (3) mengenalpastikan hubungan antara kerumitan habitat dengan cara pemakanan ikan, di kawasan rumput laut dan terumbu karang yang bersebelaha. Stesen video dalam air kawalan jauh (RUVS) telah digunakan untuk mendokumentasikan spesis dan densiti ikan dalam kuadrat 2 x 2m di kawasan rumput laut (n=30) dan terumbu karang yang bersebelahan (n=31) di Pulau Tinggi dan Pulau Babi Besar terletak dalam Kawasan Perlindungan Marin Sultan Iskandar Johor, Malaysia. Daripada 1,098 minits rakaman RUVS dianalisis, sejumlah 136 taxa ikan telah dikenalpastikan daripada 1429 individu yang sampel di kawasan terumbu karang, manakala 86 taxa ikan telah dikenalpastikan daripada 1005 individu yang sampel daripda kawasan rumput laut yang bersebelahan. Data komuniti ikan menunjukkan bahawa jumlah densiti ikan juvenil yang lebih tinggi dijumpai kawasan rumput laut dan menggunakannya sebagai kawasan memakan. Manakala berbanding dengan kawasan terumbu karang, dimana lebih banyak ikan dewasa dijumpai bertempat di habitat yang berstruktur rumit ini. Selain itu, terdapat 10 spesis ikan laut tropika dikenalpastikan mengguna kedua-dua habitat terumbu karang dan rumput laut, kebanyakan spesis tersebut adalah invertivor. Penumuan kajian ini menunjukkan potensi habitat rumput laut berfungsi sebagai nurseri dan kawasan memakan yang penting. Untuk mengenalpasti hubungan antara ikan-habitat, beberapa sifat-sifat kerumitan habitat telah dikaji untuk kawasan rumput laut (liputan rumput laut, ketinggian kanopi, kepadatan tumbuhan, kekayan sepsis) dan terumbu karang yang bersebelahan (liputan karang, bentuk pertumbuhan karang, liputan substrat, rugositi, genus karang) dengan menggunakan kaedah-kaedah seperti kuadrat gambar, rantai, pengeluaran bahagian teras rumput laut dan pengukuran in-situ. Generalized Linear Models (GLMs) telah menunjukkan bahawa peratus liputan rumput laut dan jarak berdekatan dengan habitat yang bersebelahan dikenalpasti sebagai sifat-sifat habitat yang penting untuk densiti dan kekayaan spesis ikan, dengan jumlah varians yang dapat dijelaskan sebanyak 37% dan 34% masing-masing. Liputan batu karang hidup telah dikenalpasti sebagai sifat habitat yang penting untuk densiti ikan di kawasan terumbu karang iaitu menjelaskan 16% daripada jumlah devians; manakala 14% daripada jumlah devians untuk kekayaan spesis ikan telah dijelaskan oleh liputan serpihan karang (rubble). Tetapi keputusan daripada Canonical Correspondence Analysis (CCA) menunjukkan tidak ada sebarang hubungan antara cara pemakanan ikan dengan sifat-sifat kerumitan habitat di habitat rumput laut dan batu karang. Secara kesimpulannya, sifat-sifat kerumitan habitat dan configurasi telah dikenalpasti sebagai pempengaruh yang penting untuk densiti dan kekayaan spesis ikan di habitat terumbu karang dan rumput laut. Hasil kajian ini mempunyai implikasi yang penting bagi pengurusan perikanan dan Kawasan Perlindungan Marin untuk memerlihara kawasan marin yang mempunyai sambungan habitat antara terumbu karang dan rumput laut demi memastikan fungsi dan perkhidmatan ekosistem yang mampan.

Kata kunci: sifat-sifat kerumitan habitat; hubungan ikan-habitat; penggunaan habitat; proximiti ke habitat bersebelahan; Stesen video dalam air kawalan jauh

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LIST OF SYMBOLS AND ABBREVATIONS

AIC	:	Akaike Information Criterion
Cs	:	*Cymodocea serrulata*
DC	:	Dead coral
DIST	:	Distance to adjacent habitat
GLM	:	Generalized Linear Model
HC	:	Hard coral
HEIGHT	:	Canopy height
Ho	:	*Halophila ovalis*
Hu	:	*Halodule uninervis*
LCC	:	Live coral cover
MPA	:	Marine Protected Area
OT	:	Other
RB	:	Rubble
RCK	:	Rock
RUVS	:	Remote Underwater Video Station
SCUBA	:	Self-Contained Underwater Breathing Apparatus
SD	:	Sand
Si	:	*Syringodium isoetifolium*
UVC	:	Underwater Visual Census
VIF	:	Variance Inflation Factor

CHAPTER 1: INTRODUCTION

1.1 Background of study

Tropical shallow marine habitats especially coral reefs and seagrass meadows are important habitats for many species of reef fishes including commercially important species, especially high-value fishes such as Lutjanidae (Snapper), Serranidae (Grouper) and *Cheilinus undulatus* (Humphead wrasse) (Arai, 2015; Grober-Dunsmore et al., 2006).

However, these critical habitats for marine fishes are declining at an alarming rate due to climate change and other anthropogenic factors including land reclamation, water pollution. Habitat degradation may have substantial consequences toward reduction of fish abundance and diversity. A recent study suggested habitat loss pose a greater local extinction risk to habitat-associated species in high diversity hotspots compared to a region with lowered species richness (Holbrook et al., 2015). Despite the importance and declining status, the basic ecology of fish-habitat relationships is still poorly understood, especially in tropical biodiversity hotspots where coral reefs are situated adjacent to forereef seagrass meadows where these habitats are interlinked in terms of organisms, nutrient cycling or food source.

In tropical shallow marine ecosystem, many habitats are closely linked and situated adjacently to each other (Sale et al., 2010). Based on coral reef and seagrass meadow distribution and diversity maps, the Coral Triangle known as the epicentre of marine biodiversity has both ecosystems adjacent to each other (Burke et al., 2011; Short et al., 2007), therefore seagrass-coral reef continuum are commonly found in tropical ecosystem. One of the viable measurement of inter-habitat connectivity is through a study of the fish community that utilize these adjacent habitats. It has been documented that some fish communities undergoes migration from one habitat to another, either daily migration to their foraging ground or ontogenetic migration throughout their life stages (Nagelkerken et al., 2000b; Verweij et al., 2008).

In the present study, fish habitat utilisation in tropical coral reefs and adjacent forereef seagrass habitats were examined and compared. Subsequently, fish species that utilise and migrate between both habitats are then identified as those that have cross habitat utilisation. These habitat utilisation patterns in coral reefs and seagrass show the functional habitat for fish community in the area, whereas the cross-habitat utilisation shows the connectivity between habitats.

Fish community structure in tropical shallow marine habitats are known to be influenced by habitat complexity and configuration. Studies have been mainly focused on coral reef habitats, and often one or two variables are chosen to explain the variability on fish community structure. Examples of habitat complexity and configuration that influences fish community structure are live coral cover, coral rugosity, seagrass shoot density, seagrass canopy height, seagrass biomass and proximity to adjacent habitat (Ambo-Rappe et al., 2013; Bell & Galzin, 1984; Dorenbosch et al., 2005b; Friedlander & Parrish, 1998; Gratwicke & Speight, 2005a; Komyakova et al., 2013; Nagelkerken et al., 2002). In this study, habitat complexity attributes that have significant correlations with fish community (fish density, species richness, feeding guilds) were examined in both seagrass and coral reef habitats.

Understanding the fish-habitat relationships in tropical shallow marine habitat is a fundamental goal in community ecology. By identifying factors that determine spatial patterns of fish community and by providing valuable information for sustainable conservation efforts for these important habitats, their functions as nursery, refuge and food source for marine fishes can be further understood and predicted. This study outcome may provide useful information for coastal marine protection and fisheries resource management.

1.2 Scope of study

This study focused on coral reef and seagrass habitats in proximity to each other. This will allow for exploring the similarity and differences, or inter-relationships between the habitats through fish community structure and habitat utilisation patterns.

Seagrass habitat in the present study was focused on the forereef system, where seagrass is located on the seaward side of the reef slope in the subtidal zone. This system can be found in the Tinggi Island Archipelago, whereby limited report on the associated fish community in this area are available.

1.3 Significance of study

Forereef seagrass adjacent to coral reefs are mostly found at Tinggi Island and Babi Besar Island, south-east of Peninsular Malaysia. Limited studies have been done on fish communities in area where coral reefs and seagrass are adjacent habitats. This study will contribute important ecological data on tropical forereef seagrass habitat where information is lacking, especially in the South-East Asia region (Ooi et al., 2011b). Ecological data obtained from this study is needed to provide a long-term management plan for these highly-threatened ecosystems.

In addition, this study emphasises on fish-habitat interactions which form critical information needed for ecosystem and coral reef fish management. Sound ecosystem management requires local-level knowledge of habitat interactions to successfully enhance or conserve fish community (Unsworth et al., 2008). To fill in the knowledge gaps of fish-habitat interactions, it is necessary to examine the abundance, species richness, and assemblage structure of fish in coral reef and seagrass habitats that are in proximity to each other. The high level of connectivity between seagrass and coral reef habitats mean that the loss of one habitat could have implications on the other (Waycott et al., 2011) and subsequently its fish communities. Thus, the combined approach of this study, i.e. targeting both coral reef and seagrass habitats, is essential to better manage and safeguard the future of these vulnerable local habitats.

Numerous research has been conducted on fish assemblages in seagrass meadows (Acosta et al., 2007; Aziz et al., 2006; Unsworth et al., 2007; Yeager & Ariaz-Gonzalez, 2008). However, based on a review of research published related to coral reef fishes from 1999 until 2009, Malaysia falls within the category of 1-9 citations, whereas the highest citation recorded was 316 from Australia (Montgomery, 2011). Limited studies had been carried out for coral reef fishes in Malaysia, even though we are part of the Coral Triangle and has more than 2,500 species of reef fishes in our waters (Allen, 2008). In the context of Malaysia studies on coral reef ecosystems along the coast are substantial, but there are limited studies on adjacent forereef system or subtidal seagrass-coral reef continuum (Ooi et al., 2011b).

Technology advancement makes fish survey methods possible in all types of environments and underwater video survey method is an alternative to Underwater Visual Census (UVC). This research work is perhaps one of the few documentations of fish community structure in the coral reef and adjacent seagrass habitats using Remote Underwater Video Station (RUVS) in the study area. By using this video survey method, it also enabled us to collect additional information on habitat utilisation patterns of fish communities in the coral reefs and adjacent seagrass.

This study showed that seagrass and coral reef habitats are interconnected by reef fishes. This has implications for habitat connectivity, an important ecological process driven by reef fishes during their daily activities on a local scale, such as feeding and seeking shelter from predators, and is also responsible for the survivorship of the population at a broader scale such as spawning aggregation and dispersal of larvae (Sale et al., 2010). Ecosystem connectivity as such is known as one of the critical ecological processes for enhancing the long-term resilience of marine ecosystems (McCook et al., 2009; Sale et al., 2010).

Therefore, this study of fish communities in coral reefs and adjacent seagrass is essential to address the existing knowledge gaps about the combined role of marine habitats for fish populations, which will help improve coastal habitats and fisheries management in the future.

1.4 Overview of the dissertation

Chapter 1 is the brief introduction of the study, stating the background of research, study scope and significance, research aims, objectives and hypotheses. Chapter 2 summarises the review of related literature in the context of the research objectives. Chapter 3 describes the detailed methodology for each research objectives. Chapter 4 presents the analysed data with graphs and statistical tests as per research objectives and hypotheses. Chapter 5 contains the discussion on each result from this study and subsequently a comparison to other studies. Chapter 6 summarises the research findings are provides conclusion and recommendations for the study.

1.5 Research aim, objectives and hypotheses

The primary aim of this research follows the three objectives to achieve each hypotheses as shown in the flowchart (Figure 1.1).

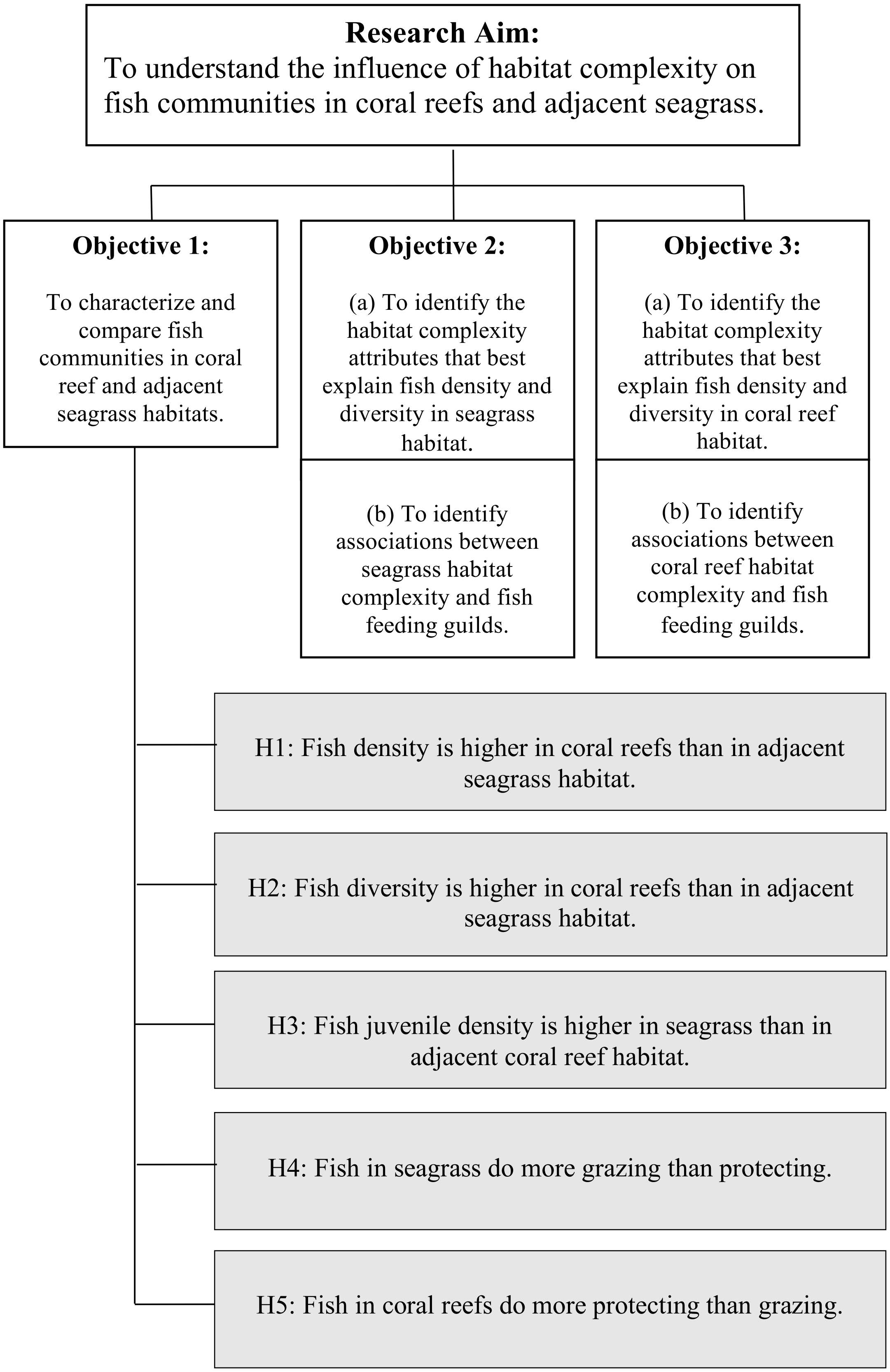


Figure 1.1: Flowchart of research aim, objectives and hypotheses (H1-H5) of this study.

CHAPTER 2: LITERATURE REVIEW

2.1 Fish communities in coral reefs and adjacent seagrass

Ecologists Begon et al. (1986) define ‘community’ as the related groups of plants and animals living in a specific region under relatively similar conditions. In this study, ‘fish community’ refers to the composition of fish that live in a specific area in the same habitat. The major aspects of fish community studied were density, species richness, feeding guilds, fish maturity stage, and their habitat utilisation patterns.

2.1.1 Fish density

Fish density is the number of fish occupying an area, which can serve as a proxy for ecosystem health. A complex and healthy ecosystem is able to sustain a higher density of fish with sufficient food supplies and shelter. In tropical shallow water marine habitat, fish densities are reported to be 3 times higher in coral reefs than in adjacent subtidal seagrass habitat (Dorenbosch et al., 2005a). Fish density in Malaysian coral reefs are reported at relatively low numbers of targeted species for the aquarium trade (e.g.: Butterflyfishes average at 4.75 individual/ 500 m^3), food fish (e.g.: Snapper (5.84 individual/ 500 m^3), Grouper (0.65 individual/ 500 m^3), Parrotfish (2.36 individual/ 500 m^3)) and live-fish trade (e.g.: Barramundi Cod (not sighted at all sites), Bumphead Parrotfish (0.10 individual/ 500 m^3), Humphead wrasse (0.01 individual/ 500 m^3)) (Reef Check Malaysia, 2014). A review by Paddack et al. (2009) spanning over five decades of 48 studies on 318 reefs revealed that fish densities had declined significantly due to ecosystem degradation. Reef loss has been associated with the decline in abundance of over 75% of reef fish species, with 50% dropping to less than half of their initial numbers (Jones et al., 2004). Strong relationships between fish density and ecosystem health has enabled assessments of Marine Protected Area (MPA) conservation effectiveness of, evaluating reef status and fishing pressure through fish density and biomass data (McClanahan et al., 2006).

2.1.2 Fish species richness

Species composition is a list of different organisms that make up a community in a specific area and time. Subsequently, species richness derived from the species list is the total number of species within the particular space and time. It is vital for monitoring purposes where studies are able to detect changes over time and compare habitats or locations. A higher species assemblage within an area indicates a more complex community (Gratwicke & Speight, 2005a).

Marine fishes in the South China Sea are highly diverse with at least 3365 species and more than one third is coral reef fish (Allen et al., 2000; Arai, 2014). Overall, there are 1400 species of marine fishes recorded in Malaysia with 925 species found in coral reefs (Chong et al., 2010) compared to 1820 species in Indonesia, 1627 species in Australia and 1525 in the Philippines (Allen, 2000). Based on previous research conducted between 1980s-2010s, reef fish diversity had been recorded from Redang Island with 210 species, Tinggi Island with 219 species, Simbang Island with 112 species, Babi Besar Island (Batuan Tikus) with 133 species, Tunku Abdul Rahman Park (Sabah) with 573 species, Semporna (Sabah) with 768 species and Miri Reef (Sarawak) with 263 species (Wood, 1986; Gerald R Allen, 1992; Harborne et al., 2000; Stockwell & Carpenter, 2012; Townsend, 2015).

Studies of the fish community in seagrass meadows around the world recorded 249 species of fish from Quirimbas island at Mozambique and 156 species in the Florida Keys (Acosta et al., 2007; Gell & Whittington, 2002). Records from Malaysia included 22 species of fish from blackish water lagoon seagrass in Terengganu (Aziz et al., 2006) , approximately 70-76 species of fish in 41 families recorded from Tanjung Adang-

Merambong seagrass beds and adjacent mangrove areas (Sasekumar et al., 1989) and 106 species of fish recorded from Pulai river estuarine seagrass (Chong & Sasekumar, 2002). There is a need to answer the knowledge gaps for the fish diversity in forereef seagrass habitats especially for the largest seagrass meadows in Peninsular Malaysia located at the east coast of Johor.

2.1.3 Fish maturity stage

Fish maturity stage is usually classified based on their total length (TL) and known species maximum length (Froese & Pauly, 2012). A juvenile is defined as an individual with <1/3 maximum length, and an adult is an individual with >1/3 maximum length (Nagelkerken & Van Der Velde, 2002). The densities of juvenile and adult reef fish for targeted species has been used to identify critical nursery area or possibly ontogenetic shifts between two interlinked habitats (Dorenbosch et al., 2005a). Fish communities in seagrass mainly consists of high abundance of juveniles and immature individuals (Nagelkerken et al., 2000a). In contrast, coral reefs contain higher density of adult reef generalist and residents (Dorenbosch et al., 2005a). This implies that seagrass habitats that are adjacent to coral reefs may serve as an important nursery grounds for many coral reef fishes as a result of food availability and low predation risks as compared to the complex and crowded coral reefs (Nagelkerken et al., 2000a; Parrish, 1989; Verweij et al., 2008).

2.1.4 Fish habitat utilisation patterns

'Habitat utilisation' refers to how marine fauna utilise habitats in a way that contributes to ecological connectivity, community structure and population dynamics (Zeller, 1997). In the marine environment, 'ecosystem connectivity' refers to ecological interactions among ecosystems by movement of living organisms (e.g., fishes, invertebrates and plankton), and exchange of nutrients and organic matter (Nagelkerken, 2009; Sale et al., 2010).

Fish and crustaceans are known for undergoing migration and foraging between mangrove, seagrass and coral reef habitats (Jones et al., 2010; Waycott et al., 2011). This plays an important role in the ecological connectivity between shallow water habitats (Mumby et al., 2004; Nagelkerken et al., 2000a). Extensive studies on the ontogenetic migrations of fish between habitats have been conducted, which included the families Lutjanidae, Haemulidae and Acanthuridae (Berkström et al., 2013; Nagelkerken et al., 2000a; Nakamura et al., 2008; Parrish, 1989). This ontogenetic movement is known as a survival strategy from predation and to increase availability of food source in their early life stage (Adams et al., 2006; Appeldoorn & Bouwmeester, 2009; Nagelkerken et al., 2000a; Nagelkerken et al., 2002).

A habitat utilisation study conducted on fish in coral reefs and seagrass beds habitats in the Philippines have shown significantly higher fish species richness and abundance in coral reefs (234 species, 12,306 individuals) than in seagrass (38 species, 1,198 individuals) (Honda et al., 2013). Their study also revealed that 85.6% of recorded fishes inhabited a single habitat, whereas another 14.4% used more than one habitat (Honda et al., 2013). In Malaysia, Chong et al. (2010) reported that there were at least 250 species of marine–euryhaline fishes that occupy various habitats at one stage of their life history. The reasons for the migration behaviour of fish in different stages of their life cycle are varied and include: (i) meeting requirements for different food sources in different life stages; (ii) seeking shelter as a response to the risks of predation; and (iii) fulfilling the need to reproduce in habitats with optimal conditions for larvae dispersal or higher survival (Mumby, 2006). The multiple-habitat user might show diurnal, tidal or ontogenetic movement between seagrass and coral reefs and is often referred to as 'cross-habitat utilisation'. There is insufficient knowledge on fish habitat utilisation and their significant contributions toward ecosystem connectivity in coral reefs and adjacent forereef seagrass, as well as the fish communities living in those habitats.

To study fish habitat utilisation, ultrasonic tag and diver visual observation on selected large species (e.g., Mullidae, Haemulidae, Carangidae and Serranidae) have been used but this mainly focused on home range and activity patterns in fishes (Holland et al., 1993a; Holland et al., 1993b; Sale, 1991; Tulevech & Recksiek, 1994; Zeller, 1997). It is however very expensive and needs high technical expertise in electronics. Therefore, an alternative cost-efficient video observation method of Remote Underwater Video Station (RUVS) was used to record fish communities and simultaneously observe their habitat utilisation activities (Mallet & Pelletier, 2014).

2.2 Habitat complexity attributes and configurations

Coral reef and seagrass habitats are recognised among the most productive and highly diverse marine habitats in the coastal ecosystem (Connell, 1978; Hemminga & Duarte, 2000; Odum & Odum, 1955). These important habitats provide high-value ecosystem services including coastal protection, food and shelter provision, nutrient recycling and others (Duarte, 2002; Larkum et al., 2006; Moberg & Folke, 1999; Nagelkerken et al., 2000b). Coral reefs and seagrass meadows also serve as critical habitats for diverse marine species, ranging from the commercially important fishes and crustaceans to the endangered species such as seahorses, sea turtles, sharks and dugong (Short et al., 2007; Watson et al., 1993; Williams & Heck, 2001).

'Habitat' is defined as a place where organisms live and consists of all the living and non-living features of the environment referred to 'habitat attributes', which provide resources necessary for a species in a particular setting (Begon et al., 2006; Hayward & Suring, 2013). The spatial arrangements of environmental elements in a specific context are referred as 'habitat configuration'. Studies have shown that proximity to adjacent habitats significantly influences the fish community structure. Coral reefs with adjacent seagrass meadows are found to harbour higher densities of fish than on reefs located distance away from seagrass meadows (Dorenbosch et al., 2005b; Nagelkerken et al., 2002; Unsworth et al., 2008). Therefore, any habitat degradation, defragmentation, loss or total absence of adjacent habitats will have a direct impact on the state of fish standing stocks.

Various studies have shown that habitat attributes and configurations play important roles in structuring fish community. However, these studies were mainly conducted on coral reefs and few examined seagrass habitats to understand the fish-habitat relationships as discussed in the subtopic 2.3 Fish-habitat relationships.

Ecologists have long acknowledged the importance of habitat structural complexity and its relationship with species richness. 'Habitat complexity' has been defined and measured in many ways (Bartholomew et al., 2000). McCoy and Bell (1991) explained 'habitat structure' as comprising two indices: 'complexity', the absolute abundance of habitat structural components and 'heterogeneity', which is the relative abundance of the different structural components.

Habitat complexity consists of many variables that vary between different habitats. The variables that have been used in coral reefs are live coral cover (Bell & Galzin, 1984), rugosity (Friedlander & Parrish, 1998; Luckhurst & Luckhurst, 1978), growth forms (Gratwicke & Speight, 2005a) and refuge hole size and depth (Almany, 2004). On the other hand, the standard variables used in seagrass meadows are species composition, percent cover, biomass, canopy height and shoot density (Ambo-Rappe et al., 2013).

The world's coral reefs and seagrass meadows are rapidly declining because of a suite of factors, including global warming with associated bleaching events, sea level rise, increase intensity of storms, crown-of-thorns predation, overfishing and coastal pollution (Wilkinson, 2004; Orth et al., 2006; Waycott et al., 2009). Habitat degradation has direct impacts on the fish community, especially on species richness and abundance. Jones et al. (2004) found that a decline in live coral cover resulted in a more than 25% decline in species richness for local coral-dependent species such as Chaetodontidae (Butterflyfish) and Pomacentridae (Damselfish). In short, habitat attributes are closely linked to fish community and serve as a proxy for ecosystem's health. Thus it is essential to understand how habitat complexity attributes influence fish community to develop sustainable resource management for the marine ecosystem.

2.2.1 Seagrass meadows

In this present study, the definition for 'seagrass species diversity' is the species that occur in a given area and 'canopy height' is the above-ground height of the seagrass within the quadrat (Mckenzie, 2003). 'Seagrass cover percentage' is the surface percent cover of seagrass in a given area (Mckenzie, 2003). 'Seagrass shoot density' is the number of seagrass shoots in 4 cores (core diameter Ø = 0.25m) obtained from each quadrat and shoot density count is based on species (Duarte & Kirkman, 2001).

Worldwide there are 60 different species of seagrasses (Green & Short, 2003). A total of 14 species of seagrass from three families Hydrocharitaceae (*Enhalus acoroides*, *Halophila beccarii*, *H. decipiens*, *H. ovalis*, *H. minor*, *H. spinulosa*, *Halodule pinifolia*, *H. uninervis, Thalassia hemprichii*), Cymodoceaceae (*Cymodocea rotundata*, *C. serrulata, Syringodium isoetifolium, Thalassodendron ciliatum*) and Ruppiaceae (*Ruppia maritima*) were recorded in Malaysia (Bujang et al., 2006; Japar Sidik et al., 2001). There were five species recorded in Babi Besar Island (*T. hemprichii*, *H. ovalis*, *C. rotundata*, *H. uninervis* and *S. isoetifolium*) (Japar Sidik et al., 1995; Zakaria et al., 2003). Tinggi Island had a recent record of 7 species (*H. ovalis*, *H. uninervis*, *C. serrulata*, *H. minor*, *H. decipiens*, *H. spinulosa* and *S. isoetifolium*) in the forereef seagrass and other 2 species (*T. hemprichii* and *C. rotundata*) were recorded from the backreef shallow water less than 1 m depth (Ooi et al., 2011a). These highly diverse seagrass meadows in Tinggi Island comprise more than half of the total species found in Malaysia, and is believed to represent the most extensive forereef meadow in Peninsular Malaysia. This indicates that Tinggi Island and Babi Besar Island Archipelago's seagrass meadows may play an essential role in sustaining the seagrass ecosystem in Peninsular Malaysia.

Different species of seagrass are morphologically distinct in size and shape, there are spoon shape, ribbon-like, cylindrical, and broad-leaf and canopy height from short (1-2 cm) to tall (> 1 m) (Larkum et al., 2006) (Figure 2.1).

Figure 2.1: Seagrass species with different shape and increasing size and canopy height. Ho: *Halophila ovalis*; Th: *Thalassia hemprichii*; Hu: *Halodule uninervis*; Cr: *Cymodocea roduntata*; Cs: *Cymodocea serrulata*; Si: *Syringodium isoetifolium*; Ea: *Enhalus acoroides*.

Although seagrass meadows have no hard substratum unlike coral reefs, habitat complexity can be quantified using structural characteristic in seagrass meadows such as shoot density, species diversity, and percent cover (Ambo-Rappe et al., 2013; Heck & Wetstone, 1977). Therefore, mixed species seagrass meadow may constitute a complex habitat based on canopy height, percent cover and shoot density configurations in an area. These habitat variables that contributes to complexity have been extensively studied, and research have shown significant relationships with fish community structure (see in subtopic 2.3.1 Seagrass meadows).

Seagrass meadows supports commercial fisheries worth as much as US$3500 ha^{-1} yr^{-1} (Watson et al., 1993). Seagrass habitats are estimated to be declining and accelerating at a rate of 7 % per year with habitat loss due to localized threats (e.g. increased loads of sedimentation, nutrients and contaminants) as well as threats from global climate change (e.g. sea level rise and increased intensity of storms that can wipe out the meadows) (Orth et al., 2006; Waycott et al., 2009). However, the current status of Malaysian seagrass habitat distribution and size is still uncertain due to insufficient studies done. There is a critical need to understand the ecological functions of seagrass meadows, fish-habitat relationships and their linkages with other ecosystems to better conserve this critical habitat to support ecosystem services.

2.2.2 Coral reefs

Coral reefs are known as one of the most diverse and complex ecosystems on earth with biodiversity that surpasses the rainforest ecosystem (Connell, 1978; Odum & Odum, 1955; Ray, 1988). Despite the fact that the world's coral reefs cover less than 1% of Earth's surface, they are a habitat for more than 800 species of corals and 4000 species of fishes (Burke et al., 2011).

Coral reefs are built from colonies of tiny coral polyps with endosymbiont known as zooxanthellae that live in coral tissues. Coral reefs are built mostly by hard coral (scleractinian), also known as hermatypic or reef-building animals that form hard structure (limestone) from calcium carbonate. The colony growth forms by corals can vary even within the same species. The intraspecific morphological variations may be due to their genetic or environmental factors (Todd, 2008). Environmental factors play a role in shaping the coral structure, including light exposure and wave energy in the area where coral grow. Coral growth in a location with high wave energy mostly are slow with massive shape or flattened encrusting shape that can withstand impacts from the wave energy, whereas sheltered lagoon reefs are dominated by fast-growing branching corals.

Coral growth forms can be categorised as branching, foliose, massive, sub-massive, free-living, encrusting and plates (English et al., 1997; Hill & Wilkinson, 2004) (Figure 2.2). Growth forms are the morphological descriptions of the reef community, and each growth form provides a different degree of structural complexity toward a coral reef habitat, e.g. branching coral will offer higher structural complexity than a massive coral growth form. Higher complexity of coral structure provides higher level of shelter and surface area for other organisms to live on it.

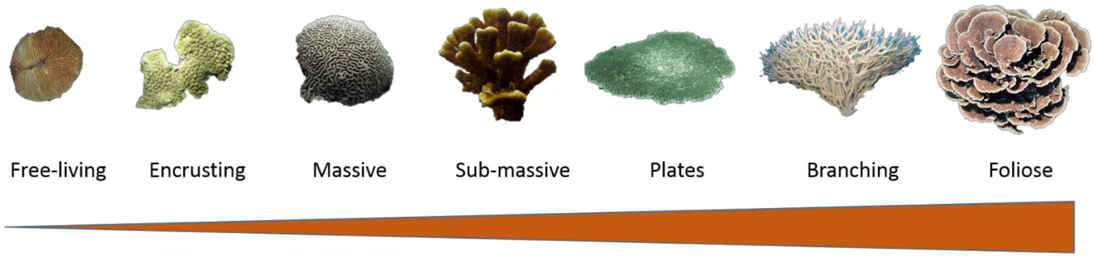


Figure 2.2: Coral growth form categories with increasing structural complexity.

Coral reefs in the east coast of Peninsular Malaysia has recorded high coral species richness up to 398 species (Huang et al., 2015). Based on previous reports there were 221 species of scleractinian corals reported from Tioman Island (Affendi et al., 2005), 82 species from Tinggi Island and 79 species from Babi Besar Island (Harborne et al., 2000). The diversity of corals is an important attribute that influences on habitat complexity besides other habitat attributes including coral growth forms, substrate type and rugosity. In the present study, the definition of 'live coral cover' refers to percent cover of living hard and soft corals (English et al., 1997). Globally, the mean hard coral cover was 32% between 1997 to 2002. In over 1107 sites, only 34 reefs had higher than 70% hard coral cover, and none had higher than 85% cover (Hodgson & Liebeler, 2002). The status of coral reefs in Malaysia for 2013 (during the sampling year) recorded a relatively high level of live coral cover at 48.33%, out of which 43.7% is the mean hard coral cover, which is above the global average in 2002. Sibu Island and Tinggi Island had average live coral cover of 55.88% with 53.9% consisting of hard coral, and Babi Tengah Island recorded 63.7% of live coral cover which all is hard coral (Reef Check Malaysia, 2014).

‘Rugosity’ is the state of ruggedness or irregularity of a surface (Magno & Villanoy, 2006). In marine ecology, rugosity is a measure of habitat complexity to indicate the availability of space for shelter and area for other organisms to grow as a food source (Friedlander & Parrish, 1998; Graham & Nash, 2013). Rugosity has been measured at different scales from using simple chain and tape method to remote sensing satellite imagery and new digital technique of Digital Reef Rugosity (DRR) (Dustan et al., 2013; Friedman et al., 2012; Hill & Wilkinson, 2004; Purkis et al., 2008; Risk, 1972).

Coral reefs provide tremendous ecological goods and services to the coastal populations (Moberg & Folke, 1999) with estimated US$352,000 per hectare per year based on their values (e.g., recreation, fish habitat, coastal protection from storms) (Costanza et al., 2014). The total net benefit per year of the world’s coral reefs is estimated to be US$29.8 billion with tourism and recreation accounting for US$9.6 billion of this amount, coastal protection for US$9.0 billion, fisheries for US$5.7 billion, and biodiversity for US$5.5 billion (Conservation International, 2008). Total Economic Value (TEV) of Malaysia’s coral reefs from 6 marine parks (Payar Island, Perhentian Island, Redang Island, Tioman Island, Tinggi Island and Labuan Island) is estimated at RM8.7 billion (≈US$2.2 billion with exchange rate at RM1=US$0.25) per year. This estimated TEV included ecosystem services from sustainable fisheries, eco-tourism, coastal protection and climate regulatory function, as well as nutrient recycling. Tinggi Island had the highest value among other marine parks with TEV estimated at RM3.667 billion (Department of Marine Park Malaysia, 2015).

The coral reefs worldwide are seriously under threat, and the current situation is critical with the most recent back-to-back mass bleaching events which happened in 2016 and 2017 that wiped out more than a quarter of the corals in the Great Barrier Reefs due to abnormal sea surface temperature rise (GBRMPA, 2017). Although Malaysia’s coral reefs were not greatly affected in 2016 and 2017. However, Malaysia recorded a significant mass coral bleaching event in 2010, where some sites had bleached up to 80% of the reef area (Tun et al., 2010; Tan & Heron, 2011). This severe bleaching event has alarmed the marine park authorities and they closed some of the sites for tourist activities (Thomas & Heron, 2011; Doshi et al., 2012). Further habitat degradation and structure smothering may have severe impacts on fisheries production in the coastal ecosystems.

2.2.3 Proximity to adjacent habitat

Fish are known for undergoing migration and foraging between seagrass and coral reef habitats (Jones et al., 2010; Waycott et al., 2011), contributing to the ecological connectivity between shallow water habitats (Mumby et al., 2004; Nagelkerken et al., 2000a). Thus, proximity to adjacent habitats significantly influences the fish community structure by having more cross-habitat species utilising both habitats that are in proximity to each other (Dorenbosch et al., 2005b; Gullström et al., 2008; Nagelkerken et al., 2002; Unsworth et al., 2008). Therefore, any habitat degradation, defragmentation, loss or total absence of adjacent habitats will have a direct impact on the fish population.

There had been a number of extensive studies on ontogenetic migration of fish between habitats, which included the economically and ecologically important species from families Lutjanidae (Snapper), Haemulidae (Sweetlips) and Acanthuridae (Surgeonfishes) (Berkström et al., 2013; Nagelkerken et al., 2000a; Nakamura et al., 2008; Parrish, 1989). The ontogenetic migration is determined by the distance to adjacent habitat, where Grober-Dunsmore et al. (2006) suggests that reef fish-seagrass associations with functional linkage is evident at 1 km spatial extent, with juveniles in closer distance (100 & 250 m) as compared to adults (500 m & 1 km).

Additionally, studies have shown that when adjacent habitats are close together, there are higher species richness and density of seagrass associated organisms within seagrass meadows (Jelbart et al., 2007; Tuya et al., 2011; Unsworth et al., 2008), up to 2 times higher in proximity to adjacent habitat compared to when they are distant. The ecotones between habitats serve as common ground for multiple-habitat utilising fishes and this enhances the carrying capacity for each adjacent habitat to contain higher species richness (Jelbart et al., 2007; Tuya et al., 2011). This habitat configuration also influences the trophic structure of fish community, where a habitat in proximity to coral reefs are dominated by carnivores and omnivores, while planktivores and herbivores were found at areas close to mangroves (Unsworth et al., 2008).

Previous studies have shown substantial evidence that spatial arrangements of habitat do have significant contribution in determining fish density, species richness or trophic composition. Proximity to adjacent habitat also promote connectivity between habitats via fish migration (daily or ontogenic migration) and mediated predator-prey interactions which enhance survivorship of juveniles with provision of food and shelter in a distance to coral reefs. However, with limited knowledge and research on proximity and habitat connectivity, the fish-habitat relationships of proximity to adjacent habitat in forereef seagrass and coral reefs remain unknown.

2.3 Fish-habitat relationships

Tropical coral reefs and seagrass meadows are known as high primary productivity ecosystems that provide goods and ecological services and serves as the habitat for diverse reef fishes (Connell, 1978; Duarte & Chiscano, 1999; Odum & Odum, 1955). In return, tropical reef fish community is responsible for the maintenance of ecosystem health (Mumby & Steneck, 2008), enhancement of phase-shift resilience (Hughes et al., 2007; Hughes et al., 2010; McClanahan et al., 2012) and provision of services to other marine creatures, such as cleaning (Losey, 1979), symbiosis (Losey, 1978), regulating and linking services (Holmlund & Hammer, 1999), food source and others. Hence, the reef fish community structure in coral reef and seagrass meadows can be one of the vital checklist or indicator for ecosystem health and vice versa. For example, corallivorous butterflyfishes (Family: Chaetodontidae) are known as bio-indicator in reef monitoring programme worldwide such as Reef Check (Hodgson et al., 2006). Reef condition can be predicted with the distribution and abundance of butterflyfishes (Reese, 1981) due to their direct relationship as consumers of coral tissue (Hilty & Merenlender, 2000; Hourigan et al., 1988).

2.3.1 Seagrass meadows

Habitat complexity studies on tropical seagrass meadows have shown a positive correlation between structural complexity (e.g., species composition, percent cover and shoot density) with fish communities (Ambo-Rappe et al., 2013). Additional findings from this study are smaller fishes move from lower to higher structurally complex seagrass meadows as they increase in size, due to the ecosystem function as a nursery ground for coral reef fishes.

There is inconsistency in findings on the correlation between habitat complexity and fish communities from literature review and this maybe due to a variety of methodologies that are being used, choice of different families of fish for study and even the time of sampling (Chabanet et al., 1997; Graham & Nash, 2013). The results have been varied in these studies possibly due to differences in meadow type (mixed or monospecific), methodologies (active gear, passive gear or visual surveys) and complexity attributes used. For instance, canopy height showed a strong influence on fish assemblages over other habitat complexity attributes such as biomass, shoot density and species richness (Gullström et al., 2008; Hori et al., 2009), but this may have been caused by the location of these studies in high canopy *E. acoroides*-dominated meadows.

Tropical meadows often consist of multiple co-occurring species, each species with different morphologies of plant size, leaf shape and canopy height (Vermaat et al., 1995; Ooi et al., 2011b) that contribute to structural complexity and consequently, mediate the distribution of fish assemblages by providing more surface area and interstitial space for prey species (Den Hartog, 1970; Robbins & Bell, 1994; Dibble, Killgore, & Dick, 1997; Almany, 2004; Warfe & Barmuta, 2004; Den Hartog & Kuo, 2006; Kuo & Den Hartog, 2007; Short et al., 2007). In previous studies on habitat complexity effects on fish, the seagrass meadows consisted of highly variable life forms, ranging from the large *Enhalus acoroides* (30-200 cm height) and *Thalassodendron ciliatum* (10-70 cm height) to the small-leaved *Halophila ovalis* (<3 cm height). However, seagrass meadows in the tropics also occur in the forereef where they consist of a narrower range of life forms, the smallest being *Halophila ovalis* and the largest being *Syringodium isoetifolium.* This is typical of tropical forereef meadows (Ooi et al., 2011b).

2.3.2 Coral reefs

Habitat complexity is suggested to be the primary factor in fish community structure in reef area. Bell and Galzin (1984), conducted a study that showed a significant positive relationship between live coral cover and fish community; an increase of live coral cover provide more structure as habitat and thus enhanced the fish species richness and number of individuals. An increase of surface area provides more shelter and food source, therefore enhances species richness. In addition, a complex structure provides more habitat for invertebrates which eventually become the nutrient source for many reef fishes (Parrish et al., 1985, as cited in Friedlander & Parrish, 1998). Galzin et al. (1994) supported the findings of Bell and Galzin (1984), and suggested that a higher complexity of habitat supports higher fish diversity, and highlighted ecological parameters such as live coral cover, food diversity and reproductive behaviour as significantly important in determining fish diversity. A greater reef complexity with lots of microhabitats acts as a refuge for many smaller fishes from large predators, as the densities of predators and the availability of preferred refuges affects the abundance of fishes (Beukers & Jones, 1997). Furthermore, Almany (2004) also stressed that other factors such as shelter characteristics (e.g., depth and size of holes), structurally or topographically complex (e.g., substratum rugosity), distance to reef edge, behavioural attributes of predators or physical capabilities of prey may influence predation and competition of coral reef fishes, thus impacting fish community structure (Friedlander & Parrish, 1998).

Habitat complexity consists of many variables, and most researchers only choose one or two variables. Hence, Gratwicke and Speight (2005a) had designed a simple and rapid habitat assessment score (HAS) method to access habitat complexity across different shallow marine habitats including sandy patches, algal beds, seagrass beds and coral reefs. The assessment components included: rugosity, a variety of growth forms, height, refuge size categories, live cover and hard substratum percentage. Another similar assessment was designed for comparison of seagrass habitats – Habitat structural index (HSI) based on continuity, proximity, percentage cover and species identity to produce habitat structural scores from 0 (poor) to 100 (excellent) (Irving et al., 2013).

However, the methods mentioned above might be best for monitoring purposes because the simple and rapid assessment can be conducted covering a large area within a short time, is repeatable, allows assessment of the various type of habitats across the reef, produces a quick overview of the condition and detects temporal changes.

There was a study conducted on the growth of reef fishes in response to live coral cover in Papua New Guinea suggesting that live coral cover has a positive effect on the growth of associated fishes and hence a direct impact on recruitments and mortality (Feary et al., 2009). A qualitative and quantitative study conducted on literature from 1972 to 2010 regarding the role of structural complexity in coral reef ecosystems has revealed a strong positive relationship between structural complexity and fish density and biomass (Graham & Nash, 2013).

A recent study reveals that coral species richness and coral cover demonstrate a stronger relationship with fish community structure compared to habitat complexity (Komyakova et al., 2013). In conclusion, all three variables are important to draw a bigger picture for better understanding the complex habitats in long-term studies (Komyakova et al., 2013; Messmer et al., 2011).

2.4 Fish feeding guilds and habitat complexity

Fish feeding guilds generally refer to trophic group, such as carnivores, omnivores and herbivores. Carnivores are defined as species that primarily consume micro-invertebrates (e.g. crustaceans, echinoderms, gastropods) and/or fish. Omnivores are categorised as species that consume both plants and animals. Herbivores refer to species that primarily consume plant matter and/or detritus (Froese & Pauly, 2012). Diet may play a significant role in determining the fish community structure in an ecosystem based on the habitat components such as availability of food and space.

2.5 Remote Underwater Video Station (RUVS)

In the recent decade, underwater video sampling technique has become a popular method because of the same ability and consistency to census fish communities as the conventional Underwater Visual Census (UVC) (Assis et al., 2013; English et al., 1997; Watson et al., 2005). Due to its non-destructive approach with minimum disturbance to fish, it is highly recommended to be used in MPAs (Harvey et al., 2012; Mallet & Pelletier, 2014; Radford et al., 2005).

Video census technique has been used in many habitats for various purposes. In the early stage, it is mainly used in high seas fisheries research (Alevizon & Brooks, 1975; Barnes, 1952; Chabanet et al., 2012; Dorman et al., 2012; Harvey et al., 2007; Harvey et al., 2004; Harvey et al., 2001a, 2001b, 2002; Harvey & Shortis, 1995; Machan & Fedra, 1975; Pelletier et al., 2012; Pelletier et al., 2011; Spencer et al., 2005; Watson et al., 2005). There were a few studies using underwater video sampling technique to census fish communities in shallow marine habitats such as Stereo-Baited Remote Underwater Video Station (Stereo-BRUVS) (Dorman et al., 2012; Harvey et al., 2012; Smith et al., 2012) and Baited Remote Underwater Video Station (BRUVS) (Harvey et al., 2004; Harvey et al., 2007; Gladstone et al., 2012; Taylor et al., 2013; Whitmarsh et al., 2014).

CHAPTER 3: METHODOLOGY

3.1 Study sites

This study was conducted at Tinggi Island (2°18'N, 104°07'E) and Babi Besar Island (2°26'N, 103°59'E) located in the east coast of Johor, Peninsular Malaysia (Figure 3.1). Islands are nested in the South China Sea, exposed to the annual north-east monsoon with heavy rainfall and strong waves between November to February (Malaysian Meteorological Department, 2016).

Both continental islands were gazetted as Tinggi Island Marine Park since October 1994 under the Fisheries Act 1985 (Amended 1993). In August 2013, had been rebranded as the Sultan Iskandar Marine Park in tribute to the Johor monarchy. A research permit (JLTM630-7Jld.4(21)) was granted from the management of Department of Marine Parks and Johor National Park. Field samplings were conducted from July 2013 to September 2014 during the non-monsoon season between April to September.

Babi Besar Island and Tinggi Island were selected as study sites because of the common characteristic of both islands where forereef seagrass are found adjacent to coral reefs. These islands are surrounded by narrow fringing reefs of 100 m in width and forereef seagrass meadows are found at the seaward side after the fringing reefs at a depth of between 3-10m, whereby dense meadows are mainly located on the southwest of the island. There is backreef seagrass extending from fringing reef to shore. However, this backreef seagrass system was not included in this current study.

The marine habitats around these islands have low impacts from human activities with mainly small-scale fishing and tourism as compared to other islands, e.g. Tioman Island and Redang Island, which are primarily driven by tourism business.

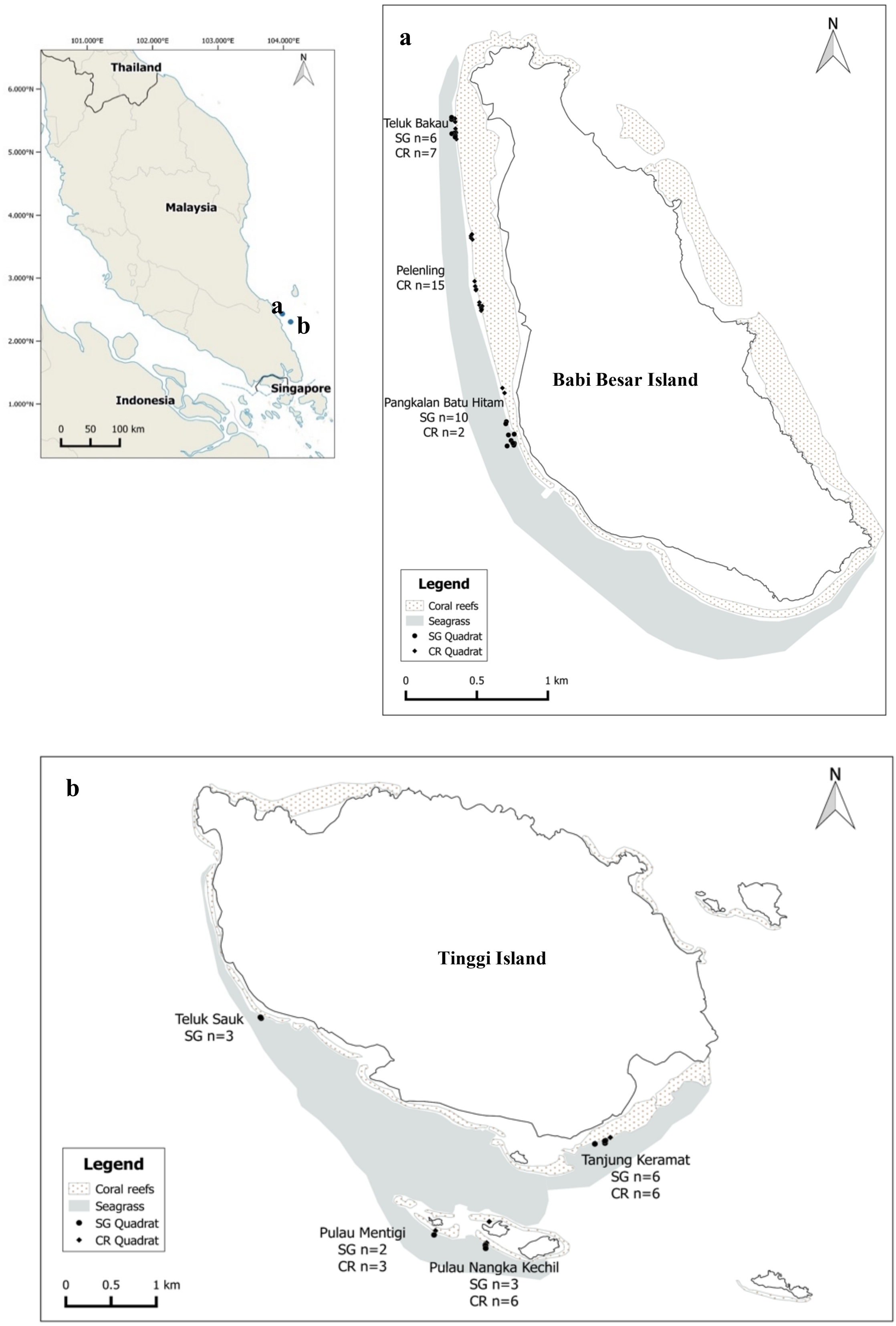


Figure 3.1: Location of sampling points in seagrass and coral reefs of (**a**) Babi Besar Island (SG n=14; CR n=24) and (**b**) Tinggi Island (SG n=16; CR n=15), off the south-east coast of Peninsular Malaysia. (SG= Seagrass; CR= Coral Reefs).

3.2 Field sampling design and data collection

The field sampling and data collection required licensed SCUBA divers working in pairs with experience in conducting underwater research following the standard safety diving procedures. A minimum of four divers conducting two dives per day were used to complete a maximum of four quadrats in a day. From July 2013 to September 2014, a total of 69 quadrats (quadrat size = 4 m^2) were delineated in seagrass meadows (n=30) (Table 3.1) and coral reefs (n=39) (Table 3.2).

Table 3.1: List of forereef seasgrass quadrat locations, site and GPS coordinates for seagrass habitat.

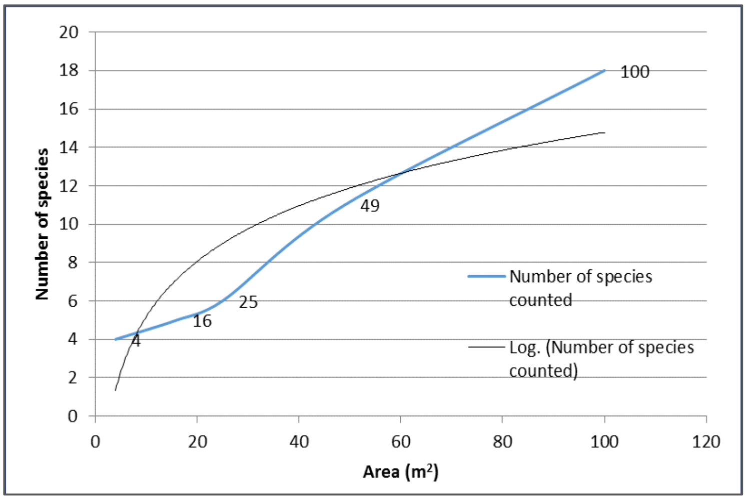
Quadrat No.	Date	Location	Site	Latitude	Longitude
1S	23/07/2013	Tinggi Island	Teluk Sauk	2°17'36.36"N	104° 5'54.85"E
2S	23/07/2013	Tinggi Island	Teluk Sauk	2°17'36.77"N	104° 5'54.59"E
3S	23/07/2013	Tinggi Island	Teluk Sauk	2°17'36.71"N	104° 5'54.60"E
4S	26/07/2013	Tinggi Island	Tanjung Keramat	2°16'49.51"N	104° 7'54.35"E
5S	26/07/2013	Tinggi Island	Tanjung Keramat	2°16'49.49"N	104° 7'54.38"E
6S	26/07/2013	Tinggi Island	Tanjung Keramat	2°16'49.45"N	104° 7'54.37"E
7S	25/09/2013	Tinggi Island	Nanga Kechil Island	2°16'11.76"N	104° 7'15.16"E
8S	25/09/2013	Tinggi Island	Nanga Kechil Island	2°16'11.45"N	104° 7'15.19"E
9S	25/09/2013	Tinggi Island	Nanga Kechil Island	2°16'10.47"N	104° 7'15.27"E
10S	26/09/2013	Tinggi Island	Mentigi Island	2°16'15.54"N	104° 6'56.83"E
11S	26/09/2013	Tinggi Island	Mentigi Island	2°16'15.50"N	104° 6'56.78"E
12S	27/09/2013	Tinggi Island	Tanjung Balang	2°16'50.70"N	104° 7'58.19"E
13S	27/09/2013	Tinggi Island	Tanjung Balang	2°16'49.75"N	104° 7'58.02"E
14S	27/09/2013	Tinggi Island	Tanjung Balang	2°16'50.50"N	104° 7'57.93"E
15S	07/04/2014	Babi Besar Island	Teluk Bakau	2°27'13.76"N	103°58'17.00"E
16S	07/04/2014	Babi Besar Island	Teluk Bakau	2°27'13.62"N	103°58'16.45"E
17S	07/04/2014	Babi Besar Island	Teluk Bakau	2°27'13.18"N	103°58'17.25"E
18S	07/04/2014	Babi Besar Island	Teluk Bakau	2°27'12.84"N	103°58'17.22"E
19S	08/04/2014	Babi Besar Island	Pangkalan Batu Hitam	2°26'5.22"N	103°58'30.68"E
20S	08/04/2014	Babi Besar Island	Pangkalan Batu Hitam	2°26'5.04"N	103°58'29.36"E
21S	08/04/2014	Babi Besar Island	Pangkalan Batu Hitam	2°26'3.77"N	103°58'29.97"E
22S	08/04/2014	Babi Besar Island	Pangkalan Batu Hitam	2°26'2.53"N	103°58'29.06"E
23S	20/08/2014	Babi Besar Island	Pangkalan Batu Hitam	2°26'3.11"N	103°58'30.73"E
24S	20/08/2014	Babi Besar Island	Pangkalan Batu Hitam	2°26'2.91"N	103°58'30.69"E
25S	20/08/2014	Babi Besar Island	Pangkalan Batu Hitam	2°26'2.71"N	103°58'30.59"E
26S	20/08/2014	Babi Besar Island	Pangkalan Batu Hitam	2°26'3.19"N	103°58'30.37"E
27S	20/09/2014	Babi Besar Island	Teluk Bakau	2°27'16.86"N	103°58'16.40"E
28S	20/09/2014	Babi Besar Island	Teluk Bakau	2°27'17.34"N	103°58'16.40"E
29S	21/09/2014	Babi Besar Island	Pangkalan Batu Hitam	2°26'8.06"N	103°58'28.89"E
30S	21/09/2014	Babi Besar Island	Pangkalan Batu Hitam	2°26'7.59"N	103°58'28.76"E

Table 3.2: List of coral reef habitat locations, site and GPS coordinates for coral reefs habitat. Quadrat 4C, 5C, 6C, 9C, 13C, 14C, 24C and 36C were removed due to sampling instrumental failure or were outlier (see Chapter 3.5.2).

Quadrat No.	Date	Location	Site	Latitude	Longitude
1C	24/07/2013	Tinggi Island	Nangka Kecil Island	2°16'20.50"N	104° 7'16.51"E
2C	24/07/2013	Tinggi Island	Nangka Kecil Island	2°16'20.46"N	104° 7'16.45"E
3C	24/07/2013	Tinggi Island	Nangka Kecil Island	2°16'20.47"N	104° 7'16.56"E
7C	25/09/2013	Tinggi Island	Nangka Kechil Island	2°16'12.16"N	104° 7'15.24"E
8C	25/09/2013	Tinggi Island	Nangka Kechil Island	2°16'12.35"N	104° 7'15.38"E
10C	26/09/2013	Tinggi Island	Mentigi Island	2°16'17.11"N	104° 6'57.22"E
11C	26/09/2013	Tinggi Island	Mentigi Island	2°16'17.11"N	104° 6'57.28"E
12C	26/09/2013	Tinggi Island	Mentigi Island	2°16'17.06"N	104° 6'57.30"E
15C	27/09/2013	Tinggi Island	Tanjung Balang	2°16'51.86"N	104° 7'59.91"E
16C	09/04/2014	Babi Besar Island	Teluk Bakau	2°27'14.76"N	103°58'17.29"E
17C	10/04/2014	Babi Besar Island	Teluk Bakau	2°27'13.80"N	103°58'17.41"E
18C	10/04/2014	Babi Besar Island	Teluk Bakau	2°27'13.99"N	103°58'17.36"E
19C	10/04/2014	Babi Besar Island	Teluk Bakau	2°27'12.84"N	103°58'17.31"E
20C	10/04/2014	Babi Besar Island	Teluk Bakau	2°27'12.39"N	103°58'17.50"E
21C	11/04/2014	Babi Besar Island	Pelenling	2°26'35.22"N	103°58'22.74"E
22C	11/04/2014	Babi Besar Island	Pelenling	2°26'34.61"N	103°58'22.77"E
23C	11/04/2014	Babi Besar Island	Pelenling	2°26'33.95"N	103°58'23.10"E
25C	16/09/2014	Babi Besar Island	Pelenling	2°26'14.60"N	103°58'28.48"E
26C	16/09/2014	Babi Besar Island	Pelenling	2°26'15.73"N	103°58'27.99"E
27C	17/09/2014	Babi Besar Island	Pelenling	2°26'34.38"N	103°58'23.38"E
28C	17/09/2014	Babi Besar Island	Pelenling	2°26'34.00"N	103°58'23.18"E
29C	17/09/2014	Babi Besar Island	Pelenling	2°26'33.60"N	103°58'23.26"E
30C	18/09/2014	Babi Besar Island	Pelenling	2°26'40.03"N	103°58'21.65"E
31C	18/09/2014	Babi Besar Island	Pelenling	2°26'38.89"N	103°58'21.78"E
32C	18/09/2014	Babi Besar Island	Pelenling	2°26'38.25"N	103°58'22.00"E
33C	18/09/2014	Babi Besar Island	Pelenling	2°26'38.01"N	103°58'21.95"E
34C	19/09/2014	Babi Besar Island	Pelenling	2°26'49.54"N	103°58'21.15"E
35C	19/09/2014	Babi Besar Island	Pelenling	2°26'49.89"N	103°58'20.85"E
37C	19/09/2014	Babi Besar Island	Pelenling	2°26'50.72"N	103°58'21.04"E
38C	20/09/2014	Babi Besar Island	Teluk Bakau	2°27'16.30"N	103°58'17.23"E
39C	20/09/2014	Babi Besar Island	Teluk Bakau	2°27'17.06"N	103°58'17.17"E

A preliminary investigation was done at the study sites in June 2013, a species-area curve for optimal quadrat size was determined using Underwater Visual Census (UVC) method for various sizes of quadrat from 4 m^2 to 100 m^2 (English et al., 1997; Krebs, 1989; Rice & Kelting, 1955). Based on the species-area curve (Figure 3.2), the number of fish species has reached a plateau at 5 m x 5 m in seagrass habitat, but for coral reefs the fish species count still increased. Therefore, the optimal quadrat size to census fish community structure for both habitats was estimated to be a 7 m x 7 m quadrat. However, considering the field work limitations such as poor underwater visibility (usually < 3 m horizontal visibility), logistics, capacity, cost and time, a 2 m x 2 m quadrat size was selected to be used with the underwater video method in this research.

(a) Coral reefs



(b) Seagrass meadows

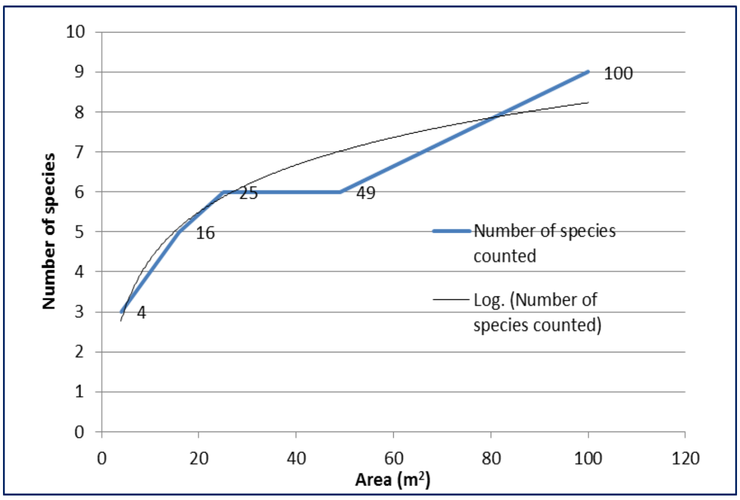


Figure 3.2: Number of fish species-area (m^2) curve from (a) coral reefs and (b) seagrass meadows in Tinggi Island.

3.3 Fish community assessment using Remote Underwater Video Station (RUVS)

In recent decades, underwater video techniques have been widely used in marine-based research including assessment of fish community structures in both coral reefs and seagrass habitats. The Remote Underwater Video Station (RUVS) method was chosen to sample fish community data due to the reliability and consistency of field data sampling, low impact to the sensitive environments and the targeted organisms as discussed in the previous chapter (2.5 Remote Underwater Video Station (RUVS)).

Fish communities were assessed by RUVS from 30 quadrats in seagrass meadows and 39 quadrats from coral reefs. However, there were four coral reef quadrats that had unusable video recordings to extract fish data due to poor visibility and an off-centre video set up.

3.3.1 Remote Underwater Video Station (RUVS) design

At each sampling station, RUVS was deployed (Figure 3.3). A 2 m x 2 m quadrat was delineated by placing a underwater marker at each corner, and a surface marker buoy was deployed to enable relocation of the quadrat for habitat properties sampling. A RUVS was placed at the corner of each quadrat to document fish communities. Video recordings were taken during optimum sunlight for better visibility, and when water current conditions allowed relatively safe deployment of the cameras.

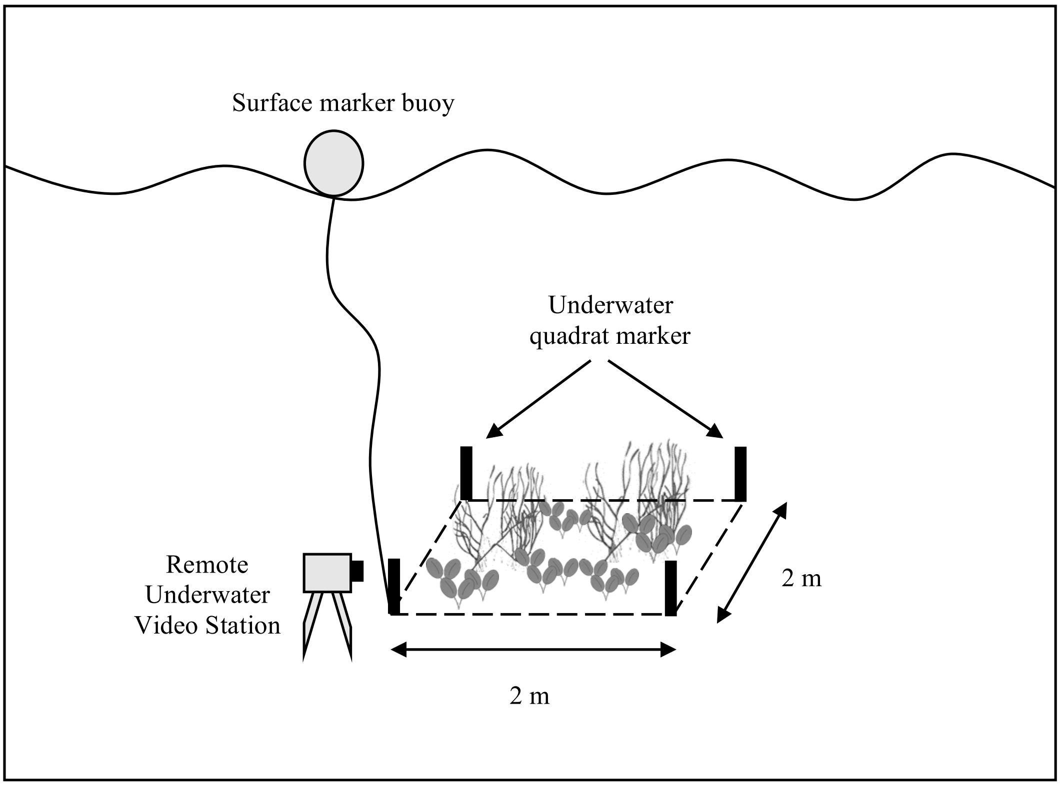


Figure 3.3: Sampling design with 2 m x 2 m quadrat and Remote Underwater Video Station (RUVS) set up at one corner, diagram show example in seagrass meadow.

3.3.2 Remote Underwater Video Station (RUVS) sampling method

Fish communities and habitat utilisation activities were surveyed using Remote Underwater Video Station (RUVS) between 9:00 to 16:30 to maximise optimal light conditions while avoiding the overlap with nocturnal species (English et al., 1997; Halford & Thompson, 1994). A small underwater video camera (GoPro Hero3 HD camera, video setting at 1080 x 24 fps) was deployed at each quadrat and set to record for at least 80 minutes. The retrieved video footages were then analysed in the laboratory to obtain fish community data including species richness, fish density, fish activity and fish maturity stage (Conn, 2011; Pelletier et al., 2011; Assis et al., 2013; Bacheler et al., 2013; Schobernd et al., 2014; Stobart et al., 2015).

3.3.3 Video analysis method

The first and last 10 minutes of the video footage were not used in the analyses, to allow fish community to become accustomed to the quadrat and RUVS set up, and to eliminate disturbance from scuba divers presence. Fish community from each quadrat was then analysed from the remaining 60 minutes; six subsets comprising of 3-minute video segments were extracted at 5-minute intervals using the video software Adobe Premier CC. Within each of the 3-minute video segment, a MinCount was made for each species, which is the greatest number of individuals observed within that segment (Ellis & DeMartini, 1995; Willis et al., 2000; Cappo et al., 2006; Ajemian et al., 2015). The average fish species richness and density were obtained from the 6 subsets and converted to mean count per m^2 (Conn, 2011; Assis et al., 2013; Bacheler et al., 2013; Bacheler & Shertzer, 2014; Schobernd et al., 2014; Ajemian et al., 2015; Stobart et al., 2015). All fishes above 3 cm in total length were identified to the lowest possible taxonomic level by using fish identification references of Kuiter and Debelius (2006), Nelson (2006), Atan et al. (2010), Matsunuma et al. (2011), Allen et al. (2012) and Froese and Pauly (2012). A fish is classified as a juvenile if it has a total length of less than one-third of the species maximum length (I Nagelkerken et al., 2002; Froese & Pauly, 2012).

In addition, each 3-minute video segment was chosen for observations of fish behaviour and habitat utilisation patterns in seagrass and coral reef habitats. Fish habitat utilisation activities were categorised as grazing (fish observed browsing on sand, nibbling on seagrass blades or coral, etc.) and protecting (territorial fish that were guarding or defending their feeding or shelter territories). Other fishes present in the video but were not using the habitat directly were categorised as passing through (fish swam pass and did not stop for grazing).

3.4 Assessment methods of habitat attributes

This study involved the assessment of two different habitats. Thus different approaches of habitat attributes assessment were applied for each habitat. However, similar assessment methods were used to obtain habitat configurations (distance to adjacent habitat and water depth) for both habitats.

3.4.1 Forereef seagrass meadows

Assessment methodology of seagrass habitat attributes was listed in the flow chart in Figure 3.4. Seagrass species diversity and canopy height were recorded from each 2 m x 2 m RUVS quadrat with four replicates of 0.25 m^2 quadrats. Four readings of canopy height were taken from the dominant species by ignoring 20% of the tallest leaves from each replicate of 0.25 m^2 quadrat (Mckenzie, 2003). Seagrass percent cover was obtained by photography method and analysed for percent cover (Mckenzie, 2003). In addition, mean seagrass shoot density by species was obtained by taking four cores (core diameter Ø = 0.25 m) (Figure 3.5) from each 0.25 m^2 quadrat (Duarte & Kirkman, 2001).

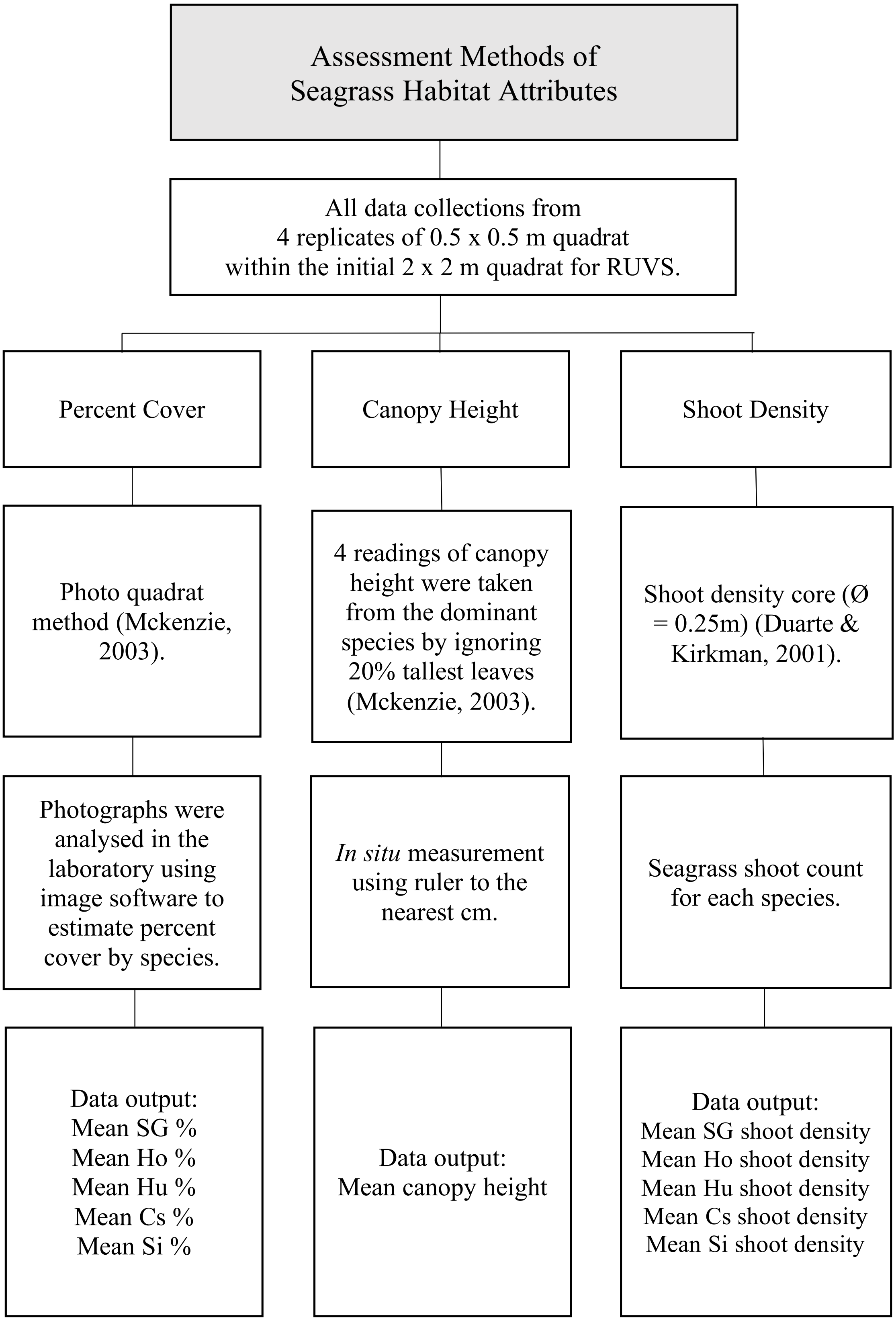


Figure 3.4: Methodology flow chart of assessment of habitat attributes in seagrass meadows. (SG: seagrass; Ho: *H. ovalis*; Hu: *Halodule univervis*; Cs: *C. serrulata*; Si: *S. isoetifolium*.

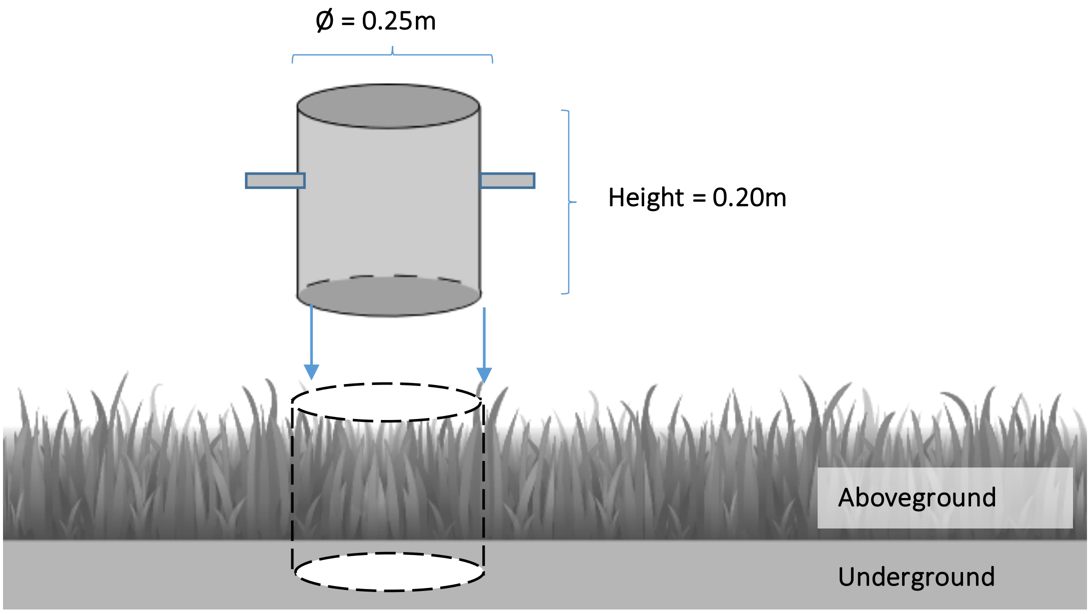


Figure 3.5: Seagrass shoot density count using the core method.

3.4.2 Coral reefs

Habitat attributes for coral reefs were assessed by using different methods as the characteristic features were different from seagrass (Figure 3.6). For each coral quadrat (2 m x 2m), coral genus richness, growth form and substrate cover were obtained by photography method. The close-up photos of all coral species present in each quadrat were identified to genus level according to the Coral Finder 2.0 Indo-Pacific identification guide (Kelley, 2012). Photographs of substrate surface from a 2 m x 2 m quadrat were rendered using image software and subsequently were analysed using Coral Point Count with Excel extensions (CPCe) image software (Kohler & Gill, 2006). Percent cover of each coral category i.e. growth forms and substrate types, they were firstly outline and subsequently the surface area of each categories were calculated using CPCe image software.

Habitat substrate in the present study were classified as hard coral (HC), soft coral (SC), dead coral (DC), rubble (RB), sand (SD), rock (RC) and other (OT) according to guidelines of coral reef substrate survey (English et al., 1997; Hill & Wilkinson, 2004; Hodgson et al., 2006). Additionally, the hard coral (HC) were sub-classified further to growth forms including branching (B), massive (M), sub-massive (SubM), encrusting (En), foliose (Fo), plate-like (Pl) and free-living (Fl) (Table 3.3) (English et al., 1997; Kelley, 2012).

Rugosity of reef is defined as the surface roughness serves as the index of substrate complexity. Rugosity index was measured using the chain method, which is the ratio of the length of a flexible chain on substrate surface (L) divided by the length the quadrat (D) as shown in Figure 3.7 (Risk, 1972; Hill & Wilkinson, 2004; Friedman et al., 2012). The rugosity index range starts from 1 for a perfectly flat surface and tends toward infinity as the structural complexity increases (Alvarez-Filip et al., 2009).

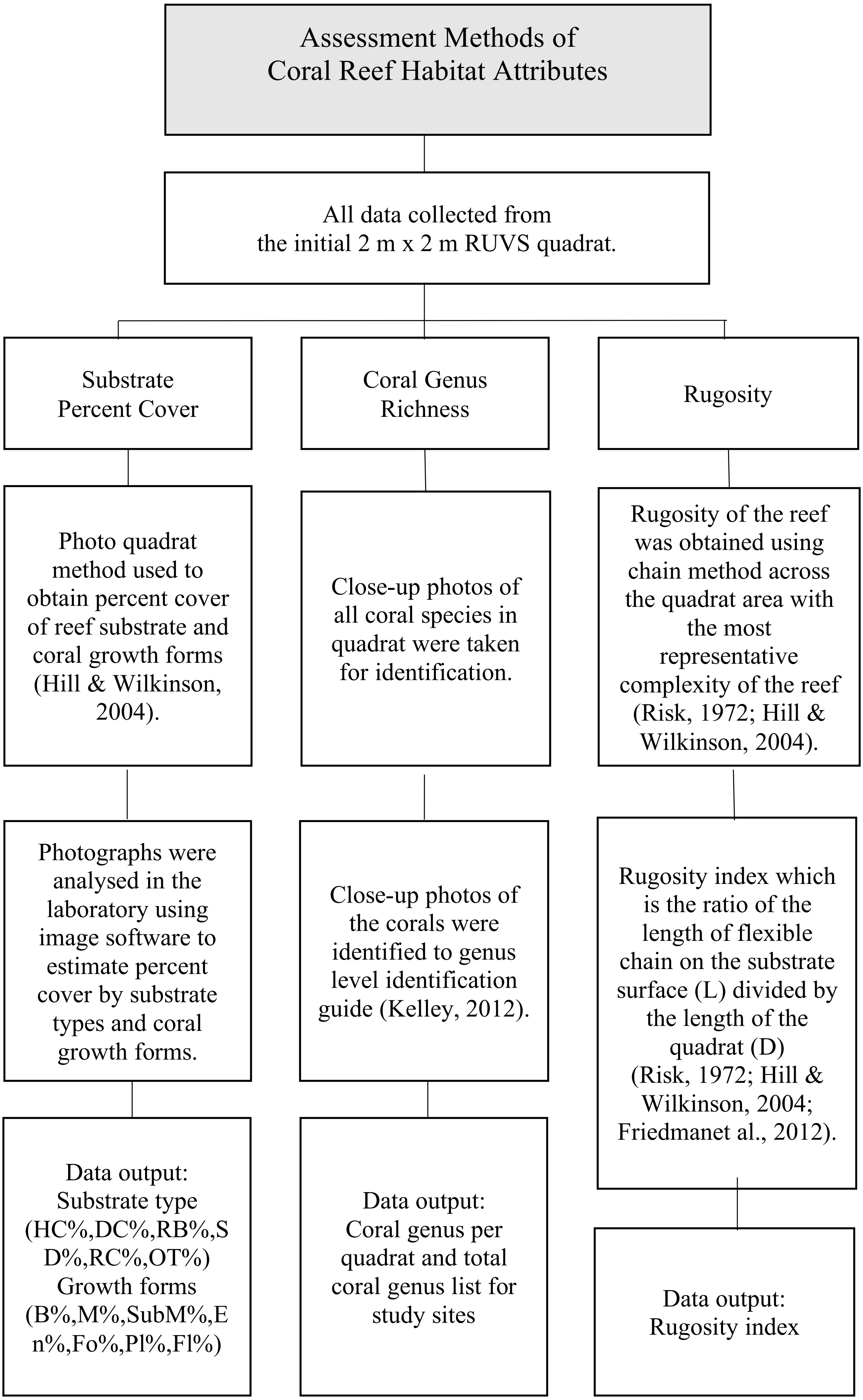


Figure 3.6: Coral reefs methodology flow chart of habitat attributes assessment. (HC: Hard coral; DC: Dead coral; RB: Rubble: SD: Sand; RC: Rock; OT: Other; B: Branching; M: Massive; SubM: SubMassive; En: Encrusting; Pl: Plate-like; Fl: Free-living).

Table: 3.3: Coral reef habitat substrate and coral growth forms categories and code according to field guides (English et al., 1997; Hodgson et al., 2006; Kelley, 2012).

Substrate Category	Growth form Category	Code	Remarks
Hard coral		HC	Live reef-building coral including fire coral (*Millepora*), blue coral (*Heliopora*) and organ pipe coral (*Tubipora*)
	Branching	B	At least 2° branching
	Encrusting	En	Major portion attached to substrate form a laminar plate
	Foliose coral	Fo	Coral attached at one or more points, leaf-like, or plate-like appearance
	Massive coral	M	Solid boulder or mound
	Sub-massive	SubM	Robust with knob or wedge-like form
	Plate-like	Pl	Horizontal flattened plates or tabular coral
	Free-living	Fl	Solitary, free-living coral of *Fungia*
Soft coral		SC	Soft bodied coral
Dead coral		DC	Recently dead, white or dirty white
Rubble		RB	Unconsolidated coral fragments
Sand		SD	Particles smaller than 0.5 cm
Rock		RC	Any hard substrate whether is covered in encrusting coraline algae, barnacles, etc. Rock also include dead coral that is more than a year with worn down and few visible corallite structure, usually covered with algae
Other		OT	Ascidians, anemones, gorgonian, giant clams etc.

$$\text{Rugosity index, } r = \frac{\text{Length of chain on coral surface, } L}{\text{Quadrat distance, } D}$$

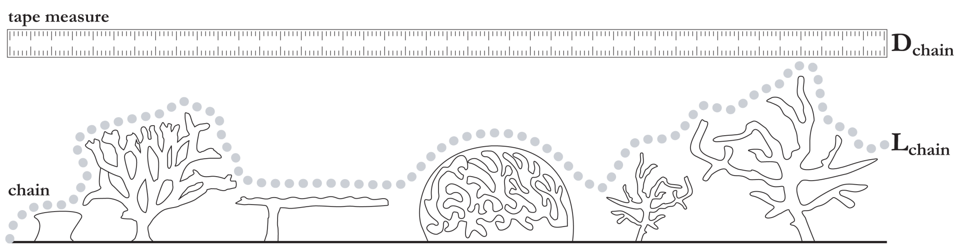


Figure 3.7: Measurement of rugosity index in coral reefs using chain method. Reprinted from *Methods for ecological monitoring of coral reefs* (p.117), by J. Hill, & C. Wilkinson, 2004, Townsville, QLD: Australian Institute of Marine Science. Reprinted with permission.

3.4.3 Proximity to adjacent habitat and water depth

Habitat configuration is defined as spatial characteristics and arrangement of the habitat (Farina, 2008). This study measured habitat configuration of the proximity to adjacent habitat. The proximity is the distance (metre) of the quadrat sampling location to the nearest adjacent habitat and was measured using the Google Earth software based on the quadrat GPS coordinates recorded during deployment at the respective sampling stations.

The water depth measurement was obtained *in situ* using a dive computer with recorded date and time for each quadrat. Water depth for each quadrat was corrected to chart datum by referring to National Hydrographic Centre (2013, 2014) tables. To verify the depth data, chart datum using the tide tables were referred to with Babi Besar Island as the Secondary Port, and Mersing as the Standard Port. The time of high and low water were obtained by applying the time differences tabulated in the Secondary Ports Table to the daily predictions for the designated Standard Port tide chart. Secondary Port Babi Besar Island is 16 minutes earlier for Higher High Water (HHW) and 4 minutes earlier for Lower Low Water (LLW) compared to the Standard Port Mersing (Table 3.4).

The Mersing Standard Port tide datum for each sampling date was used to obtain predicted times and heights of high and low waters. Calculation table (Table 3.5) was used to obtain the times and heights of high and low water in the Secondary Port.

Subsequently, the recorded sampling time and depth from depth gauge (dive computer) were used to calculate the height of tide at the specified time according to the Secondary Port correction. The actual water depth for each quadrat was obtained from the subtraction of depth gauge reading to the corrected height of low water (or high water) (Table 3.6). This calculation was repeated for each quadrat with their respective date, time and depth.

Table 3.4: Secondary port table of Babi Besar Island.

No.	Place	Lat N.	Long E.	Time Differences HHW LLW (Zone-0800)		Height Differences (in Meters) MHHW MLHW MHLW MLLW				M.L Zom.
4887	**MERSING**	**2 26**	**103 51**	**Standard Port**		3.3	2.1	1.7	0.5	1.91
4886	Babi Besar Island	2 26	103 59	**-0016**	**-0004**	-0.4	-0.3	-0.4	-0.3	1.55

* A negative (-) time will give an earlier time than the Standard Port.

Table 3.5: Calculation table of height of high and low water for the secondary port.

Standard Port Data (Mersing)	Time (1) HW	Time (1) LW	Heights (2) HW	Heights (2) LW	MSL (3)	Levels (4) MHWS	Levels (4) MLWS	Levels Range (5) MHWS-MLWS
	1036 2123	0319 1649	3.0 2.1	0.1 1.4	1.9	3.3	0.5	2.8
(6) Predicted Height - MSL (2-3)			1.1 0.2	-1.8 -0.5				
Secondary Port Data (Pulau Besar)	Times Difference (7) HW	Times Difference (7) LW			MSL (8)	Levels (9) MHWS	Levels (9) MLWS	Levels Range (10) MHWS-MLWS
	-0016	-0004			1.6	2.9	0.2	2.7
Calculations (12) (6x11)			1.1 0.2	-1.7 -0.5				Range Ratio (11) (10/5)
Secondary Port Data	Time (13) (1+7) HW	Time (13) (1+7) LW	Heights (14) (8+12) HW	Heights (14) (8+12) LW				
	1020 **2107**	**0315** **1645**	**2.7** **1.55**	**0.0** **1.1**				0.96

Table 3.6: Calculation table for the actual water depth at the specified sampling time.

Correction of Water Depth (m)			
Sampling Date	Sampling Time	SG Q1	
23/07/2013	1250		
According to tide table,	Time	Meter	
Low Tide	1645	1.1	
High Tide	1020	2.7	
Difference	6hours 25min	1.6	
According to the Table 3.5 (Table for finding the height of the tide at times):			
Duration of rise or fall:	6 hours 25 min		(the nearest point taken: 0630)
Interval from the nearest low water (high water)	0355	(1645-1250)	(the nearest point taken: 0354)
Range	1.6m		(the nearest point taken: 16)
Corrections to height of low water (high water)	1.1m		
Therefore,			
Reading of depth on the dive computer	5.4m		
(Low tide + Corrections)	2.2m	(1.1+1.1)	
Corrected water depth	3.2m	(5.4-2.2)	

3.5 Statistical analysis

Data from field surveys and subsequent video processing were analysed according to research objectives (Figure 1.1). All data were converted to the appropriate unit of measurement (Table 4.6 & 4.10). Data analyses and graphic outputs were produced using R software version 3.2.1 (R Core Team, 2017).

3.5.1 Characterising fish community data

The Mann-Whitney U test, which is also known as the Wilcoxon rank sum test (Wilcoxon, 1945; Mann & Whitney, 1947), a nonparametric version of the parametric t-test was used to test for differences between two groups of non-parametric data in fish communities in adjacent seagrass and coral reefs, including fish density, fish species richness, fish maturity stage and fish habitat utilisation.

For the fish maturity stage (juvenile and adult) and fish habitat utilisation (grazing and protecting) within each habitat, the Wilcoxon signed-rank test was used to compare two related variables within the single sample as the non-parametric paired student t-test (Wilcoxon, 1945).

3.5.2 Data exploratory analysis

Firstly, the response (dependent) variable data was tested for normality with the Shapiro-Wilks test together with a quantile-quantile-plot. Response variables with non-normal distribution were transformed prior to further statistical analyses to meet statistical assumptions, except for fish species richness in coral reefs that had a normal distribution. Fish density and fish species richness in seagrass habitat were log (y+1) transformed with an arbitrary constant added due to mean observation less than 1 (Underwood, 1997), whereas fish density in coral habitat with higher mean was log transformed.

An outlier is an observation with an extreme number that is far away from sample means and causes high skewness in data distribution. An outlier test function in the 'car' package (Fox et al., 2015) in the R software was used to eliminate possible outliers for each variable. Four coral quadrats were identified as outliers (4C, 5C, 24C and 36C) because of the presence of schooling fish, and removed from the dataset prior to regression analyses.

A scatterplot matrix with Spearman's rank correlation coefficient was used to check for the relationship (positive or negative) of fish density and fish species richness with all other explanatory (independent) variables as listed in Table 4.6 and Table 4.10. Scatterplot of each univariate relationship was used to show if the regression line is potentially linear or curvilinear (Bakus, 2007). When the variables are not normally distributed or the relationship between the variables was not linear, Spearman's rank correlation method was used to measure the strength of the relationships for each interaction between fish community data and habitat complexity attributes.

3.5.3 Generalized Linear Models (GLMs)

Generalized Linear Models (GLM) were used to perform the statistical analyses in this study because GLM is appropriate to explain the non-linear relationships commonly found in ecological studies (Guisan & Zimmermann, 2000; Guisan et al., 2002; Venables & Dichmont, 2004). The assumptions for GLM non-parametric regression are independence of Y (response or dependent variable), no influential observations, correct link function and scale of measurement of explanatory variables (McCullagh & Nelder, 1989). Response variables were tested in univariate GLM regression with Gaussian family and identify link against each explanatory variable (log transformed fish density and fish species richness). The response variable with significant contribution to the model was identified prior to select variables to perform a multiple variable GLM.

In regression analysis, the one in ten rule applies to avoid overfitting, where one predictive variable can be studied for every ten events (Harrell et al., 1984; Harrell et al., 1996). Recent studies have suggested that the previous rule may be too conservative; therefore a general recommendation of five to nine predictors can be enough depending on the research question (Vittinghoff & McCulloch, 2007). In this study, the one in ten rule and the new recommendation applied with GLM fitting between three to six variables due to the small sampling size (n=30). Therefore, only selected variables with significant explained variability of the fish density and fish species richness in the univariate GLM were used in the multiple variables final tested model. In addition, habitat configurations (distance to adjacent habitat and water depth) were added into the final tested model as the covariates. Subsequently, a stepwise backward regression was performed using Akaike Information Criterion (AIC) to select the best model with a minimum AIC value (Akaike, 1981).

Multicollinearity check was done using Variance Inflation Factors (VIF) in the package 'VIF' (Lin et al., 2011) to eliminate explanatory variables with high collinearity in the regression model. A common rule of thumb with VIF threshold at 10 refers to variables with high multicollinearity and hence should be removed (Montgomery et al., 2012). However, Zuur et al. (2010) suggested a more stringent approach to use a threshold at 3 especially for weak ecological signals, where collinearity can cause non-significance in parameter estimates. If there were two or more variables with high VIF in a model, the variable with the highest VIF value was removed, the VIF values recalculated in a reduced model, and the variable with next highest value removed until all VIF values are below the threshold >3 for the remaining variables.

The model's goodness-of-fit was assessed by the deviance. In GLM, D^2 is equivalent to R^2 in linear regression models. D^2 and adjusted D^2 for each model were obtained using the package 'modEvA' in the R software (Barbosa et al., 2015). Adjusted D^2 was used in comparing models because it takes into account the number of observations and the number of model parameters (Guisan & Zimmermann, 2000). ANOVA was tested on each model to see the significance level of each variable contributing to the deviance model.

The goodness-of-fit for the best-fit model was reported with deviance (dev.), adjusted D^2 (adj D^2) and Akaike Information Criterion (AIC). Subsequently, the percentage of explained deviance of each variable toward the model was calculated using the equation below:

$$\text{Percentage of explained deviance} = \frac{\text{(Full model residual deviance} - \text{Residual deviance of model minus the variable)}}{\text{Full model residual deviance}} \times 100\%$$

3.5.4 Canonical Correspondence Analysis (CCA)

Canonical Correspondence Analysis (CCA) was used to examine the relationship between the environmental variables (substrate type and growth form) and fish diversity (taxonomic composition). Environmental data represented as percent cover were arcsine transformed before CCA to reduce the influence of outliers on the results. To avoid multicollinearity between environmental variables, a Variance Inflation Factor (VIF) multicollinearity analysis was performed and those variables highly associated with any other (VIF >20) were removed from the analysis, as they would have no unique contribution to the regression equation. A reduced fish species data set was used in the analyses which included only fish species with at least three occurrences in the sampling quadrats to reduce the strong influence of rare species in the ordination (Table 4.8 & Table 4.12). Fish species were assigned to one of the feeding guilds of carnivores, omnivores and herbivores according to food diet information (Froese & Pauly, 2012). The model was calculated and tested for significance using Monte Carlo permutation tests (999 random permutations). The variance attributed to each variable independent of other environmental variables (marginal effects) was determined and reported. The relationships between species and the selected environmental variables were examined in CCA ordination plots based on species scores. CCA output and ordination plot were performed in the R software by using the package 'vegan' (Oksanen et al., 2014).

CHAPTER 4: RESULTS

4.1 Fish communities in adjacent seagrass and coral reefs

4.1.1 Dominant fish families

Overall, fish community in the forereef seagrass was dominated by the Lethrinidae family (Emperors). *Lethrinus variegatus* had the highest count of individuals with a total of 966 individuals (43% of total observed individuals) and the highest occurrence frequency of up to 80% of the total sampling quadrats. Other common species in the forereef seagrass include *Upeneus tragula*, *Pentapodus setosus*, *Scolopsis affinis*, *Siganus canaliculatus*, *Acreichthys tomentosus*, *Scolopsis monogramma*, *Scolopsis aurata*, *Halichoeres nigrescens* and *Carangoides ferdau*, representing trophic categories from omnivores and herbivores, but mainly from benthic invertivores and invertivores (Table 4.1). However, Nemipteridae family (Coral breams) had the most diverse species, with four identified species observed, namely *Scolopsis aurata*, *S. affinis*, *S. monogramma* and *Pentapodus setosus.*

In contrast, Pomacentridae (Damselfish) and Labridae (Wrasse) were the most abundant and diverse reef fish families observed in the coral reef habitats with 14 identified species from Pomacentridae and 13 identified species from Labridae. The pomacentrids appeared to have the highest occurrence frequency (100%) and highest density (0.49±0.04 individual per m^2) from *Neoglyphidodon nigroris* (Cuvier, 1830) (Table 4.2).

Table 4.1: List of dominant fish species in the forereef seagrass habitat.

Family	Species	Common name	Trophic group	Fisheries value	Occurrence frequency (%)	Mean fish density per m^2	± SE
Lethrinidae	*Lethrinus variegatus* (Valenciennes,1830)	Slender emperor	Benthic invertivore	Commercial	80	1.34	0.32
Mullidae	*Upeneus tragula* (Richardson, 1846)	Freckled goatfish	Benthic invertivore	Commercial	70	0.15	0.03
Nemipteridae	*Petapodus setosus* (Peters, 1877)	Peters' monocle bream	Benthic invertivore	Commercial	57	0.26	0.10
Nemipteridae	*Scolopsis affinis* (Valenciennes,1830)	Butterfly whiptail	Invertivore	Minor commercial	57	0.14	0.03
Siganidae	*Siganus canaliculatus* (Park, 1797)	White-spotted spinefoot	Herbivore	Commercial	43	0.18	0.08
Monacanthidae	*Acreichthys tomentosus* (Linnaeus, 1758)	Bristle-tail file-fish	Invertivore	Minor commercial	23	0.02	0.01
Nemipteridae	*Scolopsis monogramma* (Cuvier, 1830)	Mongrammed monocle bream	Omnivore	Minor commercial	23	0.06	0.03
Nemipteridae	*Scolopsis aurata* (Park, 1797)	Yellowstripe monocle bream	Omnivore	Subsistence fisheries	20	0.02	0.01
Labridae	*Halichoeres nigrescens* (Bloch & Schneider, 1801)	Bubblefin wrasse	Benthic invertivore	NA	17	0.11	0.05
Carangidae	*Carangoides ferdau* (Forsskål, 1775)	Blue trevally	Omnivore	Commercial	13	0.05	0.03

Table 4.2: List of dominant fish species in the coral reef habitat.

Family	Species	Common name	Trophic group	Fisheries value	Occurrence frequency (%)	Mean fish density per m^2	± SE
Pomacentridae	*Neoglyphidodon nigroris* (Cuvier, 1830)	Black-and-gold chromis	Omnivore	Aquarium	100	0.49	0.04
Chaetodontidae	*Chaetodon octofasciatus* (Bloch, 1787)	Eightband butterflyfish	Corallivore	Aquarium	90	0.29	0.04
Pomacentridae	*Amblyglyphidodon curacao* (Bloch, 1787)	Staghorn damselfish	Planktivore	Aquarium	52	0.20	0.05
Pomacentridae	*Abudefduf sexfasciatus* (Lacepède, 1801)	Scissortail sergeant	Planktivore	minor comm, aquarium	32	0.18	0.08
Nemipteridae	*Scolopsis margaritifer* (Cuvier, 1830)	Pearly monocle bream	Invertivore	artisanal	26	0.03	0.01
Labridae	*Diproctacanthus xanthurus* (Bleeker, 1856)	Yellowtail tubelip	Corallivore	Aquarium	26	0.04	0.02
Pomacentridae	*Abudefduf vaigiensis* (Quoy & Gaimard, 1825)	Indo-Pacific sergeant	Planktivore	artisanal; aquarium	26	0.09	0.04
Labridae	*Labroides dimidiatus* (Valenciennes, 1839)	Bluestreak cleaner wrasse	Invertivore	Aquarium	23	0.03	0.01
Serranidae	*Cephalopholis boenak* (Bloch, 1790)	Chocolate hind	Piscivore	artisanal; aquarium	23	0.02	0.01
Caesionidae	*Caesio teres* (Sale, 1906)	Yellow and blueback fusilier	Planktivore	minor comm.	23	0.13	0.05

4.1.2 Multiple habitat utilisation by common fish

There was a total of 10 fish species identified as utilisers of multiple habitats from the species list of both seagrass and coral reef habitats at the study sites (Table 4.3). Fish species found in higher density in coral reefs than forereef seagrass habitats were *Aeoliscus strigatus* (Family: Centriscidae), *Apogon compressus* (Family: Apogonidae) and *Scolopsis ciliatus* (Family: Nemipteridae). There was a significant difference in the mean density of *A. compressus* being six times higher in the coral reefs than seagrass habitat.

Fish species found in higher density in seagrass habitat than coral reefs were *Carangoides ferdau* (Family: Carangidae), Fussilier damsel (Family: Pomacentridae), *Gnathadon speciosus* (Family: Carangidae), *Halichoeres nigrescens* (Family: Labridae) and *Upeneus tragula* (Family: Mullidae). There was a significant difference for *U. tragula* species where occurrence probability and mean density were higher in seagrass habitat compared to coral reefs.

There were two species with similar low densities in both seagrass and coral reef habitats, *Aluterus scriptus* (Family: Monacanthidae) and *Pomacentrus cuneatus* (Family: Pomacentridae), categorised in the same trophic group as omnivores.

Table 4.3: List of fish species utilising multiple habitats of forereef seagrass and adjacent coral reefs.

						Coral reefs		Forereef Seagrass	
No.	**Family**	**Scientific name**	**Common name**	**Trophic group**	**Economic value**	**Occurrence Frequency (%)**	**Mean per Quadrat**	**Occurrence Frequency (%)**	**Mean per Quadrat**
1	Centriscidae	*Aeoliscus strigatus*	Razorfish	Planktivore	Aquarium	6.67	0.75	3.33	0.25
2	Monacanthidae	*Aluterus scriptus*	Scribbled leatherjacket filefish	Omnivore	Gamefish; Aquarium	3.33	0.04	3.33	0.08
3	Apogonidae	*Apogon compressus*	Split-banded cardinalfish	Carnivore	potential aquarium	3.33	1.79	3.33	0.29
4	Carangidae	*Carangoides ferdau*	Blue trevally	Piscivore/ Invertivore	comm; game fishing	10.00	0.04	13.33	0.40
5	Pomacentridae	*Unidentified*	Fussilier damsel	unknown	unknown	3.33	0.83	6.67	1.46
6	Pomacentridae	*Pomacentrus cuneatus*	Wedgespot damesl	Omnivore	None	6.45	0.03	6.67	0.08
7	Carangidae	*Gnathaodon speciosus*	Golden trevally	Piscivore/ Invertivore	minor comm;gamefish; aquaculture;aquarium	3.33	0.04	6.67	0.17
8	Labridae	*Halichoeres nigrescens*	Greenback wrasse	Invertivore	None	16.67	0.07	16.67	0.63
9	Nemipteridae	*Scolopsis ciliatus*	Whitestreak monocle bream	Invertivore	Artisanal	20.00	0.42	6.67	0.13
10	Mullidae	*Upeneus tragula*	Freckled goatfish	Invertivore	comm;aquarium	3.33	0.04	70.00	0.21

4.1.3 Fish density and species richness

A total of 2434 individuals of fish, belonging to at least 30 families and 197 taxa were recorded from 61 quadrats (30 for seagrass and 31 for coral reefs).

In the forereef seagrass meadows, 1005 individuals and 86 fish taxa were counted, 35 fish taxa were identified to species level, 17 were identified to genus level, 23 were identified to family level, and the 11 which remained unidentified as they were mostly juveniles (Appendix I).

In contrast, there were more fish enumerated from the coral reefs, with 1429 individuals from 136 taxa observed. Fishes from 69 taxa were identified to species level, 22 were identified to genus level, 41 were identified to family level, and 4 remained unidentified. (Appendix II).

In the forereef seagrass habitat, this study recorded mean fish density of 3.14 ± 0.79 individuals per m^2, mean fish species richness of 0.95 ± 0.13 species per m^2 and fish diversity index H' of 1.41 ± 0.05 per m^2 (Table 4.4). In the coral reef habitat, mean fish density of 4.13 ± 0.93 individuals per m^2, mean fish species richness of 1.51 ± 0.17 species per m^2 and fish diversity index H' of 2.00 ± 0.05 per m^2 were recorded (Table 4.4). Overall, fish density was about 32% higher ($p<0.05$), while species richness and the diversity index were nearly 59% higher ($p<0.001$) in the coral reef than in forereef seagrass (Table 4.4, Figure 4.1, Figure 4.2 a & b).

Table 4.4: Summary of fish community in forereef seagrass and adjacent coral reef habitats with Mann-Whitney U Test (Wilcoxon rank sum test) on pairwise comparison between habitats.

Fish community	Forereef seagrass (n=30)	Coral reefs (n=31)	Mann-Whitney U Test
Mean Fish density per m^2	3.14 ± 0.79	4.13 ± 0.93	W = 328.5, p < 0.05
Mean Fish species per m^2	0.95 ± 0.13	1.51 ± 0.17	W = 187.5, p < 0.001
Fish diversity H' per m^2	1.41 ± 0.05	2.00 ± 0.05	W = 159, p < 0.001

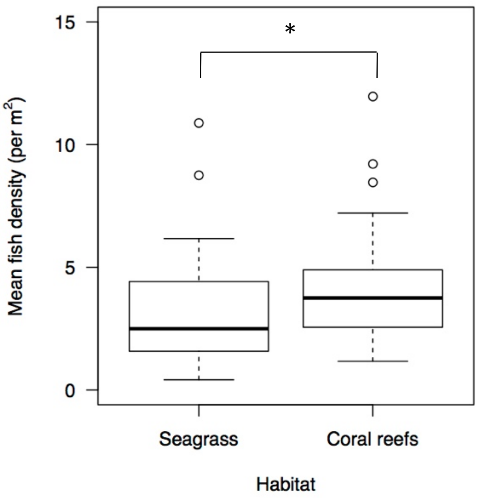


Figure 4.1: Boxplot of mean fish density in adjacent seagrass and coral reefs. Significant p-value based on Mann-Whitney U Test (Wilcoxon Rank Sum Test). Significant level p-value <0.05 (*).

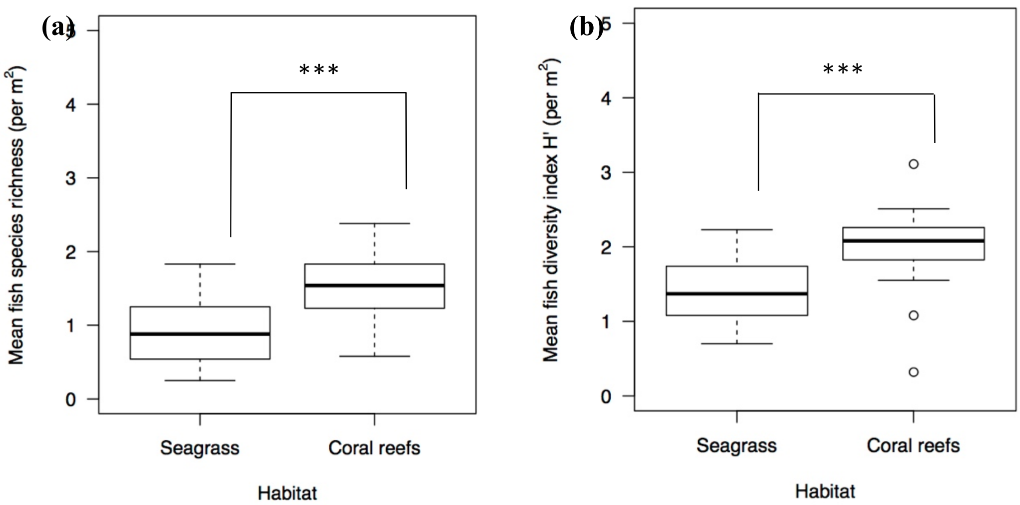


Figure 4.2: Boxplot of mean fish species richness (a) and Shannon-Wiener diversity index (b) in adjacent seagrass and coral reefs. Significant p-value based on Mann-Whitney U Test (Wilcoxon Rank Sum Test). Significant level p-value <0.001 (***).

4.1.4 Fish maturity stages

From the total mean fish density (3.14 ± 0.79 individuals per m^2) in adjacent forereef seagrass habitat, 77% consisted of juvenile fishes, which occurred in significantly higher densities than adult fish (p<0.001) (Table 4.5 & Figure 4.3). The result of the total fish counted from the coral reef habitat showed that 90% are adult fish (3.70±0.90 individual per m^2), which was significantly higher than juvenile fish (0.41±0.13 individual per m^2) (p<0.001) (Table 4.5 & Figure 4.3). Overall, the proportion of juveniles and adults were significantly different between habitats (Table 4.5) and within each habitat (Figure 4.3), where juveniles were higher in forereef seagrass than coral reefs, and coral reefs had higher adults than in adjacent seagrass habitats.

Table 4.5: Summary of fish community in coral reef and adjacent forereef seagrass habitats with Wilcoxon signed-rank test on pairwise comparison between habitats.

Fish maturity stages	Forereef seagrass	Coral reefs	Mann-Whitney U test
Mean juvenile density per m^2	2.41 ± 0.68	0.41 ± 0.13	W = 106, p < 0.001
Mean adult density per m^2	0.73 ± 0.22	3.70 ± 0.90	W = 892, p < 0.001

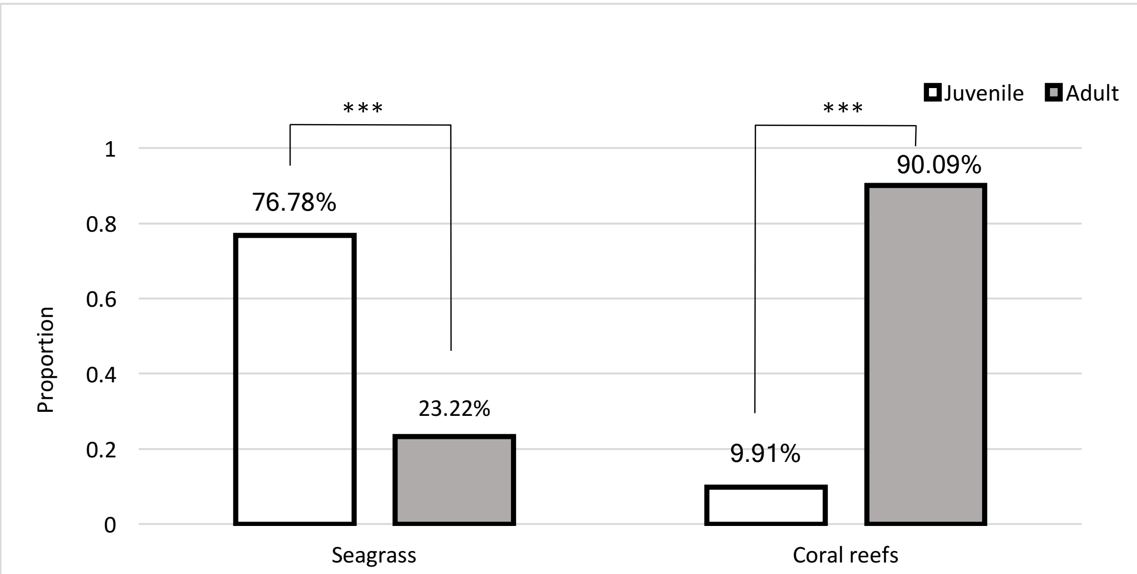


Figure 4.3: Proportion of fish maturity stages in adjacent seagrass and coral reefs. Wilcoxon Signed-rank Test with p-value significant level shown on each category (***= p <0.001; ** = p <0.01; * = p <0.05; NS = p >0.05).

4.1.5 Fish habitat utilisation

Fish activities in the seagrass and coral reef habitats were observed and counted from RUVS video footage. The typical fish activities that were observed in the footage were categorized as passing through (PS), grazing (GZ) and protecting (PT).

In the forereef seagrass meadows, the observed habitat utilisation activities were mainly grazing (1.12 ± 0.24 individual per m^2) and protecting (0.28 ± 0.05 individual per m^2), while other fish observed were passing through the habitat (1.75 ± 0.71 individual per m^2). The protecting activity was significantly lower than grazing ($W=765$, $p<0.001$) (Figure 4.4 a).

In contrast, in the coral reef habitat, the observed habitat utilisation activities were mostly protecting (1.38 ± 0.17 individual per m^2), and followed by grazing (0.39 ± 0.13 individual per m^2), while other fish were passing through the habitat (2.35 ± 0.88 individual per m^2). The grazing activity was significantly lower than protecting ($W=100$, $p<0.001$) (Figure 4.4 b).

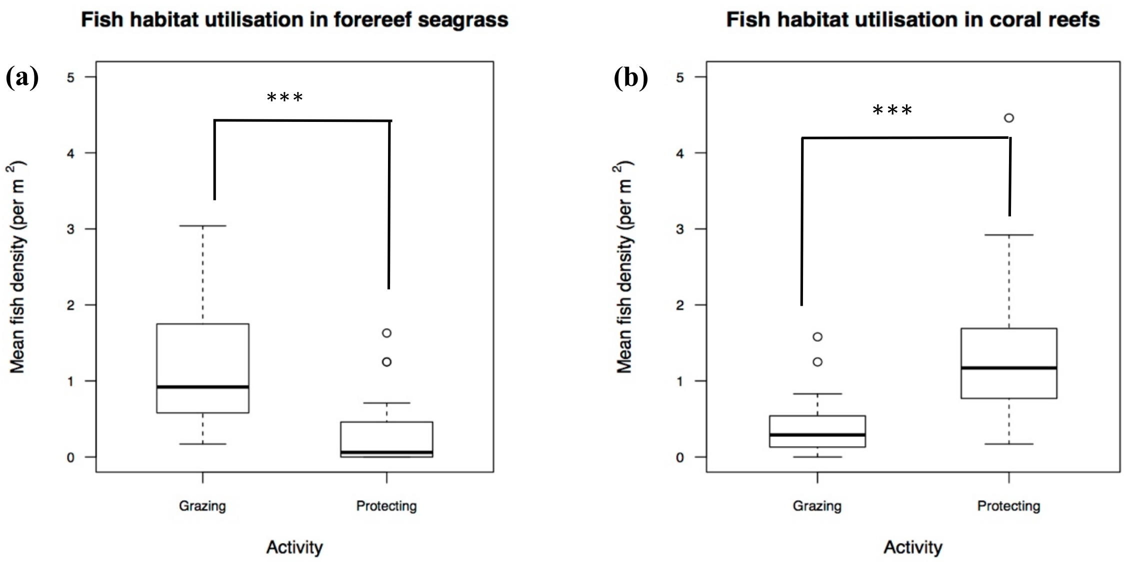


Figure 4.4: Boxplot of fish habitat utilisation in adjacent (a) forereef seagrass and (b) coral reefs. Significant p-value based on Wilcoxon Signed Ranks Test. Significant level p-value <0.001 (***).

The habitat utilisation patterns in the adjacent seagrass and coral reefs showed significant proportion difference for grazing and protecting, but not for the passing through. A total of 35.48% fishes observed in seagrass habitat were grazing, and 9.57% were in protecting mode (Figure 4.5). On the contrary, in the coral reef habitat, total observed fishes mainly in protecting mode were up to 33.48%, while grazing fish observed made up of 8.99% (Figure 4.5).

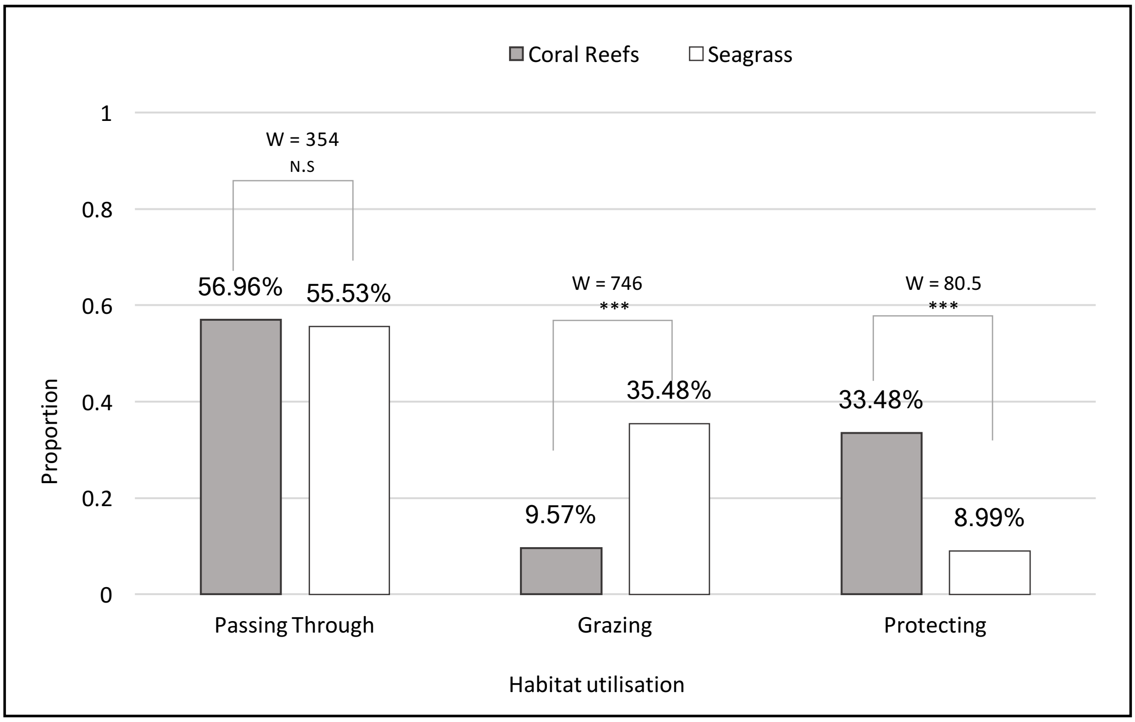


Figure 4.5: Proportion of fish habitat utilisation in coral reefs and forereef seagrass. Mann-Whitney U test and p-value significant level shown on each category (***= $p < 0.001$; ** = $p < 0.01$; * = $p < 0.05$; NS = $p > 0.05$).

4.2 Fish-habitat relationships in forereef seagrass habitat

4.2.1 Habitat complexity attributes in forereef seagrass habitat

In the forereef seagrass meadows, there was a total of 30 quadrats delineated at Tinggi Island (n=14) and Babi Besar Island (n=16). All the quadrats were used for data analysis.

In the present study, the response variables (known as dependent variables) were fish community data consisting of fish density and fish species richness, whereas all the habitat complexity attributes were the explanatory variables (known as independent variables) (Table 4.6 & Appendix III). Seagrass habitat complexity attributes measured from each quadrat included seagrass percent cover, canopy height, shoot density, species richness, as well as the percent cover and shoot density by four major species (*H. ovalis*, *H. uninervis*, *C. serrulata* and *S. isoetifolium*). The distance to the adjacent reef habitat and water depth were the measurements for habitat configurations. The habitat complexity attributes were explanatory variables that were tested against response variables of fish density and fish species richness in the statistical analyses using Generalized Linear Models (GLMs) with habitat configurations as the covariates.

The forereef seagrass in Tinggi Island and Babi Besar Island were multispecies meadows in which *H. ovalis* and *H. uninervis* occurred with higher percent cover and shoot density as compared to the co-occurring species *C. serrulata* and *S. isoetifolium* (Figure 4.6). The mixed beds of forereef seagrass had an average of 26.63±1.89% seagrass percent cover and 1,108.67±64.03 shoot density per m^2, comprising the dominant species *H. uninervis* with 44% of the total seagrass percent cover and 48% of the total shoot density, followed by *H. ovalis* with 29% and 36% of the total percent cover and shoot density, respectively. The other co-occurring species were *C. serrulata* and *S. isoetifolium* with 14% and 13% of the total percent cover, and 7% and 9% of the total shoot density respectively (Figure 4.6).

Table 4.6: List of fish community and seagrass habitat complexity attributes and proximity with unit of measurement, mean and standard error.

	Variables	Unit of measurement	n	Mean & S.E.
Response variables	**Fish community**			
	Fish density	No. of individuals per m^2	30	3.14 ± 0.79
	Fish species richness	No. of species per m^2	30	0.95 ± 0.13
Explanatory variables	**Habitat Complexity**			
	Mean seagrass percent cover	cover %	30	26.63 ± 1.89
	Mean seagrass shoot density	no. shoots m^{-2}	30	1108.67 ± 64.03
	Seagrass species richness	no. of species	30	3.47 ± 0.14
	Canopy height	cm	30	7.63 ± 0.77
	Seagrass percent cover			
	Halophila ovalis (Ho)	cover %	29	7.47 ± 0.90
	Halodule uninervis (Hu)	cover %	29	11.35 ± 1.22
	Cymodocea serrulata (Cs)	cover %	24	3.63 ± 0.73
	Syringodium isoetifolium (Si)	cover %	14	3.48 ± 1.13
	Seagrass shoot density			
	H. ovalis shoot density	no. shoots m^{-2}	28	398.33 ± 46.53
	H. uninervis shoot density	no. shoots m^{-2}	29	533.67 ± 56.96
	C. serrulata shoot density	no. shoots m^{-2}	23	79.67 ± 14.11
	S. isoetifolium shoot density	no. shoots m^{-2}	14	100.67 ± 33.00
	Habitat Configuration			
	Distance to adjacent reef habitat	metre	30	22.89 ± 2.91
	Other measurement			
	Water depth	metre	30	3.55 ± 0.28

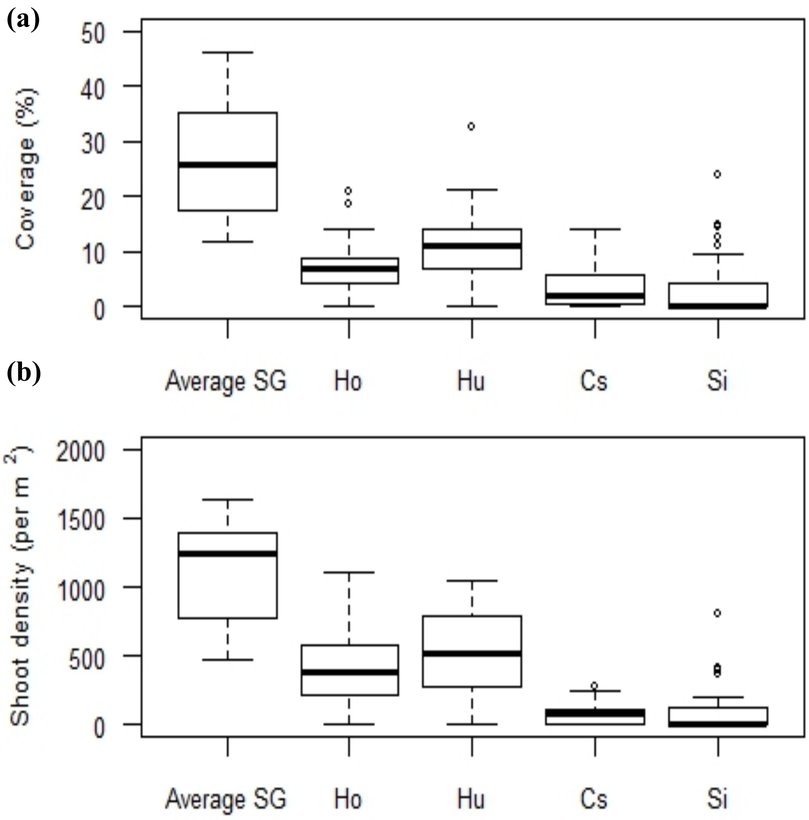


Figure 4.6: Seagrass community (a) percent cover and (b) shoot density by species (SG= seagrass; Ho= *Halophila ovalis*; Hu= *Halophila uninervis*; Cs= *Cymodocea serrulata*; Si= *Syringodium isoetifolium*).

The seagrass canopy height from the study sites was generally low with an average of 7.63 ± 0.77 cm due to the absence of boarder and higher canopy species such as *Enhalus acoroides* in the forereef seagrass, which can grow up to 2 m (Larkum et al., 2006). The seagrass canopy height was correlated with the seagrass species richness ($p<0.01$) where mixed meadows usually with the presence of *S. isoetifolium* would provide higher canopy meadow compared to monospecific *H. ovalis* at the edge of meadows (Figure 4.7). Even with the relatively low canopy of this forereef seagrass, canopy height was considered as an important structural complexity attribute in seagrass meadows beside percent cover, shoot density and biomass.

4.2.2 Spearman's rank correlation analysis

Scatterplot matrix and Spearman's rank correlation coefficient showed that there was significant correlation between seagrass habitat attributes with fish density and fish species richness (Figure 4.7).

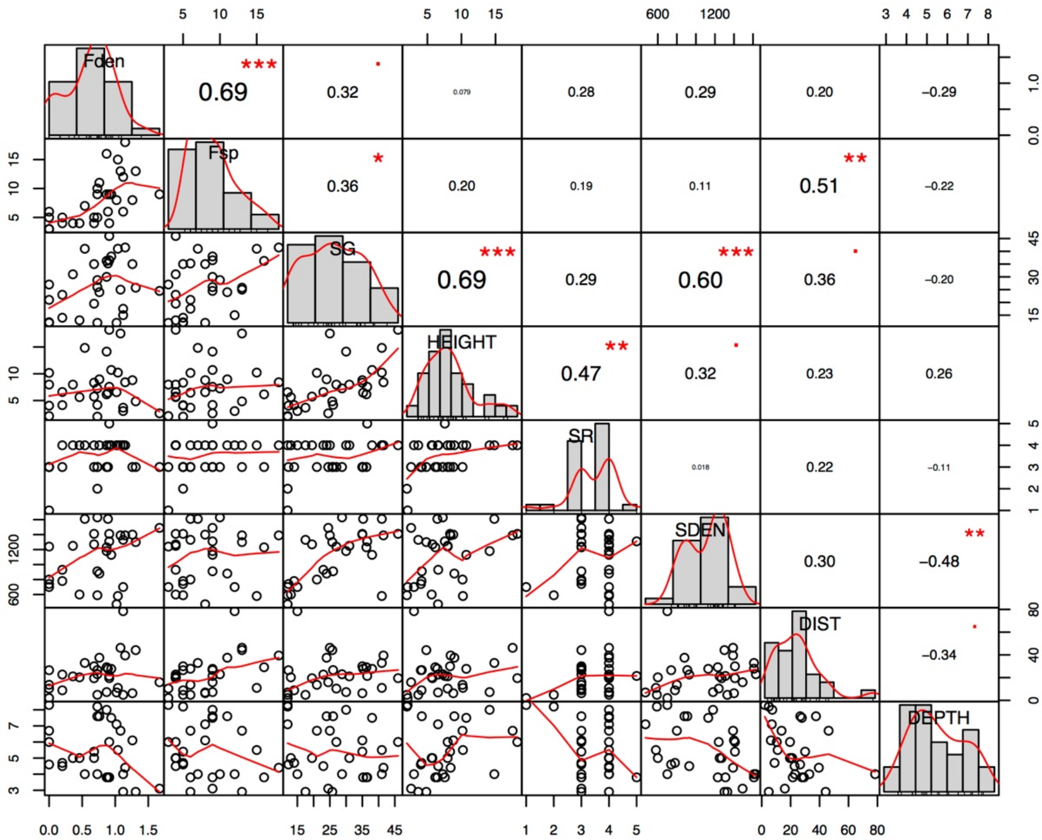


Figure 4.7: Scatterplot matrix between forereef seagrass habitat attributes with fish density (Fden) and fish species richness (Fsp) in Spearman's rank correlation coefficient. The strength of correlation coefficient (r) represented by the number on the upper right, where coefficient between .10 and .29 represent a weak relationship, coefficients between .30 and .49 represent a moderate relationship, and coefficients of .50 and above represent a strong relationship. Significant level of p-value is labelled with red * on right corner (p<0.05 = *, p<0.01=**, p<0.001=***). (SG = seagrass percent cover; HEIGHT= canopy height; SR= species richness; SDEN = shoot density; DIST= distance to adjacent coral reefs; DEPTH= water depth).

Spearman rank correlation plots showed positive correlations between seagrass percent cover and fish density (r=0.32, p<0.05) and fish species richness (r=0.36, p<0.05). Fish species richness also showed significant positive correlation with distance to adjacent coral reefs (r=0.51, p<0.01). This relationship indicated that as the distance to adjacent coral reefs or seagrass percent cover increases, fish species richness tend to increase. There was a strong positive relationship between fish density and fish species richness (r=0.69, p<0.001) (Figure 4.8).

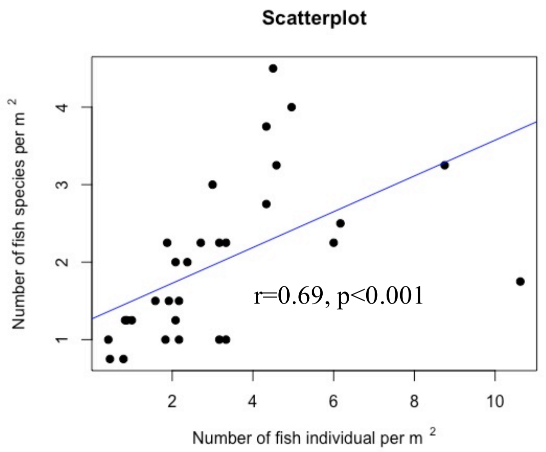


Figure 4.8: Scatterplot of correlations between fish density and fish species richness with Spearman's rank correlation coefficient (r) and p-value significance level.

There were strong positive relationships between seagrass percent cover with shoot density (r=0.60, p<0.001) and canopy height (r=0.69, p<0.001) (Figure 4.9 a & b). Additionally, there was a moderate positive correlation between seagrass percent cover and distance to adjacent coral reefs (r=0.36, p<0.05).

Water depth was negatively correlated with shoot density (r= -0.48, p<0.01). This indicates that as the water depth increases, the shoot density tends to decrease. All the habitat attributes that showed significant correlation with fish data will be considered as important predictors in the multiple regression analysis.

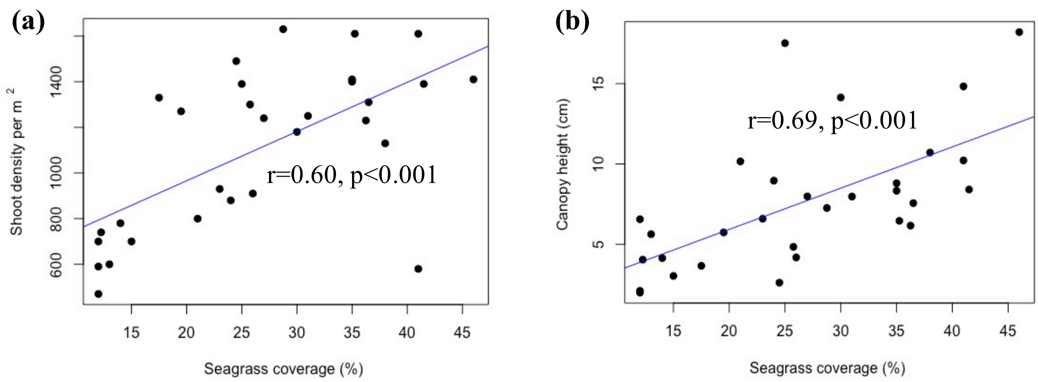


Figure 4.9: Scatterplot of correlations between habitat attributes (a) seagrass percent cover VS shoot density and (b) seagrass percent cover VS canopy height, with Spearman's rank correlation coefficient (r) and p-value significamce levels.

4.2.3 Generalized Linear Model (GLM) Analyses

Multiple regression analysis was used to identify the important predictors for fish community in the seagrass habitat. Generalized Linear Model (GLM) was performed in a Gaussian family and identity link on transformed Log fish density and fish species richness with seagrass percent cover and canopy height (Table 4.7). With a low number of samples (n=30), only explanatory variables with significant relationships with independent variables from the Spearman's rank correlation analysis (Figure 4.7) were selected into the model testing with habitat configurations (distance to adjacent coral reefs and water depth) as covariates. A total of 30 sampling quadrats for forereef seagrass sampling quadrats were used in the analyses.

Table 4.7: Results of Generalized Linear Models (GLMs) that best fit the variation in Log (x+1) transformed fish density and fish species richness models performed on seagrass percent cover (SG), distance to adjacent coral reefs (DIST) and water depth (DEPTH). A stepwise approach to determine the optimal set of explanatory variables in best-fit GLM based on both lowest Akaike Information Criterion (AIC) and lowest residual deviance is shown in Appendix VI. Analysis of Variance (ANOVA) was performed to analyse significant change of deviance from each explanatory variable. Total Deviance incorporated only variables with significant contributions to the model. Model goodness-of-fit was measured by percentage of adjusted D^2 (Adj D^2), adjusted for the number of parameters and observations.

Source of variation	**df**	**Estimate**	**Deviance**	**F**	**p (>|F|)**	**% of explained deviance**	**AIC**	**Adj D^2**
Log (Fish density +1)					**Total deviance explained= 37.45%**			
SG	1	0.56919	0.39721	10.550	**	**24.44**		
DIST	1	0.46387	0.21145	5.516	*	**13.01**		
Residual	27		1.0166			62.55		
Null	29		1.6252			100.00	**-8.4066**	**30.23**
Log (Fish species richness +1)					**Total deviance explained= 34.46%**			
SG	1	0.15687	0.03652	5.0383	*	**12.23**		
DIST	1	0.25993	0.06639	9.1606	**	**22.23**		
Residual	27		0.19568			65.53		
Null	29		0.29859			100.00	**-57.838**	**26.90**

df: degree of freedom
p: *** p <0.001, ** p <0.01, * p <0.05, ns p >0.05
Adj D^2: proportion of variation explained by habitat variables.
AIC: Akaike Information Criterion (lowest AIC value = a better model)

Fish density in seagrass habitat

Generalized linear model analysis of fish density in seagrass habitat fitted to Log (x+1) fish density and explanatory variables of seagrass percent cover, distance to adjacent habitat and water depth. The best-fit model explained 37.45% of the total deviance (adjusted D^2= 30.23, AIC= -8.4066) (Table 4.7). The best-fit model's total deviance was contributed by the significant terms of seagrass percent cover (24.44%) and distance to adjacent habitat (13.01%). Based on the best-fit GLM model, fish density showed positive linear regression with seagrass percent cover (R^2=0.20) (Figure 4.10 a) and distance to adjacent habitat (R^2=0.17) (Figure 4.10 b).

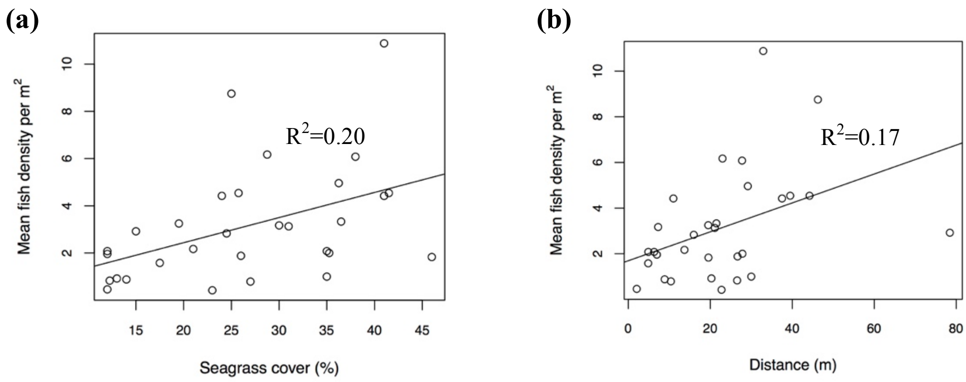


Figure 4.10: Scatterplot of best fit model of fish density in seagrass habitat with (a) seagrass percent cover, (b) distance to adjacent habitat.

Fish species richness in seagrass habitat

Generalized linear model analysis of fish species richness in seagrass habitat was fitted to Log (x+1) fish species richness and the explanatory variables of seagrass percent cover, distance to adjacent habitat and water depth. The best-fit model with two variables significantly contributed to explained 34.46% of the total deviance (adjusted D^2= 26.90, AIC= -57.838). Distance to adjacent habitat (22.23%) has the more substantial contribution to the total deviance of the model than seagrass percent cover (12.23%) (Table 4.7). From the best-fit GLM model, fish species richness showed positive linear regression with seagrass percent cover (R^2=0.11) (Figure 4.11 a) and distance to adjacent habitat (R^2=0.28), (Figure 4.11 b).

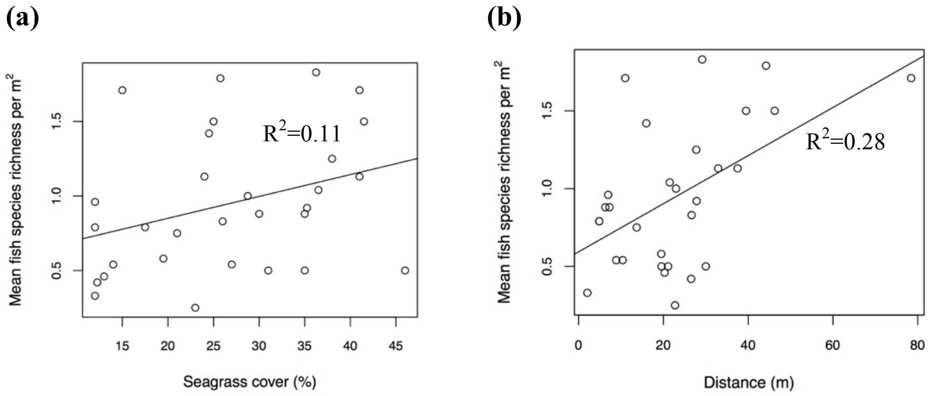


Figure 4.11: Scatterplot of best fit GLM of fish species richness in seagrass habitat with (a) seagrass percent cover and (b) distance to adjacent habitat.

4.2.4 Canonical Correspondence Analysis (CCA)

The relationships between habitat variables (shoot density, seagrass percent cover and canopy height) and fish diversity (19 species fish with ≥ 3 occurrence in samples or 21 % of the total fish species) that was categorised to three feeding guilds (omnivores, herbivores and carnivores) (Table 4.8), were examined in a Canonical Correspondence Analysis (CCA) ordination. Structural complexity index showed multicollinearity (VIF > 20) and was excluded from the CCA.

Table 4.8: List of selected fish species in seagrass habitat for Canonical Correspondence Analysis (CCA) with ≥ 3 occurrence in the samples. (Feeding guilds, H: Herbivore; C: Carnivore; O: Omnivore)

No.	Guild	Family	Acronyms	Fish species	Common name
1	C	Gobiidae	Ccct	*Cryptocentrus cinctus*	Yellow shrimp-goby
2	C	Labridae	Hngr	*Halichoeres nigrescens*	Bubblefin wrasse
3	C	Labridae	WUKW	Labridae sp 26	Wrasse unknown
4	C	Lethrinidae	Lvar	*Lethrinus variegatus*	Slender emperor
5	C	Microdesmidae	Pmlt	*Pleteleotris microleptis*	Green dartfish
6	C	Mullidae	Utra	*Upeneus tragula*	Freckled goatfish
7	C	Nemipteridae	Psts	*Pentapodus setosus*	Butterfly whiptail
8	C	Nemipteridae	Safn	*Scolopsis affnis*	Peters' Monocle bream
9	C	Nemipteridae	Sart	*Scolopsis aurata*	Yellowstripe monocle bream
10	C	Nemipteridae	Smng	*Scolopsis monogramma*	Monogrammed monocle bream
11	H	Siganidae	Scnc	*Siganus canaliculatus*	White-spotted spinefoot
12	O	Blenniidae	Pbvp	*Petroscirtes breviceps*	Shorthead fangblenny
13	O	Carangidae	Cfed	*Carangoides ferdau*	Blue trevally
14	O	Chaetodontidae	Poce	*Parachaetodon ocellatus*	Sixspine butterflyfish
15	O	Gobiidae	Gbi1	Gobiidae sp 1	Goby sp1
16	O	Gobiidae	Gbi2	Gobiidae sp 2	Goby sp2
17	O	Gobiidae	Gbi4	Gobiidae sp 4	Goby sp4
18	O	Lethrinidae	Ejv1	Emperor juv 1	Emperor fish
19	O	Monacanthidae	Atmt	*Acreichthys tomentosus*	Bristle-tail file-fish

The eigenvalues for the first two CCA axes were 0.32 and 0.28 respectively. The Monte Carlo permutation test showed a significant relationship between the species abundance matrix and the habitat variables matrix for the nine CCA axes ($F = 1.28$, $p<0.05$), explaining 34.04% of total data variation. The first two axes explained 54.12% of the total variation, with the first axis explaining 11.11% of the total inertia ($F = 3.28$, $p < 0.05$), and the second axis explaining 10.00% of the total inertia ($F=2.95$, $p<0.01$). The explained variance of the species-environment relationship was 28.48% and 25.63% for CCA axes 1 and 2, respectively (Table 4.9 & Figure 4.12). There were two habitat variables, *H. ovalis* percent cover ($F=1.81$, $p<0.05$) and *S. isoetifolium* percent cover ($F=1.79$, $p<0.05$) that showed significant contribution to the formation of the two axes in this model.

CCA showed that *S. isoetifolium* and *H. univervis* seagrass species were more associated with canopy height but opposite for low canopy *H. ovalis* and there was no significant association found between fish feeding guilds and seagrass habitat complexity attributes by species.

Table 4.9: Summary of canonical correspondence analysis (CCA) results comparing the species level habitat variables matrix and the fish species matrix of the forereef seagrass meadows.

	Axis 1	Axis 2	Total inertia
Eigenvalues	0.32	0.28	3.25
Species-environments correlations	0.86	0.74	
Cumulative percentage variance of species data	11.11	21.11	
Cumulative percentage variance of species–environment relationship	28.48	54.12	
Monte Carlo permutation test	F=3.28 **p<0.05***	F=2.95 **p<0.01****	
Sum of constrained eigenvalues			1.12

CCA model $R^2=0.34$; adjusted-$R^2=0.11$

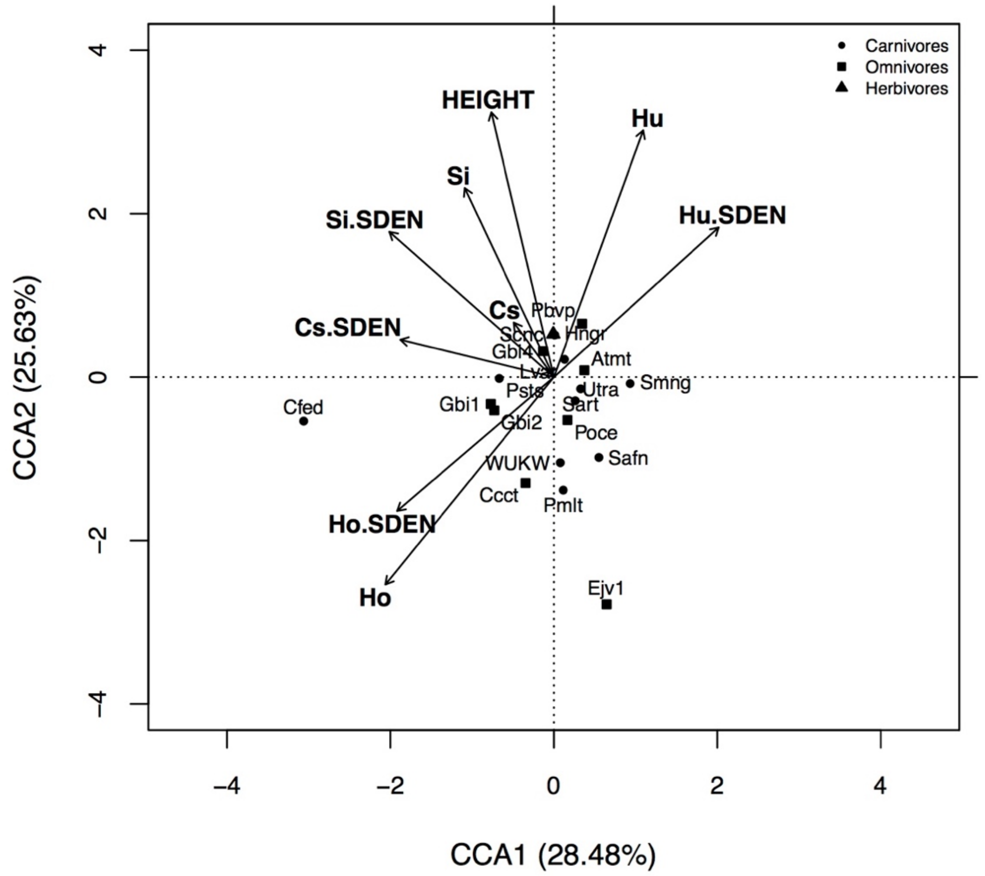


Figure 4.12: Canonical Correspondence Analysis (CCA) ordination plot of fish diversity in forereef seagrass fitted to species level habitat variables (arcsine transformed percent cover and shoot density) and distance to adjacent habitat and water depth. Site data were not plotted in to show better the relationship between abundance and environment variables. Arrows correspond to habitat variables, Ho: *H. ovalis* percent cover; Hu: *H. uninervis* percent cover; Cs: *C. serrulata* percent cover; Si: *S.isoetifolium* percent cover; Ho.SDEN: *H. ovalis* shoot density; Hu.SDEN: *H. uninervis* shoot density; Cs.SDEN: *C. serrulata* shoot density; Si.SDEN: *S.isoetifolium* shoot density; HEIGHT: Canopy Height. Fish species are categorized into three feeding guilds (carnivores, omnivores and herbivores) by symbols (circle, square and triangle). Fish species (only 19 species plotted here) are represented by symbols with letter codes. **Atmt**: *Acreichthys tomentosus*; **Cfed**: *Carangoides ferdau*; **Ccct**: *Cryptocentrus cinctus*; **Ejv1**: Emperor juv 1; **Gbi1**: Goby sp 1; **Gbi2**: Goby sp 2; **Gbi4**: Goby sp 4; **Hngr**: *Halichoeres nigrescens*; **Lvar**: *Lethrinus variegatus*; **Pbvp**: *Petroscirtes breviceps*; **Poce**: *Parachaetodon ocellatus*; **Psts**: *Petapodus setosus*; **Pmlt**: *Pleteleotris microleptis*; **Safn**: *Scolopsis affnis*; **Sart**: *Scolopsis aurata*; **Smng**: *Scolopsis monogramma*; **Scnc**: *Siganus canaliculatus*; **Utra**: *Upeneus tragula*; **WUKW**: Unidentified wrasse.

4.3 Fish-habitat relationships in coral reef habitat

4.3.1 Habitat complexity attributes in coral reef habitat

In the coral reefs, there was a total of 39 quadrats deployed at Tinggi Island (n=15) and Babi Besar Island (n=24). However, data for only 31 quadrats were used for statistical analyses. Four quadrats data had to be removed due to sampling error, in the event where RUVS was not recorded or video frame had deviated from quadrat frame, and another 4 quadrats data were eliminated after outlier test due to extreame number of schooling fish presence in the quadrats.

In the coral reef habitat, the response variables (also known as dependent variables) were fish community data consisting of fish density and fish species richness, whereas all the habitat complexity attributes were the explanatory variables (also known as independent variables) (Table 4.10 & Appendix IV). Coral reef habitat complexity attributes consisted of growth form percent cover, substrate percent cover and complexity measures including coral genus richness and rugosity. The growth forms of coral were classified into seven types. The most common growth forms found in the study sites were branching (B) and plates (Pl) with average percent cover of up to 14.02 ± 3.19% and 14.64 ± 3.12% respectively. This was followed by massive (M) and sub-massive (SubM) growth forms with 6.11 ± 1.41% and 5.33 ± 1.55% percent cover, repectively. Encrusting (En), free-living (Fl) and foliose (Fo) were the least common growth forms present in the study site.

The habitat substrate types in coral reefs comprised mainly hard coral (HC) at 47.40 ±3.45%, followed by rock (RC) and rubble (RB) with percent cover of 22.84 ±3.24% and 20.42 ±3.97%, respectively. There was low substrate percent cover of sand (SD), other (OT) and dead coral (DC).

Table 4.10: List of fish community and coral habitat complexity attributes and habitat configuration with unit of measurement, mean and standard error.

	Variables	Unit of measurement	n	Mean ± S.E.
Response variables	**Fish community**			
	Fish density	No. of individuals per m^2	31	4.13 ± 0.93
	Fish species richness	No. of species per m^2	31	1.51 ± 0.17
Explanatory variables	**Habitat Complexity**			
	Coral genus richness	No. of genera	31	12.07 ± 0.69
	Rugosity	$r = \frac{\text{coral surface length}}{\text{quadrat length}}$	31	1.68 ± 0.05
	Substrate percent cover			
	Hard coral (HC)	cover %	31	47.40 ± 3.45
	Dead coral (DC)	cover %	8	0.84 ± 0.28
	Rock (RC)	cover %	29	22.84 ± 3.24
	Rubble (RB)	cover %	24	20.42 ± 3.97
	Sand (SD)	cover %	22	6.08 ± 3.16
	Other (OT)	cover %	25	2.65 ± 0.65
	Coral growth form percent cover			
	Branching (B)	cover %	29	14.02 ± 3.19
	Massive (M)	cover %	28	6.11 ± 1.41
	Foliose (Fo)	cover %	19	1.73 ± 0.61
	Sub-massive (SubM)	cover %	25	5.33 ± 1.55
	Plates (Pl)	cover %	30	14.64 ± 3.12
	Encrusting (En)	cover %	29	3.05 ± 0.66
	Free-living (Fl)	cover %	24	2.48 ± 0.77
	Configuration			
	Distance to adjacent seagrass habitat	metre	31	15.03 ± 4.37
	Other measurement			
	Water depth	metre	31	1.13 ± 0.07

Measurements of coral genus richness and reef rugosity were included in habitat complexity. A total of 1,096 photos of coral individuals from all the quadrats were identified to 48 genera from 17 families (see Appendix V). Overall, mean coral genus richness from the study sites on average were 12 genera per quadrat. Reef rugosity index from 31 sampling quadrats had an average of 1.68 ±0.05, ranging from the least rugose reef at 1.025 to the most rugose reef at 2.39.

The distance to the adjacent habitat was one of the measurement for habitat configuration and other measurement taken during sampling was water depth of each quadrat. The habitat complexity attributes were explanatory variables that were tested against response variables of fish density and fish species richness in GLMs with habitat configuration and water depth as the covariates. The substrate of coral reefs in Tinggi Island and Babi Besar Island was dominated by hard coral (47%), rock (23%) and rubble (20%) (Table 4.10). The study sites had fair condition of coral cover, with relatively high percent cover compared to Malaysian reefs in general which were reported to have an average of 45.95% in 2015 (Reef Check Malaysia (2015). There were seven types of hard coral growth forms on the reefs, with the plate-like coral averaging 14.0% (31% of the hard coral) and 14.6% for branching (30% of the hard coral), with both growth forms being the dominant types in the study sites (Figure 4.13). Reef rugosity index from the study sites ranged between 1.025 to 2.39 with an average of 1.68 ±0.05 indicating a range of rugosity from low to medium-high.

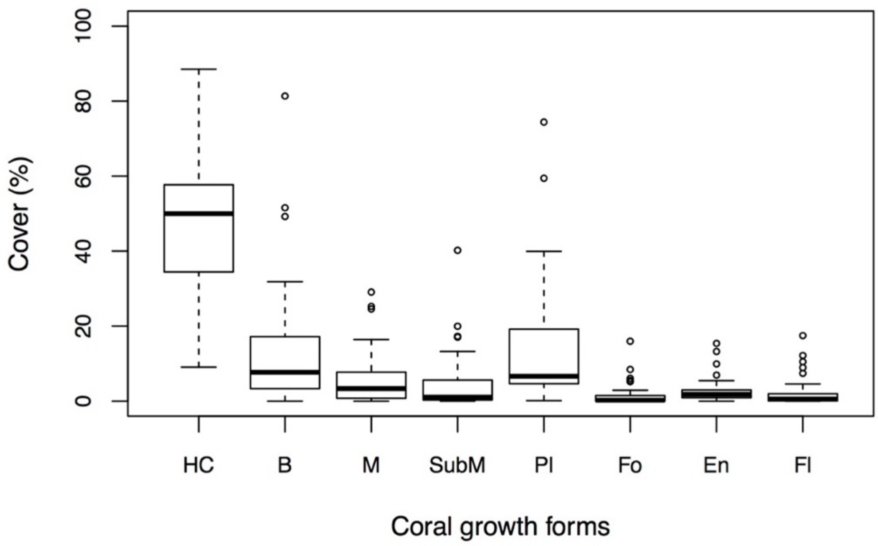


Figure 4.13: Mean coral growth forms percent cover in study sites (n=31). HC= Hard Coral; B=Branching; M=Massive; SubM= Sub-Massive; Pl= Plates; Fo= Foliose; En= Encrusting; Fl= Free-living.

Study sites recorded high coral diversity of 17 families and 48 genera (Appendix V). The dominant coral genera found were *Acropora* (Acroporiidae) with the highest occurrence frequency of 95% from the sampling quadrats, *Porites* (Poritidae) with 82%, *Favia* (Faviidae) and *Fungia* (Fungiidae) both with 72%, and *Montipora* (Acroporiidae) with 64% of occurrence frequency. *Acropora* was represented mostly by the branching coral and *Porites* commonly found with massive growth forms.

4.3.2 Spearman's rank correlation analysis

A) <u>Habitat attributes</u>

The scatterplot matrix and Spearman's rank correlation between coral reefs habitat attributes with fish density and fish species richness showed that fish density and fish species richness were significantly correlated with a positive relationship ($r=0.54$, $p<0.01$) (Figure 4.14). Fish density is statistically significant with a moderate positive linear relationship with live coral cover ($r=0.38$, $p<0.05$). There was no significant relationship in fish species richness with all habitat attribute variables. Hard coral cover was significantly correlated with water depth in a positive relationship ($r=0.34$, $p<0.05$), whereby live coral cover increase as water depth increases.

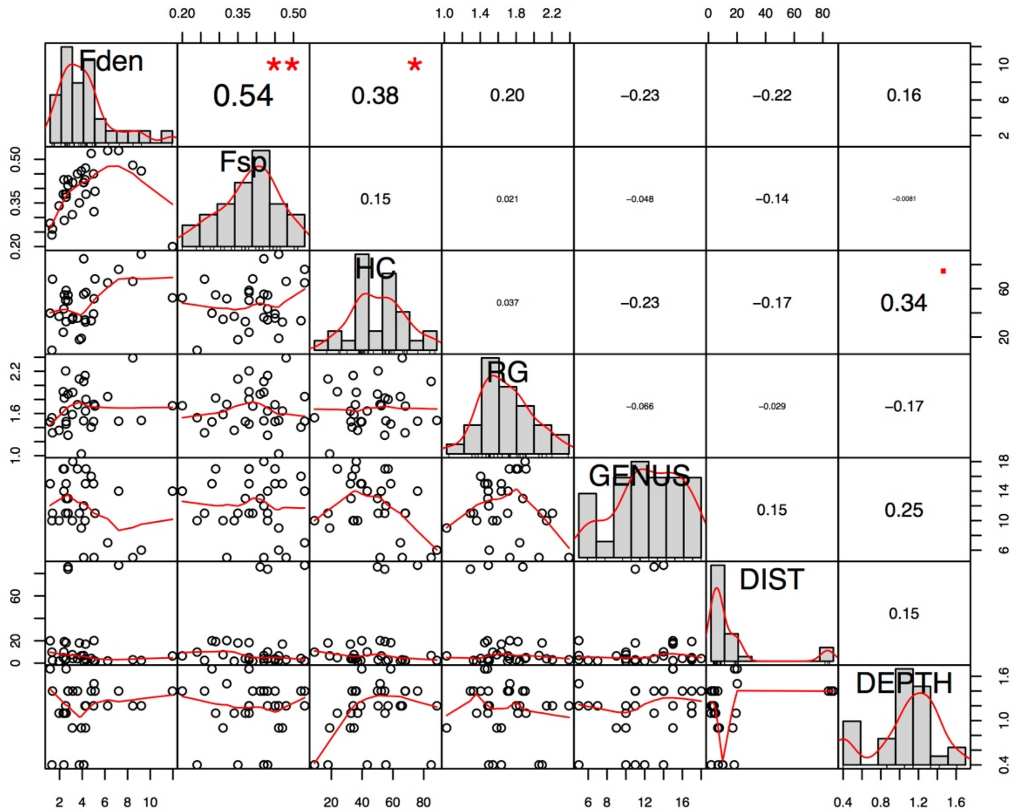


Figure 4.14: Scatterplot matrix between coral reef habitat attributes with fish density (Fden) and fish species richness (Fsp) using Spearman's rank correlation coefficient. The strength of correlation coefficient (r) is shown in the number on the upper right, where coefficient between .10 and .29 represent a weak relationship, coefficients between .30 and .49 represent a moderate relationship, and coefficients of .50 and above represent a strong relationship. Significant level of p-value is labelled with red * on right corner ($p<0.05$ = *, $p<0.01$=**, $p<0.001$=***). (HC= hard coral; RG= rugosity; GENUS= coral genus richness; DIST= proximity to adjacent seagrass; DEPTH= water depth).

B) Substrate types cover

Spearman's rank correlation between coral reefs substrate types cover and fish density data (Figure 4.15) showed no significant correlations with substrate types except for hard coral cover ($r=0.38$, $p<0.05$). Fish species richness showed a weak negative correlation with rubble percent cover ($r=-0.32$, $p<0.05$). In the natural environment, there was a significant negative correlation between hard coral and rubble ($r= -0.53$, $p<0.01$), and similarly for hard coral and sand ($r=-0.53$, $p<0.01$).

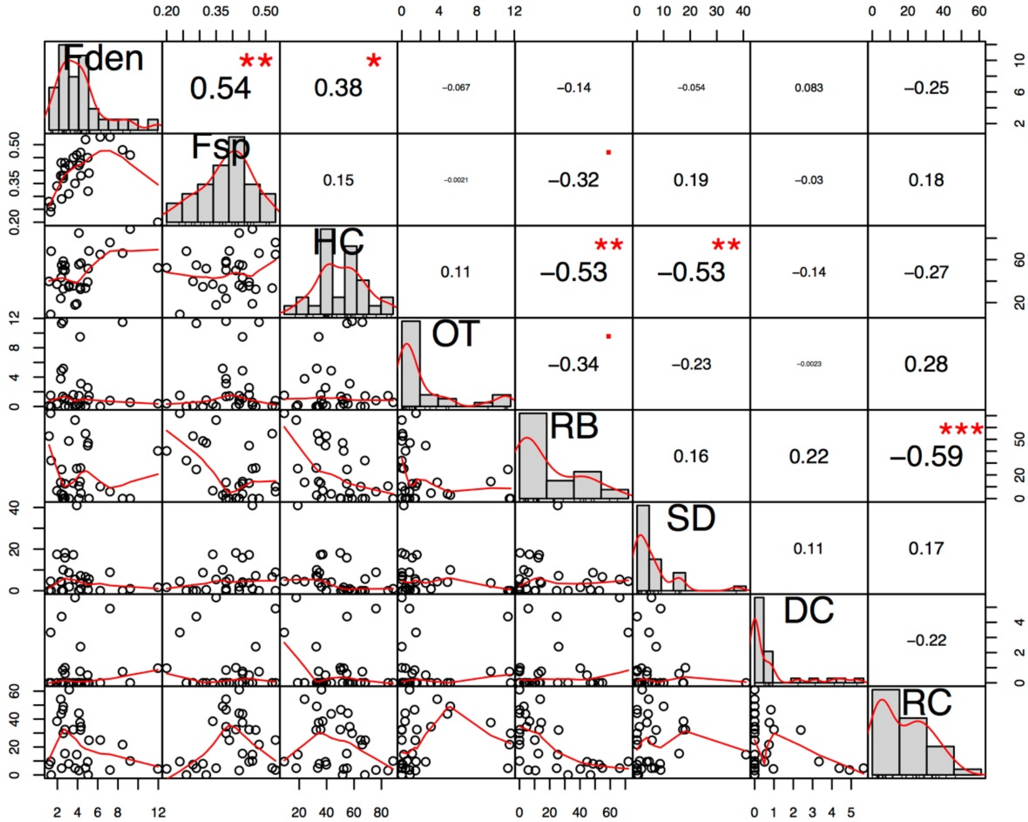


Figure 4.15: Scatterplot matrix between substrate types cover with fish density (Fden) and fish species richness (Fsp) using Spearman's rank correlation coefficient. The strength of correlation coefficient (r) represent in the number on the upper right, where coefficient between .10 and .29 represent a weak relationship, coefficients between .30 and .49 represent a moderate relationship, and coefficients of .50 and above represent a strong relationship. Significant level of p-value is labelled with red * on right corner ($p<0.05$ = *, $p<0.01$=**, $p<0.001$=***). (HC= hard coral; OT= other; RB=rubble; SD=sand; DC= dead coral; RC= rock).

4.3.3 Generalized Linear Model (GLM) Analyses

Generalized Linear Model (GLM) was performed for a total of 28 sampling quadrats after outlier removal from the distance to adjacent seagrass where distance > 80m.

Fish density in coral reefs habitat

Generalized linear model analysis of fish density in coral reef was performed on Log fish density with habitat variables of hard coral percent cover (HC), distance to adjacent habitat (DIST) and water depth (DEPTH). The best-fit model with hard coral variable significantly contributed to the GLM explaining 16.49% of the total deviance (adjusted D^2= 9.81%, AIC= -0.0418) (Table 4.11). From the best-fit model, fish density showed positive linear regression with hard coral percent cover (R^2=0.18, r=0.43) (Figure 4.16).

Table 4.11: Results of Generalized Linear Models (GLM) that best fit the variation in Log transformed fish density model performed on hard coral (HC) and fish species richness model performed on rubble (RB), with added covariates distance to adjacent habitat (DIST) and water depth (DEPTH) to both model. A stepwise approach was used to determine the optimal set of explanatory variables based on both lowest Akaike Information Criterion (AIC) and lowest residual deviance. Analysis of Variance (ANOVA) was performed to analyse significant change of deviance from each explanatory variable (Appendix VII). Model goodness-of-fit was measured by adjusted D^2 (Adj. D^2). Total Deviance explained by the best fit model incorporating only variables with significant contribution of deviance explained in the model.

Source of variation	df	Estimate	Deviance	F	p (>|F|)	% of explained deviance	AIC	Adj D^2
Log Fish density					**Total deviance explained= 16.49%**			
HC	1	0.5109	0.2610	5.1357	*	**16.49**		
Residual	26		1.3212			83.50		
Null	27		1.5822			100.00	**-0.0418**	**9.81**
Fish species richness					**Total deviance explained= 14.08%**			
RB	1	-0.8943	0.7998	4.2614	*	**14.08**		
Residual	26		4.8799			84.34		
Null	27		5.6797			100.00	**36.542**	**7.21**

df: degree of freedom
p: *** p <0.001, ** p <0.01, * p <0.05, ns p >0.05
adj D2: proportion of variation explained by habitat variables (negative value= model is a worse representation than the Null model).
AIC: Akaike Information Criterion (lowest AIC value = a better model).

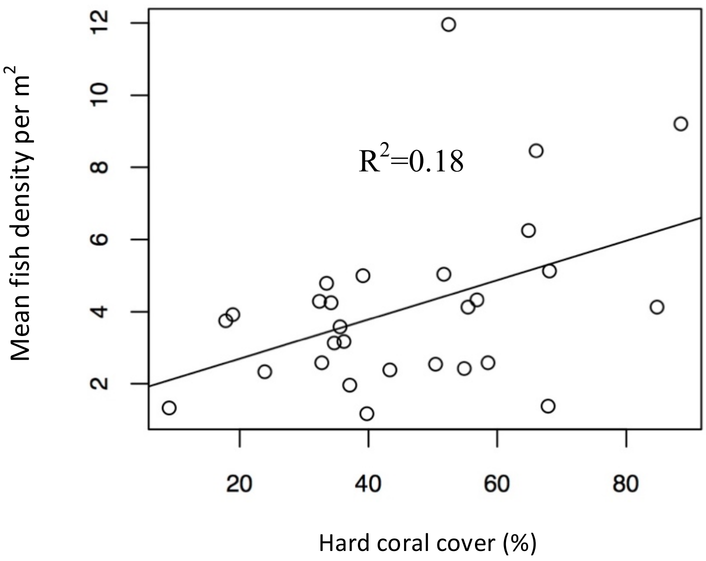


Figure 4.16: Best-fit Generalized Linear Model (GLM) for fish density in coral reefs plotted against hard coral (HC) percent cover.

Fish species richness in coral reef habitat

Generalized linear model analysis of fish species richness in coral reefs was performed on fish species richness with habitat variables of rubble percent cover (RB), distance to adjacent habitat (DIST) and water depth (DEPTH). After stepwise backward regression based on Akaike Information Criterion (AIC) was run on the tested model, a best-fit model with selected habitat attribute of rubble percent cover (RB) showed a significant contribution to the GLM with 14.08% of the total deviance explained (adjusted D^2=7.21%, AIC=36.542) (Table 4.11). From the best-fit model, fish species richness showed negative linear regression with rubble percent cover (R^2=0.14, r=-0.38) (Figure 4.17).

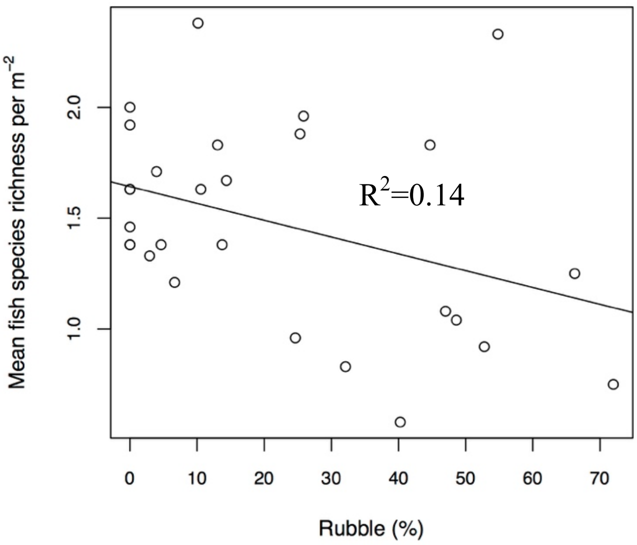


Figure 4.17: Best-fit Generalized Linear Model (GLM) for fish species richness in coral reefs plotted against rubble (RB).

4.3.4 Canonical Correspondence Analysis (CCA)

The relationships between habitat variables (Arcsine percent cover of sand, live coral cover, rock, rubble, dead coral and other; rugosity; coral genus) and coral growth form variables (Arcsine percent cover of branching, massive, sub-massive, plates foliose, encrusting and free-living; rugosity; coral genus) with fish community (49 fish taxa with ≥ 3 occurrences in samples or 37 % of the total fish species listed in Table 4.12) that was categorised to feeding guild (herbivores, carnivores and omnivores) were examined in a Canonical Correspondence Analysis (CCA) ordination with distance to adjacent habitat and depth as covariates. Structural complexity index showed multicollinearity (VIF > 20) and was excluded from the CCA.

Table 4.12: List of selected fish species in coral reefs habitat for Canonical Correspondence Analysis (CCA) with ≥ 3 occurrences in the samples (Feeding guilds, O: Omnivore; H: Herbivore; C: Carnivore).

No.	Guild	Family	Acronyms	Fish species name	Common name
1	C	Apogonidae	Cmac	*Cheilodipterus macrodon*	Large toothed cardinalfish
2	C	Caesionidae	Ccng	*Caesio cuning*	Yellowtail fusilier
3	C	Caesionidae	Cter	*Caesio teres*	Yellow and blueback fusilier
4	C	Haemulidae	Pcst	*Plectorhinchus chrysotaenia*	Yellow-stripped sweetlips
5	C	Holocentridae	Srbm	*Sargocentron rubrum*	Red-coast squirrelfish
6	C	Labridae	Cclr	*Cheilinus chlorourus*	Floral wrasse
7	C	Labridae	Cfcs	*Cheilinus fasciatus*	Red-breasted wrasse
8	C	Labridae	Dxan	*Diproctacanthus xanthurus*	Yellowtail tubelip
9	C	Labridae	Hleu	*Halichoeres leucurus*	Greyhead wrasse
10	C	Labridae	Hngr	*Halichoeres nigrescens*	Bublefin wrasse
11	C	Labridae	Hsp1	*Halichoeres* sp 1	Halichoeres wrasse sp 1
12	C	Labridae	Hsp2	*Halichoeres* sp 2	Halichoeres wrasse sp 2
13	C	Labridae	Lab1	Labridae sp 1	Wrasse sp 1
14	C	Labridae	Lab6	Labridae sp 6	Wrasse sp 6
15	C	Labridae	Lab7	Labridae sp 7	Wrasse sp 7
16	C	Labridae	Ldmd	*Labroides dimidiatus*	Bluestreak cleaner wrasse
17	C	Labridae	Hsp3	*Halichoeres* sp 3	Halichoeres wrasse sp 3
18	C	Labridae	Lab10	Labridae sp 10	Wrasse sp10
19	C	Labridae	Lab23	Labridae sp 23	Wrasse sp 23
20	C	Labridae	Lab24	Labridae sp 24	Wrasse sp 24
21	C	Lutjanidae	Llutn	*Lutjanus lutjanus*	Bigeye snapper
22	C	Lutjanidae	Lrus	*Lutjanus russelli*	Russell’s snapper

Table 4.12, continued.

No.	Guild	Family	Acronyms	Fish species name	Common name
23	C	Nemipteridae	Sclt	*Scolopsis ciliatus*	Whitestreak monocle bream
24	C	Nemipteridae	Smgr	*Scolopsis margaritifer*	Pearly monocle bream
25	C	Pempheridae	Pols	*Pempheris oualensis*	Silver sweeper
26	C	Pomacentridae	Acrc	*Amblyglyphidodon curacao*	Staghorn damselfish
27	C	Pomacentridae	Asfc	*Abudefduf sexfasciatus*	Scissortail sergeant
28	C	Pomacentridae	Asp1	*Abudefduf* sp1	Sergeant sp 1
29	C	Pomacentridae	Avgs	*Abudefduf vaigiensis*	Indo-Pacific sergeant
30	C	Serranidae	Cbnk	*Cephalopholis boenak*	Brown barred grouper
31	C	Serranidae	Cctg	*Cephalopholis cyanostigma*	Bluespotted grouper
32	H	Scaridae	Ssp1	*Scarus* sp 1	Parrotfish sp 1
33	H	Scaridae	Ssp2	*Scarus* sp 2	Parrotfish sp 2
34	H	Scaridae	Ssp3	*Scarus* sp 3	Parrotfish sp 3
35	H	Scaridae	Scd4	Scaridae sp 4	Parrotfish sp 4
36	O	Carangidae	Cfed	*Carangidae ferdau*	Blue trevally
37	O	Chaetodontidae	Cofs	*Chaetodon octofasciatus*	Eightband butterflyfish
38	O	Chaetodontidae	Crts	*Chelmon rostatus*	Beaked coralfish
39	O	Labridae	Tlnr	*Thalassoma lunare*	Moon wrasse
40	O	Pomacentridae	Aocl	*Amphiprion ocellaris*	Clown anemonefish
41	O	Pomacentridae	Dms1	Pomacentridae sp 1	Damselfish sp 1
42	O	Pomacentridae	Dms4	Pomacentridae sp 4	Damselfish sp 4
43	O	Pomacentridae	Nngr	*Neoglyphidodon nigroris*	Black and gold chromis
44	O	Pomacentridae	Npmcr	*Neopomacentrus*	Neopomacentrus damselfish
45	O	Pomacentridae	Nsp2	*Neoglyphidodon* sp 2	Chromis sp 2
46	O	Pomacentridae	Palxc	*Pomacentrus alexandeae*	Alexander’s damselfish
47	O	Pomacentridae	Pmlc	*Pomacentrus moluccensis*	Lemon damselfishDamselfish
48	O	Pomacentridae	Prcd	*Pomachromis richardsoni*	Richardson’s damselfish
49	O	Pomacentridae	Dms6	Pomacentridae sp 6	Damselfish sp 6

A) CCA habitat variables by substrate types

The eigenvalues for the first two CCA axes were 0.50 and 0.28, respectively. The Monte Carlo permutation test showed a significant relationship between the species abundance matrix and the habitat variables matrix for the five CCA axes (F = 1.70, p<0.05), explaining 23.38% of total data variation. The first two axes explained 15.58% of the total variation, with the first axis explaining 10% of the total inertia (F = 2.33, p < 0.01), and the second axis explaining 5.63% of the total inertia (F=1.78, p=0.17) (Figure 4.18). The explained variance of the species-environment relationship was 36.70% and 20.82% for CCA axes 1 and 2, respectively (Table 4.13). There were two habitat variables, hard coral (F=2.33, p<0.05) and rubble (F=2.45, p<0.05) that showed significant contribution to the formation of the two axes in this model.

Table 4.13: Summary of canonical correspondence analysis (CCA) results comparing the habitat variables matrix and the fish species matrix of the coral reefs.

	Axis 1	Axis 2	Total inertia
Eigenvalues	0.50	0.28	5.855
Species-environments correlations	0.88	0.78	
Cumulative percentage variance of species data	9.94	15.58	
Cumulative percentage variance of species–environment relationship	36.70	57.52	
Monte Carlo permutation test	F=2.33 **p<0.01****	F=1.78 **NS**	
Sum of constrained eigenvalues			1.369

CCA model R^2=0.23; adjusted-R^2=0.08.

The CCA (Figure 4.18) showed species-specific preference for certain habitat complexity attributes, where *C. marcordon*, *C. cuning*, *L. lutjanus*, *P. oualensis* and *P. moluccensis* were found to be associated with hard coral cover; *C. chlorourus* was associated with rugosity and the opposite was sand showing association with *C. boenak*. In summary, fish species richness decreased as rubble increased. There was no significant association found between fish feeding guilds and habitat complexity attributes.

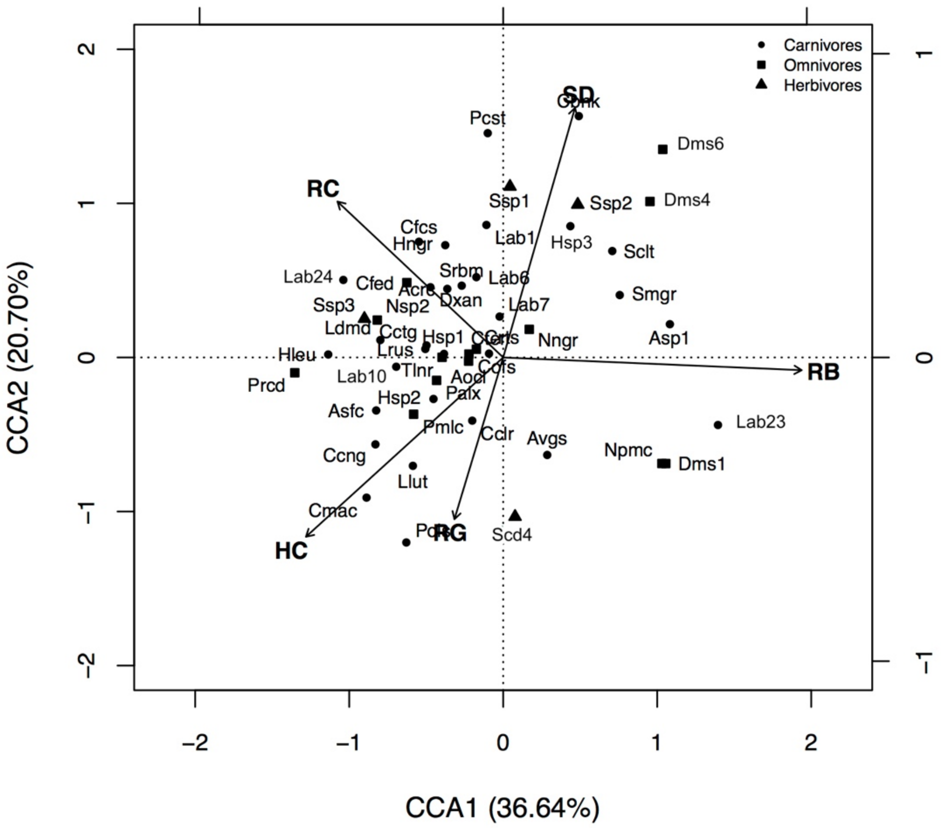


Figure 4.18: Canonical Correspondence Analysis (CCA) ordination plot of habitat variables and fish diversity in coral reefs with distance to adjacent habitat and depth as covariates. Arcsine transformed percent cover of SD: Sand; HC: Hard coral; RC: Rock; RG: Rugosity; RB: Rubble. Fish species are categorized into three feeding guilds (carnivores, omnivores and herbivores) by symbols (circle, square and triangle). Species (only 49 species plotted here) are represented by letter codes. Fish species list **Asfc**: *Abudefduf sexfasciatus*; **Asp1**: *Abudefduf sp1*; **Avgs**: *Abudefduf vaigiensis*; **Acrc**: *Amblyglyphidodon curacao*; **Aocl**: *Amphiprion ocellaris*; **Ccng**: *Caesio cuning*; **Cter**: *Caesio teres*; **Cfed**: *Carangidae ferdau*; **Cbnk**: *Cephalopholis boenak*; **Cctg**: *Cephalopholis cyanostigma*; **Cofs**:*Chaetodon octofasciatus*; **Cclr**: *Cheilinus chlorourus*; **Cfcs**:*Cheilinus fasciatus*; **Cmac**:*Cheilodipterus macrodon*; **Crts**:*Chelmon rostatus*; **Dms1**: Damselfish sp 1; **Dms4**: Damselfish sp 4; **Dms6**: Damselfish sp 6; **Dxan**: *Diproctacanthus xanthurus*; **Hleu**:*Halichoeres leucurus*; **Hngr**:*Halichoeres nigrescens*; **Hsp1**: *Halichoeres* sp 1; **Hsp2**: *Halichoeres* sp 2;**Hsp3**:*Halichoeres* sp 3;**Lab1**: Labridae sp 1; **Lab6**:Labridae sp 6; **Lab7**: Labridae sp 7; **Lab10**: Labridae sp 10; **Lab23:** Labridae sp 23**; Lab24**: Labridae sp 24; **Ldmd**: *Labroides dimidiatus*; **Llut**: *Lutjanus lutjanus*; **Lrus**: *Lutjanus russelli*; **Nngr**: *Neoglyphidodon nigroris*; **Nsp2**: *Neoglyphidodon sp 2*; **Npmc**: *Neopomacentrus*; **Pols**: *Pempheris oualensis*; **Pcst**: *Plectorhinchus chrysotaenia*; **Palx**: *Pomacentrus alexandeae*; **Pmlc**: *Pomacentrus moluccensis*; **Prcd**: *Pomachromis richardsoni*; **Srbm**: *Sargocentron rubrum*; **Scd4**: Scaridae sp 4; **Ssp1**: *Scarus sp1*; **Ssp2**: *Scarus* sp 2; **Ssp3**: *Scarus* sp 3; **Sclt**: *Scolopsis ciliatus;* **Smgr**: *Scolopsis margaritifer*; **Tlnr**: *Thalassoma lunare*.

B) CCA habitat variables by coral growth forms

The eigenvalues for the first two CCA axes were 0.60 and 0.42, respectively. The Monte Carlo permutation test showed a significant relationship between the species abundance matrix and the habitat variables matrix for the eight CCA axes ($F = 1.62$, $p<0.05$), explaining 33.81% of total data variation. The first two axes explained 20.2% of the total variation, with the first axis explaining 11.92% of the total inertia ($F = 3.57$, $p < 0.01$), and the second axis explaining 8.29% of the total inertia ($F=2.56$, $p<0.01$) (Figure 4.19). The explained variance of the species-environment relationship was 30.32% and 21.09% for CCA axes 1 and 2, respectively (Table 4.14). Only plate-like growth form ($F=2.39$, $p<0.05$) showed a significant contribution to the formation of the two axes in this model.

Table 4.14: Summary of canonical correspondence analysis (CCA) results comparing the habitat variables matrix of coral growth forms and the fish species matrix of the coral reefs.

	Axis 1	Axis 2	Total inertia	
Eigenvalues	0.60	0.42	5.855	CCA
Species-environments correlations	0.87	0.93		
Cumulative percentage variance of species data	11.92	20.20		
Cumulative percentage variance of species–environment relationship	30.32	51.41		
Monte Carlo permutation test	F=3.57 **p<0.01****	F=2.56 **p<0.01****		
Sum of constrained eigenvalues			1.980	

model R^2=0.34; adjusted-R^2=0.10

The CCA (Figure 4.19) showed fish species-specific preference for certain coral growth forms. *C. marcordon* and *P. oualensis* were found to be associated with branching coral while *C. cuning*, *L. lutjanus*, *P. moluccensis and Halichoeres* sp2 were found to be associated with rugosity. Encrusting and free-living growth forms were associated with low rugosity. This CCA also showed that there were more fish species associated with lower rugosity than higher rugosity reef, but with no significant patterns shown for fish feeding guilds.

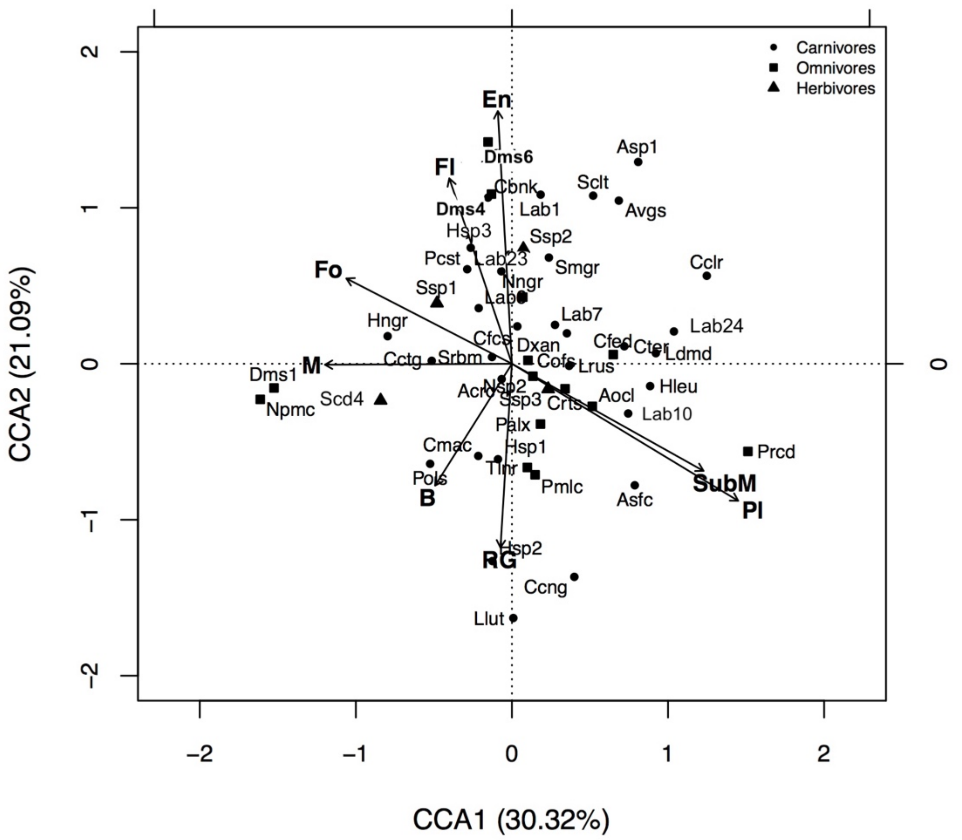


Figure 4.19: Canonical Correspondence Analysis (CCA) ordination plot of habitat variables with coral growth forms and fish diversity in coral reefs with distance to adjacent habitat and depth as covariates. Arcsine transformed percent cover of En: Encrusting; Fl: Free-living; M: Massive; B: Branching; SubM: Submassive; Fo: Foliose; Pl: Plates; RG: Rugosity. Fish species are categorized into three feeding guilds (carnivores, omnivores and herbivores) by symbols (circle, square and triangle). Species (only 49 species plotted here) are represented by point with letter codes. Fish species list **Asfc**: *Abudefduf sexfasciatus*; **Asp1**: *Abudefduf sp1*; **Avgs**: *Abudefduf vaigiensis*; **Acrc**: *Amblyglyphidodon curacao*; **Aocl**: *Amphiprion ocellaris*; **Ccng**: *Caesio cuning*; **Cter**: *Caesio teres*; **Cfed**: *Carangidae ferdau*; **Cbnk**: *Cephalopholis boenak*; **Cctg**: *Cephalopholis cyanostigma*; **Cofs**:*Chaetodon octofasciatus*; **Cclr**: *Cheilinus chlorourus*; **Cfcs**:*Cheilinus fasciatus*; **Cmac**:*Cheilodipterus macrodon*; **Crts**:*Chelmon rostatus*; **Dms1**: Damselfish sp 1; **Dms4**: Damselfish sp 4; **Dms6**: Damselfish sp 6; **Dxan**: *Diproctacanthus xanthurus*; **Hleu**:*Halichoeres leucurus*; **Hngr**:*Halichoeres nigrescens*; **Hsp1**: *Halichoeres* sp 1; **Hsp2**: *Halichoeres* sp 2;**Hsp3**:*Halichoeres* sp 3;**Lab1**: Labridae sp 1; **Lab6**:Labridae sp 6; **Lab7**: Labridae sp 7; **Lab10**: Labridae sp 10; **Lab23**: Labridae sp 23; **Lab24**: Labridae sp 24; **Ldmd**: *Labroides dimidiatus*; **Llut**: *Lutjanus lutjanus*; **Lrus**: *Lutjanus russelli*; **Nngr**: *Neoglyphidodon nigroris*; **Nsp2**: *Neoglyphidodon* sp 2; **Npmc**: *Neopomacentrus*; **Pols**: *Pempheris oualensis*; **Pcst**: *Plectorhinchus chrysotaenia*; **Palx**: *Pomacentrus alexandeae*; **Pmlc**: *Pomacentrus moluccensis*; **Prcd**: *Pomachromis richardsoni*; **Srbm**: *Sargocentron rubrum*; **Scd4**: Scaridae sp 4; **Ssp1**: *Scarus* sp1; **Ssp2**: *Scarus* sp 2; **Ssp3**: *Scarus* sp 3; **Sclt**: *Scolopsis ciliatus;* **Smgr**: *Scolopsis margaritifer*; **Tlnr**: *Thalassoma lunare*.

CHAPTER 5: DISCUSSION

5.1 Characterisation of fish communities in forereef seagrass and coral reefs

Fish communities in the forereef seagrass and adjacent coral reefs in Tinggi Island and Babi Besar Island, Johor consisted of different functional groups based on the food and space availability. Results indicated that despite their proximity to each other, the forereef seagrass and adjacent coral reefs are quite different ecosystems providing different ecosystem services and functions on its own to support their associated communities. On the other hand, these habitats showed interlinkages through fish species that use both habitats as refuge or foraging grounds, although there were significantly different utilisation patterns demonstrated by fish community users in both habitats.

The dominant trophic group found in the forereef seagrass habitat mainly consists of benthic invertivores from the Lethrinidae (Bream) family (up to 80% occurrence frequency) (Table 4.1). This may explain the observation where the fish community in the forereef seagrass habitat was found to be grazing more (Figure 4.4), either filtering sand or nibbling on seagrass blades for micro invertebrates and epiphytes. This may be due to the availability of food source in the seagrass habitat where a number of other studies found that high abundance of macro invertebrates was found associated with seagrass biomass (Stoner, 1980; Lewis III & Stoner, 1983; Leopardas et al., 2014).

In contrast, Pomacentridae (Damselfish) (up to 100% occurrence frequency) and Chaetodontidae (Butterflyfish) (up to 90% occurrence frequency) were found abundant in coral reefs (Table 4.2), while Labridae (Wrasse) was the most diverse family in coral reefs (Appendix II) because these coral-associated families highly depended on corals as food or refuge (Cole et al., 2008; Jones et al., 2004). Our findings were similar to other studies where Pomacentridae and Labridae families were the most species-rich families found in coral reefs globally (Thresher, 1991; Williams & Hatcher, 1983).

This study showed evidence of habitat connectivity via fishes between forereef seagrass habitat and adjacent coral reefs, where ten species of fishes were found utilising both habitats. These multi-habitat utilizers were from three coral dominant species (*Aeoliscus strigatus, Apogon compressus* and *Scolopsis ciliatus*), five seagrass dominant species (*Carangoides ferdau,* Fussilier damsel, *Gnathadon speciosus, Halichoeres nigrescens* and *Upeneus tragula*) and two generalists (*Aluterus scriptus and Pomacentrus cuneatus*) (Table 4.3). This may be explained by some reef fishes utilising more than one habitat throughout their life cycle or daily migration for food and shelter as shown by other research conducted in coral reefs and seagrass habitats in close proximity (Campbell et al., 2011; Dorenbosch et al., 2007).

Verweij et al. (2008) used stable isotope analysis to trace life history movement of commercially valuable fish to confirm the degree of connectivity of habitats which will be useful for further research. The results suggest that protection should be extended to adjacent nursery grounds beside the coral reef habitats to secure sustainable fisheries of commercially important species that use multiple habitats.

5.1.1 Fish density

Fish density was significantly higher by 32% in the coral reefs compared to the forereef seagrass habitat (Table 4.4), thus supporting evidence for research hypothesis H1 (Figure 1.1). One possible reason of high density for coral reef fishes is that reef structure provide substantial physical habitat complexity as refuge for many coral reef fishes (Bell & Galzin, 1984). In addition to functioning as refuge, some reef fishes are highly dependent on corals as food source known as corallivores mainly from the Chaetotontidae and Pomacentridae families (Cole et al., 2008; Jones et al., 2004). These two families showed high occurrence frequency of up to 100% within coral reef sampling quadrats in our study site.

5.1.2 Fish species richness

The current study found 59% higher species diversity in coral reefs compared to adjacent seagrass habitat (Table 4.4), thus lending support for research hypothesis H2 (Figure 1.1). This can be related to habitat structural complexity where coral reefs are structurally more complex than the adjacent seagrass habitat. In the present study, the coral reef habitats were structurally more complex with higher average coverage and seven types of growth forms from at least 48 genera of corals (Appendix V & Figure 4.13) that can provide more space and food to accommodate a diverse species of reef fishes. In comparison, the adjacent seagrass habitats had lower coverage, three types of growth forms from four seagrass species and a relatively low canopy height (Figure 4.6) forming a somewhat soft structure as habitat for fishes. This finding is similar to previous studies where fishes were found to be more diverse and higher in abundance in the coral reefs compared to the adjacent habitats (seagrass or mangrove) (Honda et al., 2013; Jaxion-harm et al., 2012). This suggests that the fish communities in the adjacent seagrass and coral reefs may choose their habitat based on structural complexity attributes and habitat configuration.

5.1.3 Fish maturity stage

There was a significant difference in the fish maturity stages between forereef seagrass and adjacent coral reef habitats in this study (Table 4.5). The proportion of the adults is significantly higher than juvenile fishes in coral reefs with a ratio of 9:1 while the opposite was observed in the adjacent seagrass habitat where the density of juveniles were 77% relative to 23% of adults (Figure 4.3). This supports research hypothesis H3, where fish juvenile density is 6 times higher in seagrass than in adjacent coral reef habitat (Figure 1.1). This finding showed that the adjacent habitats are functioning differently to accommodate different maturity stages of fishes, where coral reefs best support more adult fish, and the adjacent seagrass function as nursery for more juvenile species. This is similar to the findings by Gullström et al. (2008), who found higher juvenile density (75%) over sub-adult (16%) and adult individuals (9%) in seagrass meadows. A habitat is usually referred to as a nursery if the juveniles are present at higher densities, with higher survival rate, and growth rates than other habitats (Beck et al., 2003). This study suggests that the forereef seagrass meadows in Babi Besar Island and Tinggi Island are functioning as important nursery grounds for fish, and is consistent with previous research findings by Dorenbosch et al. (2005a), Gullström et al. (2008), Nagelkerken et al. (2000b) and Unsworth et al. (2008). These previous studies also found that nursery ground is important for many commercial fish species such as Lethrinidae (Bream), which are abundant in the forereef seagrass meadows (Table 4.1). The forereef seagrass habitats potentially support the most important fisheries for three major fishing ports in the vicinity of the study area, i.e. east coast of Johor from Mersing, north of Kota Tinggi and south of Kota Tinggi, with demersal fish landings of up to 16,517 tonnes in 2010 (Department of Fisheries, 2012), thus providing an income source for many local fishermen in the area. The protection and conservation of seagrass habitats that are adjacent to coral reefs should be emphasised because of their important roles as nursery grounds and support for the local fisheries industry besides enhancing the resilience of coral reef habitats.

5.1.4 Fish habitat utilisation in adjacent seagrass

The results revealed that fish utilisation patterns between these adjacent habitats were significantly different from each other. The fish community in the adjacent seagrass habitat was found mostly grazing rather than protecting and vice versa for coral reefs (Figure 4.4), thus lending support for research hypothesis H4 (Figure 1.1). This could be explained by the high abundance of juvenile fishes (Table 4.5) and the dominant benthic invertivores trophic guild (Table 4.1) found present in the forereef seagrass habitat. The fishes were mostly observed actively grazing, either filtering sand or nibbling on seagrass blades for micro invertebrates and epiphytes. This corroborate the finding by Casares and Creed (2008) that seagrass habitats supported higher density and richness of macrofauna than unvegetated area, which would then attract more invertivores to feed in the seagrass habitats.

5.1.5 Fish habitat utilisation in coral reefs

In contrast to seagrass, fish communities in coral reefs are mostly found in protecting rather than grazing mode (Figure 4.4), thus supporting research hypothesis H5 (Figure 1.1). Coral reefs are known as highly complex and diverse habitats that harbour diverse species and high abundance of reef fishes. Thus, large numbers of predatory fish are present in high density due to the abundant availability of food source. Given that fishes in coral reefs are exposed to higher predation risks, seeking shelter or protection is critical for their survivorship. Fish with anti-predatory and territorial behaviour tend to hunt and feed within their home range to avoid losing their shelter and occupancy to other fishes. In our study, the dominant group of fishes found in coral reef habitat such as Pomacentridae (Damselfish), Chaetodontidae (Butterflyfish) and Labridae (Wrasse) families, are commonly known as coral reef fishes that possess small home range (Sale, 1971).

5.2 Fish-habitat relationships

5.2.1 Forereef seagrass habitat

In this study, the multivariate regression GLM results showed that seagrass percent cover was the only habitat complexity attribute that significantly accounted for variations in fish density and diversity in the meadows (Table 4.7). Other commonly-used habitat complexity attributes such as shoot density and canopy height did not show significant contributions, possibly because of the narrow range of these values in these structurally simple forereef meadows (Table 4.6). Seagrass percent cover ranged from 12-46%, which was attributed mainly to the dominant species *H. uninervis* (44% of mean seagrass percent cover) and *H. ovalis* (29% of mean seagrass percent cover) (Figure 4.6). This suggests the important role these two relatively small species may have on fish community structure.

The forereef seagrass fish assemblages had higher densities and species richness where seagrass percentage cover was high. This is a novel finding because seagrass percentage cover has not commonly been shown to be a strong reflection of habitat complexity with regard to fish assemblages, but see McCloskey and Unsworth (2015) for its linkage to fish diversity. Instead, canopy height has often been the overriding factor in structuring fish assemblages in seagrass meadows (Gullström et al., 2008; Hori et al., 2009). Canopy height confers 3-dimensional complexity to a seagrass meadow, possibly by providing more interstitial space between shoots that can be used by fishes for protection against predation and for food provision (Hixon & Beets, 1993; Syms & Jones, 2000). In contrast, seagrass percent cover is a 2-dimensional habitat attribute that does not appear to provide any interstitial space for protection from predators. The implication of this finding is that structurally simple seagrass meadows such as those found in these forereefs are more likely to serve an ecological function in providing food rather than protection for fish.

The prevailing view is that large sized seagrass species such as *E. acoroides* and *Thalassodendron ciliatum* serve a significant ecological function for associated organisms by creating substrates, refuges, and by trapping resources (Hori, 2006; Williams & Heck, 2001). However, neither species was present in the forereef meadows of this study. In our study site, the highest canopies were established by what are typically considered to be mid-sized species such as *S. isoetifolium* (7-30 cm) and *H. uninervis* (3-15 cm). In contrast, *H. ovalis* (0.5-2.5 cm) produced the lowest canopies. Thus, where *H. ovalis* was dominant, it created habitats that were structurally simple, with more exposed sandy substrate. Our results suggest that these areas still do serve a function as fish habitats despite being structurally simple because of their association with fish species that have evolved strategies for these particular habitat structures (Figure 4.12). For example, bottom-dwelling gobies preferred structurally simple areas such as those dominated by *H. ovalis*, possibly because this allowed them more room to seek refuge in and forage on the substrate. Furthermore, benthic fish have usually been found associated with seagrass beds that have low canopy height and low seagrass biomass (Hori et al., 2009). This is consistent with previous research where fish communities showed species-specific preferences for both low and high seagrass cover (McCloskey & Unsworth, 2015), and varied based on their feeding guilds and survival strategies. In summary, structurally simple seagrass meadows without a complex 3-dimensional structure are still able to fulfil the niche requirements for a wide range of fish assemblages and subsequently, enhance their density and diversity.

Fish are found utilising forereef seagrass more as feeding ground than shelter (Figure 4.4A), and they are made up of mostly juvenile fish (Figure 4.3). The habitat utilisation may be species-specific based on feeding guilds and their maturity size, determined by multiple factors including inter-species competition, predation, food availability and home-range (Nagelkerken et al., 2000b). Seagrass meadows are highly diverse and abundant with macrofaunal highly associated with seagrass biomass (Heck & Wetstone, 1977; Orth et al., 1984), with food provision for many invertivores as seen for commercially important species *L. variegatus* which had a high abundance in the present study. Secondly, seagrass meadow preferred by juvenile fish might be due to low predation risk at a distance away from coral reefs (Shulman, 1985; Parrish, 1989). This indicates that adjacent forereef seagrass could act as nursery and foraging ground for many of the economically important species.

In this study, the top five most abundant fish species found in the seagrass meadows were mostly invertivores that made up 50-80% of the sampled fish population occurrences, all of which were economically important taxa such as breams, emperors and mullets (Table 4.1). These species were associated more closely with structurally small seagrass species such as *H. ovalis* and *H. uninervis* (Figure 4.12). From the video footage, these invertivores were observed to be grazing heavily on seagrass leaves, presumably to consume epiphytic invertebrates. Furthermore, even invertivores that are more often associated with coral reefs such as *Parachaetodon ocellatus*, *Scolopsis monogramma*, *Scolopsis aurata* and *Pleteleotris microleptis* appeared to frequent the seagrass meadows in this study (Figure 4.12), further underlining the function these meadows may have in supporting this specific feeding guild not just for populations within seagrass meadows, but also those from adjacent coral reefs.

The distance to adjacent coral reefs for every sampling point was found to be a significant factor in shaping fish diversity and density. In this study, fish diversity and density increased with increasing distance away from the adjacent coral reefs and farther into the seagrass meadows, which is contrary to other findings where high species richness and density of seagrass associated organisms within seagrass meadows were found closer to adjacent habitats (Jelbart et al., 2007; Tuya et al., 2011; Unsworth et al., 2008). It is possible that the change in seagrass meadow structure from edge to interior itself may have shaped such faunal distribution patterns, but our correlation tests did not show strong relationships between the 'distance from adjacent coral reefs' variable and either of the habitat complexity attributes of seagrass percent cover, shoot density, and canopy height. This suggests that with regard to fish assemblages, the position of a sampling point relative to the distance from the adjacent coral reef is independent of habitat complexity itself. One likely explanation is that the edges between seagrass and coral reefs have higher predator-prey encounters than meadow interiors (Shulman, 1985; Parrish, 1989; Smith et al., 2008; Moore & Hovel, 2010), resulting in lower fish diversity and density here. Although our study design did not test for inter-habitat connectivity and predator-prey interactions, it is still apparent that the effects of other habitats in the vicinity of seagrass meadows is an important factor to be considered in future studies on fish habitat structure.

In summary, our findings suggest that seagrass cover is the most important habitat attribute in structurally simple seagrass meadows; that the predominantly invertivorous fish assemblages here may be relying on this ecosystem more for food than for protection; and that the interiors of these meadows are more heavily populated than the edges closest to coral reefs.

5.2.2 Coral reef habitat

The multivariate GLMs suggested that hard coral cover and rubble percent cover were the important habitat variables in coral reefs for fish density and fish species richness respectively (Table 4.11).

First, our study suggested that higher fish density is correlated to higher hard coral cover in coral reefs (Figure 4.16), and this finding further supports previous studies (Carpenter et al., 1981; Grigg, 1994; Hixon & Beets, 1993; Komyakova et al., 2013; Luckhurst & Luckhurst, 1978) that found fish communities highly correlated to live coral cover with higher fish density and species richness as live coral cover increases. Live coral cover refers to percent cover of living hard and soft corals (English et al., 1997). However, soft coral was absent from this study, thus all the live coral cover was referring to reef-building hard coral. This may be explained by the importance of living coral functioning as refuge and food source particularly for habitat specialist belonging to Pomacentridae and Chaetodontidae families, which were the dominant and abundant species in the present study (Table 4.2). This is further supported by Jones et al. (2004) who observed that a decline in live coral cover resulted in more than 25% decline in species richness for local coral-dependent species such as Chaetodontidae (Butterflyfish) and Pomacentridae (Damselfish). Furthermore, these habitat specialist are more susceptible to disturbances such as climate change that causes coral bleaching and severe storms (Wilson et al., 2008) that damages and destroys the corals they heavily depend on.

This result indicates that hard coral cover plays an important role in coral reef ecosystems to maintain fish communities regardless of the rugosity of reefs. The rugosity variable was not reflected as an important factor for the fish community in coral reefs in the present study. This indicates that hard coral cover may have a more critical role in providing food than protection for fishes. However, rugosity was regarded as an essential variable that positively correlated to fish density and biomass in other studies, which emphasised that habitat surface complexity is important in providing shelter for fish community (Friedlander & Parrish, 1998; Graham & Nash, 2013; Grigg, 1994; Luckhurst & Luckhurst, 1978). The CCA showed that growth forms of coral with branching, sub-massive and plates-like features were closely associated with the reef rugosity, but not for encrusting and free-living forms (Figure 4.19). This indicates that coral reefs are highly complex with many types of growth forms and dominanted by complex branching and plates coral which provide more surface area. A greater variety of growth forms of living corals regardless of species numbers supports more specialist fish species by providing more microhabitats (Galzin et al., 1994; Sano et al., 1987; Williams, 1986). This study showed fish species-specific preferences for habitat structure, in that species such as *Cheilodipterus macrodon* and *Pempheris oualensis* which preferred a structurally complex habitat with higher branching coral cover. Branching growth forms are found to be closely related with rugosity (Figure 4.19). This is similar to the finding of Graham and Nash (2013), where branching forms were positively correlated with structural complexity. This indicates that reef rugosity still provides habitat protection for certain fish species even with no significant influence on the overall fish community in the present study.

On the other hand, this study found that rubble percent cover had a negative effect on fish species richness in coral reefs (Figure 4.17). Different components of habitat substrate are preferred by various species of reef fishes. There were more fish species that preferred habitat substrate with hard coral, rock or sand as compared to rubble area. The CCA results are in support of the GLM model (Figure 4.18), where a significant negative relationship between fish species richness and rubble percent cover was found. This indicated that high rubble substrate is the least preferred habitat by coral reef fishes which may be due to its unstable structure that is more likely to prevent recruitment of life forms and lacks of space as refuge for larger sized fishes. The exceptions are the small-bodied cryptic reef fish species (<10cm) such as those from Tripterygiidae, Gobiidae, Blenniidae and Pseudochromidae that were found more abundantly in sand/rubble microhabitats than the open reef microhabitats (Depczynski & Bellwood, 2004). Nevertheless, certain Pomacentridae and Lethrinidae species appeared to be associated with rubble area. Wilson et al. (2008) suggested a high proportion of pomacentrid species was associated with live coral as adults (40%) or juveniles (53%), and there were six species of pomacentrids that showed preference for rubble including *Neoglyphidodon nigroris* that was commonly found in the present study. The association with rubble might be due to the presence of food such as algae on rubble area where algal cover was found to be to be more abundant in less structurally complex reefs (Graham & Nash, 2013).

In brief, substrate complexity has a significant influence on fish density and species richness specifically percent cover of hard coral or rubble. This implies that degradation of coral reefs would have a direct impact on fish communities, especially through mass coral bleaching events or due to destructive fishing methods that contribute to the loss of hard coral cover and increase of rubble.

Proximity to adjacent habitat was not significant in structuring fish community in coral reefs as opposed to the result in seagrass habitat, and this may be partly due to the size of the fringing reefs that we surveyed, which is relatively narrow (< 1 km) and shallow (< 2 m). With a limited gradient of water depth and size of habitat, the fish community in the narrow fringing reefs are occupying a small habitat with overlapping niches and competition for food and refuge. The proximity factor may be negligible in structuring fish community in a narrow fringing reef.

The coral diversity (number of genera) in the present study was not significantly correlated with fish species richness. This is not unexpected because the difficulties of coral identification to species level is widely acknowledged (Chabanet et al., 1997). Despite this, this study recorded more than half of the 60 genera of hard coral reported from the east coast of Peninsular Malaysia including Redang Island, Tioman Island and Tinggi Island Marine Parks (Harborne et al., 2000). These narrow fringing reefs are highly complex and diverse, thus considered as stable and healthy reef systems in the area, despite being exposed to high sedimentation loads from the mainland and high wave energy during the annual monsoon. This reefs status is comparable to those reported in Bunaken National Park- North Sulawesi, Indonesia with 44 genera found with live coral cover of 44% and dominanted by *Porites* (Faud, 2010).

In summary, our findings suggest that hard coral cover is the most important habitat attribute in structuring fish density in the coral reefs. This suggests hard coral cover as the most basic but yet essential habitat attribute in reef health monitoring and subsequently, a reliable proxy for fish community structure, thus confirming its value in habitat assessments. Secondly, various types of growth forms and substrates fulfil more habitat niches for diverse species of reef fishes that relate to food availability and space occupancy. Thus, assessment of coral growth form and substrate type in coral reefs are essential for ecosystem management.

5.3 Potential applications for management and conservation

In conjunction with the United Nations' Sustainable Development Goals specifically Goal #14: Life below Water, there is an urgent need to prioritise the conservation and sustainable management of marine ecosystems to avoid significant adverse impacts (United Nations, 2018). Seagrass and coral reef habitats provide tremendous ecological services such as coastal protection, recycling nutrients, provide food and habitat for associated marine life. The loss of habitat structure and complexity will not only reduce the fish population that promotes habitat resilience, but also impair the ability of ecosystem to respond to a rapidly changing marine environment. Consequently, global food security and ecosystem stability are likely threats that will affect us and future generations. The findings of this study provide baseline information for the marine resource manager to understand the role of habitat complexity and proximity to adjacent habitats to estimate relative fish density and fish species richness. This is useful for spatial marine habitat planning especially in MPAs and for sustainable fisheries management.

To conserve and maintain existing fish density and diversity in coral reefs and adjacent seagrass habitats, it is critical to take into consideration continuous habitat assessment and monitoring besides addressing threats to the habitats and emphasise the sustainable use of marine resources and biodiversity conservation for enhanced ecosystem resilience.

5.4 Recommendations for future research

1) For RUVS method, fish identification can be improved with additional high-quality photograph of fishes that are present in the area prior to the RUVS video analysis, which will allow for pre-identification of key species present in the area and efficiently reduce the time needed for video analyses and identification.
2) Besides the chain method, an advanced alternative approach for reef rugosity assessment method is by using water level logger to measure reef rugosity (Dustan et al., 2013) or 3D reef modelling (McKinnon et al., 2011; Young et al., 2017), which will allow more accurate and efficient assessment of the reef surface complexity.
3) Stable isotope analysis of fish tissues can help to elucidate the trophic niche of fish communities (stable isotopes of nitrogen and carbon) and their habitat use (stable isotopes of carbon, sulfur and oxygen) in forereef seagrass and adjacent coral reefs.
4) Using DNA barcoding method by extracting DNA sequences from fish tissues will enhance taxonomic identification of fish, especially those in the juvenile phase which were most difficult to identify using video images.

CHAPTER 6: CONCLUSION

6.1 Conclusion

In conclusion, the coral reef habitats in Tinggi Island and Babi Besar Island support higher fish density and diversity compared to the adjacent forereef seagrass habitat. However, coral reefs and seagrass meadows are equally important in maintaining ecological functions as there are different dominant trophic groups and fish families found in each habitat.

Secondly, the forereef seagrass habitat harbour higher juvenile fish than adults suggesting the important role of this habitat as nursery grounds, whilst coral reefs host mostly adult fish. Ten species of fish were found utilising both adjacent seagrass and coral reef habitat. These findings suggest that the connectivity between adjacent habitats is further enhanced by these multiple habitat users. The utilisation patterns of observed fish in the forereef seagrass habitat are significantly higher for grazing or feeding as compared to protecting behaviour, but vice versa is seen for fish within the coral reefs. Thus, this study found evidence to support the five hypotheses in Objective 1 (Table 6.1).

Habitat complexity attributes and habitat configuration play a significant role in structuring the fish communities in forereef seagrass and adjacent coral reef habitats. This study has identified seagrass percent cover and proximity to adjacent habitat as having the most influence on fish density and diversity and a positive relationship in the forereef seagrass. On the other hand, hard coral cover is the most crucial habitat attribute in determining fish density in coral reefs with a positive relationship; and rubble percent cover was found negatively correlated to fish species richness in this study. No significant patterns of structural complexity attributes influencing fish feeding guilds were found in both forereef seagrass and coral reefs.

Table 6.1: Summary of research objectives, hypotheses and outcomes.

Research aim: To understand the influence of habitat complexity on fish communities in adjacent seagrass and coral reefs.	**Research Outcomes / Conclusions**
Objective 1: To characterize and compare fish communities in adjacent seagrass and coral reef habitats.	
H1: Fish density is higher in coral reefs than in adjacent seagrass habitat.	Hypothesis 1 accepted. Fish density is 32 % higher in coral reefs than in adjacent seagrass habitat.
H2: Fish diversity is higher in coral reefs than in adjacent seagrass habitat.	Hypothesis 2 accepted. Fish diversity is 59% higher in coral reefs than in adjacent seagrass habitat.
H3: Fish juvenile density is higher in seagrass than in adjacent coral reef habitat.	Hypothesis 3 accepted. Fish juvenile density is 6 times higher in seagrass than in adjacent coral reef habitat.
H4: Fish in seagrass do more grazing than protecting.	Hypothesis 4 accepted. Fish in seagrass 35% were found grazing and 10 % protecting.
H5: Fish in coral reefs do more protecting than grazing.	Hypothesis 5 accepted. Fish in coral reefs 33% were found protecting and 9% grazing.
Objective 2:	
(a) To identify the habitat complexity attributes that best explains fish density and diversity in seagrass habitat.	In seagrass habitat, seagrass percent cover and proximity to adjacent coral reef habitat best explains fish density and fish diversity.
(b) To identify associations between seagrass habitat complexity attributes and fish feeding guilds.	There are no significant patterns of seagrass habitat complexity attributes on fish feeding guilds.
Objective 3:	
(a) To identify the habitat complexity attributes that best explains fish density and diversity in coral reef habitat.	In coral reef habitat, hard coral cover best explains the fish density and rubble for fish diversity.
(b) To identify associations between coral reef habitat complexity attributes and fish feeding guilds.	There are no significant patterns of coral reef habitat complexity attributes on fish feeding guilds.

REFERENCES

Acosta, A., Bartels, C., Colvocoresses, J., & Greenwood, M. F. D. (2007). Fish assemblages in seagrass habitats of the Florida Keys , Florida : Spatial and temporal characteristics. *Bulletin of Marine Science*, *81*(1), 1–19.

Adams, A. J., Dahlgren, C. P., Kellison, G. T., Kendall, M. S., Layman, C. A., Ley, J. A., … Serafy, J. E. (2006). Nursery function of tropical back-reef systems. *Marine Ecology Progress Series*, *318*, 287–301.

Affendi, Y. A., Badrul, H., Yoke Lee, L., Kee Alfian, A. A., & Yusuf, Y. (2005). Scleractinian coral diversity of Kg. Tekek, Pulau Tioman Marine Park. In *IOES monograph series: Natural history of the Pulau Tioman group of islands* (pp. 53-68). Kuala Lumpur, MY: Institute of Ocean and Earth Sciences, University of Malaya.

Ajemian, M. J., Wetz, J. J., Shipley-Lozano, B., & Stunz, G. W. (2015). Rapid assessment of fish communities on submerged oil and gas platform reefs using remotely operated vehicles. *Fisheries Research*, *167*, 143–155.

Akaike, H. (1981). Likelihood of a model and information criteria. *Journal of Econometrics*, (16), 3–14.

Alevizon, W. S., & Brooks, M. G. (1975). The comparative structure of two western Atlantic reef-fish assemblages. *Bulletin of Marine Science*, *25*(4), 482–490.

Allen, G. R. (1992). Marine Fishes of Sabah, North Borneo. In T.D. Meagher (Ed.), *Proposed Semporna Marine Park: Environmental evaluation for expanded tourism development* (pp. 53-70). Kota Kinabalu, SBH: Sabah Parks.

Allen, G. R. (2000). Indo-Pacific coral-reef fishes as indicators of conservation hotspots. In *Proceedings 9th International Coral Reef Symposium* (Vol. 2, pp. 921–926). Bali, ID: International Society of Reef Studies.

Allen, G. R. (2008). Conservation hotspots of biodiversity and endemism for Indo-Pacific coral reef fishes. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *18*(5), 541–556.

Allen, G. R., Amaoka, K., Anderson Jr, W. D., Bellwood, D. R., Bohlke, E. B., Bradbury, M. G., … Cohen, D. M. (2000). A checklist of the fishes of the South China Sea. *The Raffles Bulletin of Zoology*, (8), 569–667.

Allen, G., Steene, R., Humann, P., & DeLoach, N. (2012). *Reef fish: Identification tropical Pacific*. Jacksonville, FLD: New World Publication.

Almany, G. (2004). Does increased habitat complexity reduce predation and competition in coral reef fish assemblages? *Oikos*, *106*, 275–284.

Alvarez-Filip, L., Dulvy, N. K., Gill, J. A., Côté, I. M., & Watkinson, A. R. (2009). Flattening of Caribbean coral reefs: Region-wide declines in architectural complexity. *Proceedings. Biological Sciences / The Royal Society*, *276*(1669), 3019–3025.

Ambo-Rappe, R., Nessa, M. N., Latuconsina, H., & Lajus, D. L. (2013). Relationship between the tropical seagrass bed characteristics and the structure of the associated fish community. *Open Journal of Ecology*, *03*(05), 331–342.

Appeldoorn, R. S., & Bouwmeester, B. L. K. (2009). Movement of fishes (Grunts : Haemulidae) across the coral reef seascape : A review of scales , patterns and processes. *Caribbean Journal of Science*, *45*(2), 304–316.

Arai, T. (2014). Diversity and conservation of coral reef fishes in the Malaysian South China Sea. *Reviews in Fish Biology and Fisheries*, *24*, 1–17.

Arai, T. (2015). Diversity and conservation of coral reef fishes in the Malaysian South China Sea. *Reviews in Fish Biology and Fisheries*, *25*(1), 85–101.

Assis, J., Claro, B., Ramos, A., Boavida, J., & Serrão, E. A. (2013). Performing fish counts with a wide-angle camera, a promising approach reducing divers' limitations. *Journal of Experimental Marine Biology and Ecology*, *445*, 93–98.

Atan, Y., Jaafar, H., & Majid, A. R. A. (2010). *Ikan laut Malaysia: Glosari nama sahih species ikan*. Ampang, SGR: Dewan Bahasa dan Pustaka.

Aziz, A., Bujang, J. S., Zakaria, M. H., Suryana, Y., & Ghaffar, M. A. (2006). Fish communities from seagrass bed of Merchang Lagoon, Terengganu, Penisular Malaysia. *Coastal Marine Science*, *30*(1), 268–275.

Bacheler, N. M., Schobernd, C. M., Schobernd, Z. H., Mitchell, W. A., Berrane, D. J., Kellison, G. T., & Reichert, M. J. M. (2013). Comparison of trap and underwater video gears for indexing reef fish presence and abundance in the southeast United States. *Fisheries Research*, *143*, 81–88.

Bacheler, N. M., & Shertzer, K. W. (2014). Estimating relative abundance and species richness from video surveys of reef fishes. *Fishery Bulletin*, *113*(1), 15–26.

Bakus, G. J. (2007). *Quantitative analysis of marine biological communities field biology and environment*. New Jersey, NJ: A John Wiley & Sons, Inc.

Barbosa, A. M., Brown, J. A., Jimenez-Valverde, A., & Real, R. (2015). modEvA: Model evaluation and analysis. R package version 1.3.2.

Barnes, H. (1952). Underwater television and marine biology. *American Scientist*, *40*(4), 679–681.

Bartholomew, A., Diaz, R., & Cicchetti, G. (2000). New dimensionless indices of structural habitat complexity: Predicted and actual effects on a predator's foraging success. *Marine Ecology Progress Series*, *206*, 45–58.

Beck, J. G., Heck, K., Halpern, B., & Orth, R. J. (2003). The role of neasrshore ecosystems as fish and shellfish nurseries. *Issues in Ecology*, *11*, 1–12.

Begon, M., Harper, J. L., & Townsend, C. R. (1986). *Ecology. Individuals, populations and communities.* Oxford, UK: Blackwell Scientific Publications.

Begon, M., Townsend, C. R., & Harper, J. L. (2006). *Ecology: From individuals to ecosystems*. Malden, MA: Blackwell Publishing.

Bell, J. D., & Galzin, R. (1984). Influence of live coral cover on coral-reef fish communities. *Marine Ecology Progress Series*, *15*, 265–274.

Berkström, C., Jörgensen, T., & Hellström, M. (2013). Ecological connectivity and niche differentiation between two closely related fish species in the mangrove-seagrass-coral reef continuum. *Marine Ecology Progress Series*, *477*, 201–215.

Beukers, J. S., & Jones, G. P. (1997). Habitat complexity modifes the impact of piscivores on a coral reef fish population. *Oecologia*, *114*, 50–59.

Bujang, J. S., Zakaria, M. H., & Arshad, A. (2006). Distribution and significance of seagrass ecosystems in Malaysia. *Aquatic Ecosystem Health & Management*, *9*(2), 203–214.

Burke, L., Reytar, K., Spalding, M., & Perry, A. (2011). *Reefs at risk revisited*. Washington, DC: World Resources Institute.

Campbell, S., Kartawijaya, T., & Sabarini, E. (2011). Connectivity in reef fish assemblages between seagrass and coral reef habitats. *Aquatic Biology*, *13*(1), 65–77.

Cappo, M., Harvey, E. S., & Shortis, M. (2006). Counting and measuring fish with baited video techniques - an overview. In J.M. Lyle, D.M. Furlani & C.D. Buxton (Eds.), *Cutting-edge technologies in fish and fisheries science*: *Australian Society for Fish Biology Workshop Proceedings* (Vol. 1, pp. 101-114)., Hobart, TAS: Australian Society for Fish Biology.

Carpenter, K., Miclat, R., Albadalejo, V., & Corpuz, V. (1981). The influence of substrate structure on the local abundance and diversity of Philippine reef fishes. *Proceedings of the Fourth International Coral Reef Symposium, Manila*.

Casares, F. A., & Creed, J. C. (2008). Do small seagrasses enhance density, richness, and diversity of macrofauna? *Journal of Coastal Research*, *243*(May 2015), 790–797.

Chabanet, P., Loiseau, N., Join, J.-L., & Ponton, D. (2012). VideoSolo, an autonomous video system for high-frequency monitoring of aquatic biota, applied to coral reef fishes in the Glorioso Islands (SWIO). *Journal of Experimental Marine Biology and Ecology*, *430–431*, 10–16.

Chabanet, P., Ralambondrainy, H., Amanieu, M., Faure, G., & Galzin, R. (1997). Relationships between coral reef substrata and fish. *Coral Reefs*, *16*(2), 93–102.

Chong, V. C., Lee, P. K. Y., & Lau, C. M. (2010). Diversity, extinction risk and conservation of Malaysian fishes. *Journal of Fish Biology*, *76*(9), 2009–2066.

Chong, V. C., & Sasekumar, A. (2002). Fish communities and fisheries of Sungai Johor and Sungai Pulai Estuaries (Johor, Malaysia). *Malayan Nature Journal*, *56*(January 2002), 279–302.

Cole, A. J., Pratchett, M. S., & Jones, G. P. (2008). Diversity and functional importance of coral-feeding fishes on tropical coral reefs. *Fish and Fisheries*, *9*(3), 286–307.

Conn, P. B. (2011). *An evaluation and power analysis of fishery independent reef fish sampling in the Gulf of Mexico and U.S. South Atlantic*. Beaufort, NC: National Oceanic and Atmospheric Administration.

Connell, J. H. (1978). Diversity in tropical rain forests and coral reefs. *Science*, *199*(4335), 1302–1310.

Conservation International. (2008). *Economic Values of Coral Reefs, Mangroves, and Seagrasses: A Global Compilation*. Arlington, VA: Conservation International.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., … Turner, R. K. (2014). Changes in the global value of ecosystem services. *Global Environmental Change*, *26*(1), 152–158.

Den Hartog, C. (1970). The sea-grasses of the world. *Verh. Kon. Ned. Akad. Wet., Afd. Natuurkunde*, *59*(1), 275.

Den Hartog, C., & Kuo, J. (2006). Taxonomy and biogeography of seagrasses. In *Seagrasses: Biology, ecology and conservation* (pp. 1–23). Dordrecht, NL: Springer Dordrecht.

Department of Fisheries. (2012). *Annual fisheries statistics 2010*. Kuala Lumpur, MY: Department of Fisheries.

Department of Marine Park Malaysia. (2015). *Total economic value of marine biodiversity: Malaysia marine parks*. (A. G. Lim & B. I. Md Repin, Eds.). Putrajaya, Malaysia.

Depczynski, M., & Bellwood, D. R. (2004). Microhabitat utilisation patterns in cryptobenthic coral reef fish communities. *Marine Biology*, *145*(3), 455–463.

Dibble, E. D., Killgore, K. J., & Dick, G. O. (1997). Measurement of plant architecture in seven aquatic plants. *Journal of Freshwater Ecology*, *11*(3), 311–318.

Dorenbosch, M., Grol, M., Christianen, M., Nagelkerken, I., & van der Velde, G. (2005). Indo-Pacific seagrass beds and mangroves contribute to fish density and diversity on adjacent coral reefs. *Marine Ecology Progress Series*, *302*, 63–76.

Dorenbosch, M., Grol, M., Nagelkerken, I., & van der Velde, G. (2005). Distribution of coral reef fishes along a coral reef-seagrass gradient: Edge effects and habitat segregation. *Marine Ecology Progress Series*, *299*, 277–288.

Dorenbosch, M., Verberk, W. C. E. P., Nagelkerken, I., & Van Der Velde, G. (2007). Influence of habitat configuration on connectivity between fish assemblages of Caribbean seagrass beds, mangroves and coral reefs. *Marine Ecology Progress Series*, *334*, 103–116.

Dorman, S. R., Harvey, E. S., & Newman, S. J. (2012). Bait effects in sampling coral reef fish assemblages with stereo-BRUVs. *PLoS ONE*, *7*(7), e41538.

Doshi, A., Pascoe, S., Thébaud, O., Thomas, C. R., Setiasih, N., Tan C. H., … Heron, S. F. (2012). Loss of economic value from coral bleaching in Southeast Asia. *Proceedings of the 12th International Coral Reef Symposium* (pp. 1–5), Cairns, QLD: International Society for Reef Studies.

Duarte, C. M. (2002). The future of seagrass meadows. *Environmental Conservation*, *29*(02), 192–206.

Duarte, C. M., & Chiscano, C. L. (1999). Seagrass biomass and production: A reassessment. *Aquatic Botany*, *65*(1), 159–174.

Duarte, C. M., & Kirkman, H. (2001). Methods for the measurement of seagrass abundance and depth distribution. In F. T. Short & R. G. Coles (Eds.), *Global seagrass research methods* (pp. 141-154). Amsterdam, NL: Elsevier.

Dustan, P., Doherty, O., & Pardede, S. (2013). Digital reef rugosity estimates coral reef habitat complexity. *PLoS ONE*, *8*(2), e57386.

Ellis, D. M., & DeMartini, E. E. (1995). Evaluation of a video camera technique for indexing abundances of juvenile pink snapper, *Pristipomoides filamentosus*, and other Hawaiian insular shelf fishes. *Fishery Bulletin*, *93*(1), 67–77.

English, S., Wilkinson, C., & Baker, V. (1997). *Survey manual for tropical marine resources* (2nd ed., Vol. 390). Townsville, QLD: Australian Institute of Marine Science (AIMS).

Farina, A. (2008). *Principles and methods in landscape ecology: towards a science of the landscape* (Vol. 3). Dordrecht, NL: Springer.

Faud, M. A. Z. (2010). *Coral reef rugosity and coral biodiversity. (Master's thesis)*. International Institute for Geo-Information Science and Earth Observation Enschede, The Netherlands.

Feary, D. a., McCormick, M. I., & Jones, G. P. (2009). Growth of reef fishes in response to live coral cover. *Journal of Experimental Marine Biology and Ecology*, *373*(1), 45–49.

Fox, J., Weisberg, S., Adler, D., Bates, D., Baud-Bovy, G., Ellison, S., … R-Core. (2015). *An {R} companion to applied regression* (2nd ed.). Sage, CA: Thousand Oaks.

Friedlander, A. M., & Parrish, J. D. (1998). Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. *Journal of Experimental Marine Biology and Ecology*, *224*(1), 1–30.

Friedman, A., Pizarro, O., Williams, S. B., & Johnson-Roberson, M. (2012). Multi-scale measures of rugosity, slope and aspect from benthic stereo image reconstructions. *PLoS ONE*, *7*(12), e50440.

Froese, R., & Pauly, D. Editors (2012). FishBase. Retrieved June 20, 2012, from www.fishbase.org.

Galzin, R., Planes, S., Dufour, V., & Salvat, B. (1994). Variation in diversity of coral reef fish between French Polynesian atolls. *Coral Reefs*, *13*(3), 175–180.

GBRMPA. (2017). *Interim report: 2016 coral bleaching event on the Great Barrier Reef.* Townsville, QLD: Great Barrier Reef Marine Park Authority.

Gell, F. R., & Whittington, M. W. (2002). Diversity of fishes in seagrass beds in the Quirimba Archipelago, Northern Mozambique. *Marine and Freshwater Research*, *53*(2), 115–121.

Gladstone, W., Lindfield, S., Coleman, M., & Kelaher, B. P. (2012). Optimisation of baited remote underwater video sampling designs for estuarine fish assemblages. *Journal of Experimental Marine Biology and Ecology*, *429*, 28–35.

Graham, N. A. J., & Nash, K. L. (2013). The importance of structural complexity in coral reef ecosystems. *Coral Reefs*, *32*(2), 315–326.

Gratwicke, B., & Speight, M. (2005). The relationship between fish species richness, abundance and habitat complexity in a range of shallow tropical marine habitats. *Journal of Fish Biology*, *66*(3), 650–667.

Gratwicke, B., & Speight, M. R. (2005). Effects of habitat complexity on Caribbean marine fish assemblages. *Marine Ecology Progress Series*, *292*, 301–310.

Green, E. P., & Short, F. T. (2003). *World atlas of seagrasses*. Berkerley, CA: University of California Press.

Grigg, R. W. (1994). Effects of sewage discharge, fishing pressure and habitat complexity on coral ecosystems and reef fishes in Hawaii. *Marine Ecology Progress Series. Oldendorf*, *103*(1), 25–34.

Grober-Dunsmore, R., Frazer, T. K., Lindberg, W. J., & Beets, J. (2006). Reef fish and habitat relationships in a Caribbean seascape: The importance of reef context. *Coral Reefs*, *26*(1), 201–216.

Guisan, A., Edwards, T. C., & Hastie, T. (2002). Generalized linear and generalized additive models in studies of species distributions: Setting the scene. *Ecological Modelling*, *157*(2), 89–100.

Guisan, A., & Zimmermann, N. E. (2000). Predictive habitat distribution models in ecology. *Ecological Modelling*, *135*, 147–186.

Gullström, M., Bodin, M., Nilsson, P. G., & Öhman, M. C. (2008). Seagrass structural complexity and landscape configuration as determinants of tropical fish assemblage composition. *Marine Ecology Progress Series*, *363*, 241–255.

Halford, A. R., & Thompson, A. A. (1994). *Visual census surveys of reef fish. Long-term Monitoring of the Great Barrier Reef. Standard operational procedure No. 3.* Townville, QLD: Australian Institute of Marine Science (AIMS).

Harborne, A., Fenner, D., Barnes, A., Beger, M., Harding, S., & Roxburgh, T. (2000). *Status report on the coral reefs of the east coast of Peninsular Malaysia*. Kuala Lumpur, MY: Marine Park Section Department of Fisheries Malaysia.

Harrell, F. E., Lee, K. L., Califf, R. M., Pryor, D. B., & Rosati, R. A. (1984). Regression modeling strategies for improved prognostic prediction. *Statistics in Medicine*, *3*(2), 143–152.

Harrell, F., Lee, K., & Mark, D. (1996). Multivariable prognostic models: Issues in developing models, evaluating assumptions and adequacy, and measureing and reducing errors. *Statistics in Medicine*, *15*, 361–387.

Harvey, E., Cappo, M., Butler, J., Hall, N., & Kendrick, G. (2007). Bait attraction affects the performance of remote underwater video stations in assessment of demersal fish community structure. *Marine Ecology Progress Series*, *350*, 245–254.

Harvey, E., Fletcher, D., & Shortis, M. (2001a). A comparison of the precision and accuracy of estimates of reef-fish lengths determined visually by divers with estimates produced by a stereo-video system. *Fishery Bulletin-National Oceanic and Atmospheric Administration*, *99*(1), 63–71.

Harvey, E., Fletcher, D., & Shortis, M. (2001b). Improving the statistical power of length estimates of reef fish: a comparison of estimates determined visually by divers with estimates produced by a stereo-video system. *Fishery Bulletin-National Oceanic and Atmospheric Administration*, *99*(1), 72–80.

Harvey, E., Fletcher, D., & Shortis, M. (2002). Estimation of reef fish length by divers and by stereo-video A first comparison of the accuracy and precision in the field on living fish under operational conditions. *Fisheries Research*, *57*, 255–265.

Harvey, E., Fletcher, D., Shortis, M., & Kendrick, G. A. (2004). A comparison of underwater visual distance estimates made by scuba divers and a stereo-video system: Implications for underwater visual census of reef fish abundance. *Marine and Freshwater Research*, *55*, 573–580.

Harvey, E. S., Newman, S. J., McLean, D. L., Cappo, M., Meeuwig, J. J., & Skepper, C. L. (2012). Comparison of the relative efficiencies of stereo-BRUVs and traps for sampling tropical continental shelf demersal fishes. *Fisheries Research*, *125–126*, 108–120.

Harvey, E., & Shortis, M. (1995). A system for stereo-video measurement of sub-tidal organisms. *Marine Technology Society Journal*, *29*(4), 10–12.

Hayward, G. D., & Suring, L. H. (2013). Selecting key habitat attributes for monitoring. In M.M. Rowland & C.D. Vojta (Eds.), *A technical guide for monitoring wildlife habitat* (pp. 1–20). Washington, DC: U.S. Department of Agriculture, Forest Service.

Heck, K. L., & Wetstone, G. S. (1977). Habitat complexity and invertebrate richness species and abundance in tropical meadows seagrass. *Journal of Biogeography*, *4*(2), 135–142.

Hemminga, M. A., & Duarte, C. M. (2000). *Seagrass ecology*. Cambridge, UK: Cambridge University Press.

Hill, J., & Wilkinson, C. (2004). *Methods for ecological monitoring of coral reefs*. Townsville, QLD: Australian Institute of Marine Science.

Hilty, J., & Merenlender, A. (2000). Faunal indicator taxa selection for monitoring ecosystem health. *Biological Conservation*, *92*(2), 185–197.

Hixon, M. A., & Beets, J. P. (1993). Predation, prey refuges, and the structure of coral-reef fish assemblages. *Ecological Monographs*, *63*(1), 77–101.

Hodgson, G., Hill, J., Kiene, W., Maun, L., Mihaly, J., Liebeler, J., … Torres, R. (2006). *Reef Check instruction manual: A guide to Reef Check coral reef monitoring*. Los Angeles, CA: Reef Check Foundation.

Hodgson, G., & Liebeler, J. (2002). *The global coral reef crisis: Trends and solutions*. Los Angeles, CA: Reef Check Foundation.

Holbrook, S. J., Schmitt, R. J., Messmer, V., Brooks, A. J., Srinivasan, M., Munday, P. L., & Jones, G. P. (2015). Reef fishes in biodiversity hotspots are at greatest risk from loss of coral species. *PLoS ONE*, *10*(5), e0124054.

Holland, K. N., Peterson, J. D., Christopher, G. L., & Wetherbee, B. M. (1993). Movements distribution and growth rates of the white goatfish *Mulloides flavolineatus* in a fisheries conservation zone. *Bulletin of Marine Science*, *52*(3), 982–992.

Holland, K. N., Wetherbee, B. M., Peterson, J. D., & Lowe, C. G. (1993). Movements and distribution of hammerhead shark pups on their natal grounds. *Copeia*, 495–502.

Holmlund, C. M., & Hammer, M. (1999). Ecosystem services generated by fish populations. *Ecological Economics*, *29*(2), 253–268.

Honda, K., Nakamura, Y., Nakaoka, M., Uy, W. H., & Fortes, M. D. (2013). Habitat use by fishes in coral reefs, seagrass beds and mangrove habitats in the Philippines. *PLoS ONE*, *8*(8), e65735.

Hori, M. (2006). Intertidal surfgrass as an allochthonous resource trap from the subtidal habitat. *Marine Ecology Progress Series*, *314*, 89–96.

Hori, M., Suzuki, T., Monthum, Y., Srisombat, T., Tanaka, Y., Nakaoka, M., & Mukai, H. (2009). High seagrass diversity and canopy-height increase associated fish diversity and abundance. *Marine Biology*, *156*(7), 1447–1458.

Hourigan, T. F., Timothy, C. T., & Reese, E. S. (1988). Coral reef fishes as indicators of environmental stress in coral reefs. In *Marine organisms as indicators* (pp. 107–135). Springer.

Huang, D., Licuanan, W. Y., Hoeksema, B. W., Chen, C. A., Ang, P. O., Huang, H., … Chou, L. M. (2015). Extraordinary diversity of reef corals in the South China Sea. *Marine Biodiversity*, *45*(2), 157–168.

Hughes, T. P., Graham, N. a J., Jackson, J. B. C., Mumby, P. J., & Steneck, R. S. (2010). Rising to the challenge of sustaining coral reef resilience. *Trends in Ecology & Evolution*, *25*(11), 633–642.

Hughes, T. P., Rodrigues, M. J., Bellwood, D. R., Ceccarelli, D., Hoegh-Guldberg, O., McCook, L., … Willis, B. (2007). Phase shifts, herbivory, and the resilience of coral reefs to climate change. *Current Biology*, *17*(4), 360–365.

Irving, A. D., Tanner, J. E., & Gaylard, S. G. (2013). An integrative method for the evaluation, monitoring, and comparison of seagrass habitat structure. *Marine Pollution Bulletin*, *66*(1–2), 176–184.

Japar Sidik, B., Arshad, A., & Law, A. T. (1995). *Inventory for seagrass beds in Malaysia. UNEP: EAS-35: Malaysia Inventory of Watersheds, Coastal Wetlands, Seagrasses and Coral Reefs* (Vol. 50662). Kuala Lumpur, MY: Department of Environment, Ministry of Science, Technology and Environment.

Japar Sidik, B., Muta Harah, Z., Kanamoto, Z., Mohd Pauzi, A., Sidik, B. J., Arshad, A., … Sugiyama, S. (2001). Seagrass communities of the Straits of Malacca. *Aquatic Resource and Environmental Studies of the Straits of Malacca*, 81–98.

Jaxion-Harm, J., Saunders, J., & Speight, M. R. (2012). Distribution of fish in seagrass, mangroves and coral reefs: Life-stage dependent habitat use in Honduras. *Revista de Biologia Tropical*, *60*(2), 683–698.

Jelbart, J. E., Ross, P. M., & Connolly, R. M. (2007). Fish assemblages in seagrass beds are influenced by the proximity of mangrove forests. *Marine Biology*, *150*(5), 993–1002.

Jones, D., Walter, J., Brooks, E., & Serafy, J. (2010). Connectivity through ontogeny: Fish population linkages among mangrove and coral reef habitats. *Marine Ecology Progress Series*, *401*, 245–258.

Jones, G. P., McCormick, M. I., Srinivasan, M., & Eagle, J. V. (2004). Coral decline threatens fish biodiversity in marine reserves. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(21), 8251–8253.

Kelley, R. (2012). *Indo-Pacific Coral finder 2.0*. EYO Guides, Townsville, QLD: The Australian Coral Reef Society.

Kohler, K. E., & Gill, S. M. (2006). Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. *Computers & Geosciences*, *32*(9), 1259–1269.

Komyakova, V., Munday, P. L., & Jones, G. P. (2013). Relative importance of coral cover, habitat complexity and diversity in determining the structure of reef fish communities. *PLoS ONE*, *8*(12), e83178.

Krebs, C. J. (1989). *Ecological methodology*. New York, NY: Harper & Row New York.

Kuiter, R. H., & Debelius, H. (2006). *World atlas of marine fishes*. Germany: IKAN; ISBN 3-925919-77-5.

Kuo, J., & Den Hartog, C. (2007). Seagrass morphology, anatomy, and ultrastructure. In *Segrasses: Biology, ecology and conservation* (pp. 51–87). Springer.

Larkum, A. W. D., Orth, R. J., & Duarte, C. M. (2006). *Seagrasses : Biology Ecology and Conservation*. Dordrecht, NL: Springer Netherlands.

Leopardas, V., Uy, W., & Nakaoka, M. (2014). Benthic macrofaunal assemblages in multispecific seagrass meadows of the southern Philippines: Variation among vegetation dominated by different seagrass species. *Journal of Experimental Marine Biology and Ecology*, *457*, 71–80.

Lewis III, F. G., & Stoner, A. W. (1983). Distribution of macrofauna within seagrass beds an explanation for patterns of abundance. *Bulletin of Marine Science*, *33*(2), 296–304.

Lin, D., Foster, D. P., & Ungar, L. H. (2011). VIF regression: A fast regression algorithm for large data. *Journal of the American Statistical Association*, *106*(493), 232-247.

Losey, G. S. (1978). The symbiotic behavior of fishes. *The Behavior of Fish and Other Aquatic Animals*, 1–31.

Losey, G. S. (1979). Fish cleaning symbiosis: Proximate causes of host behaviour. *Animal Behaviour*, *27*, 669–685.

Luckhurst, B. E., & Luckhurst, K. (1978). Analysis of the influence of substrate variables on coral reef fish communities. *Marine Biology*, *49*(4), 317–323.

Machan, R., & Fedra, K. (1975). A new towed underwater camera system for wide-range benthic surveys. *Marine Biology*, *33*(1), 75–84.

Magno, M., & Villanoy, C. (2006). Quantifying the complexity of Philippine coastlines for estimating entrainment potential. In *Proceedings 10th International Coral Reef Symposium* (pp. 1471-1476). Okinawa, JP: International Society of Reef Studies.

Malaysian Meteorological Department. (2016). Retrieved August 22, 2016, from http://www.met.gov.my

Mallet, D., & Pelletier, D. (2014). Underwater video techniques for observing coastal marine biodiversity: A review of sixty years of publications (1952-2012). *Fisheries Research*, *154*, 44–62.

Mann, H. B., & Whitney, D. R. (1947). On a test of whether one of two random variables is stochastically larger than the other. *The Annals of Mathematical Statistics*, 50–60.

Matsunuma, M., Motomura, H., Matsuura, K., Shazili, N. A. M., & Ambak, M. A. (2011). *Fishes of Terengganu: East coast of Malay Peninsula, Malaysia*. Terengganu, MY: National Museum of Nature and Science, Universiti Malaysia Terengganu and Kagoshima University Museum.

McClanahan, T. R., Donner, S. D., Maynard, J. A, MacNeil, M. A., Graham, N. A. J., Maina, J., … van Woesik, R. (2012). Prioritizing key resilience indicators to support coral reef management in a changing climate. *PLoS ONE*, *7*(8), e42884.

McClanahan, T. R., Marnane, M. J., Cinner, J. E., & Kiene, W. E. (2006). A comparison of marine protected areas and alternative approaches to coral-reef management. *Current Biology*, *16*(14), 1408–1413.

McCloskey, R. M., & Unsworth, R. K. F. (2015). Decreasing seagrass density negatively influences associated fauna. *PeerJ*, *3*, e1053.

McCook, L. J., Almany, G. R., Berumen, M. L., Day, J. C., Green, a. L., Jones, G. P., … Thorrold, S. R. (2009). Management under uncertainty: Guide-lines for incorporating connectivity into the protection of coral reefs. *Coral Reefs*, *28*(2), 353–366.

McCoy, E. D., & Bell, S. S. (1991). Habitat structure: The evolution and diversification of a complex topic. In S. Bell, E. McCoy & H. Mushinsky (Eds.), *Habitat Structure SE - 1* (Vol. 8, pp. 3–27). Dordrecht, NL: Springer Netherlands.

McCullagh, P., & Nelder, J. A. (1989). *Generalized Linear Models, no. 37 in Monograph on Statistics and Applied Probability*. London, UK: Chapman & Hall.

Mckenzie, L. (2003). *Guidelines for the rapid assessment and mapping of tropical seagrass habitats*. Cairns, QLD: Department of Primary Industries.

McKinnon, D., He, H., Upcroft, B., & Smith, R. N. (2011). Towards automated and in-situ, near-real time 3-D reconstruction of coral reef environments. *Proceedings of the MTS/IEEE Oceans* (pp. 1–10). Kona, HI: MTS/IEEE.

Messmer, V., Jones, G. P., Munday, P. L., Holbrook, S. J., Schmitt, R. J., & Brooks, A. J. (2011). Habitat biodiversity as a determinant of fish community structure on coral reefs. *Ecology*, *92*(12), 2285–2298.

Moberg, F., & Folke, C. (1999). Ecological goods and services of coral reef ecosystems. *Ecological Economics*, *29*(2), 215–233.

Montgomery, D. C., Peck, E. a., & Vining, G. G. (2012). *Introduction to linear regression analysis* (4th ed., Vol. 821). Hoboken, NJ: John Wiley & Sons.

Montgomery, W. L. (2011). Coral Reefs: An Ecosystem in Transition. In Z. Dubinsky & N. Stambler (Eds.), *Coral Reefs: An Ecosystem in Transition* (pp. 327–346). Dordrecht, NL: Springer Netherlands.

Moore, E. C., & Hovel, K. A. (2010). Relative influence of habitat complexity and proximity to patch edges on seagrass epifaunal communities. *Oikos*, *119*(8), 1299–1311.

Mumby, P. J. (2006). Connectivity of reef fish between mangroves and coral reefs: Algorithms for the design of marine reserves at seascape scales. *Biological Conservation*, *128*(2), 215–222.

Mumby, P. J., Edwards, A. J., Arias-gonzalez, J. E., Lindeman, K. C., Blackwell, P. G., Gall, A., … Llewellyn, G. (2004). Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature*, *427*, 533–536.

Mumby, P. J., & Steneck, R. S. (2008). Coral reef management and conservation in light of rapidly evolving ecological paradigms. *Trends in Ecology and Evolution*, *23*(10), 555–563.

Nagelkerken, I. (2009). *Ecological Connectivity among Tropical Coastal Ecosystems*. London, UK: Springer.

Nagelkerken, I., Dorenbosch, M., Verberk, W. C. E. P., Cocheret de la Moriniere, E., & Van der Velde, G. (2000a). Importance of shallow-water biotopes of a Caribbean bay for juvenile coral reef fishes: Patterns in biotope association, community structure and spatial distribution. *Marine Ecology Progress Series*, *202*, 175–192.

Nagelkerken, I., Roberts, C., van der Velde, G., Dorenbosch, M., van Riel, M., Cocheret de la Morinière, E., & Nienhuis, P. (2002). How important are mangroves and seagrass beds for coral-reef fish? The nursery hypothesis tested on an island scale. *Marine Ecology Progress Series*, *244*, 299–305.

Nagelkerken, I., & Van Der Velde, G. (2002). Do non-estuarine mangroves harbour higher densities of juvenile fish than adjacent shallow-water and coral reef habitats in Curaçao (Netherlands Antilles)? *Marine Ecology Progress Series*, *245*, 191–204.

Nagelkerken, I., van der Velde, G., Gorissen, M. W., Meijer, G. J., Van't Hof, T., & den Hartog, C. (2000b). Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. *Estuarine, Coastal and Shelf Science*, *51*(1), 31–44.

Nakamura, Y., Horinouchi, M., Shibuno, T., Tanaka, Y., Miyajima, T., Koike, I., … Sano, M. (2008). Evidence of ontogenetic migration from mangroves to coral reefs by black-tail snapper *Lutjanus fulvus*: Stable isotope approach. *Marine Ecology Progress Series*, *355*(2001), 257–266.

National Hydrographic Centre. (2013). *Tide tables Malaysia 2013* (Vol. 1). Port Klang, SGR: National Hydrographic Centre, Royal Malaysian Navy.

National Hydrographic Centre. (2014). *Tide tables Malaysia 2014* (Vol. 1). Port Klang, SGR: National Hydrographic Centre, Royal Malaysian Navy.

Nelson, J. S. (2006). *Fishes of the World* (4th ed). New York, NY: John.

Odum, H. T., & Odum, E. P. (1955). Trophic structure and productivity of a windward coral reef community on Eniwetok Atoll. *Ecological Monographs*, *25*(3), 291–320.

Oksanen, J., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., Hara, R. B. O., … Stevens, M. H. H. (2014). vegan: Community ecology package. R package version 2.5-3.

Ooi, J. L. S., Kendrick, G. A., & Van Niel, K. P. (2011a). Effects of sediment burial on tropical ruderal seagrasses are moderated by clonal integration. *Continental Shelf Research*, *31*(19–20), 1945–1954.

Ooi, J. L. S., Kendrick, G. A., Van Niel, K. P., & Affendi, Y. A. (2011b). Knowledge gaps in tropical Southeast Asian seagrass systems. *Estuarine, Coastal and Shelf Science*, *92*(1), 118–131.

Ooi, J. L. S., Van Niel, K. P., Kendrick, G. a., & Holmes, K. W. (2014). Spatial structure of seagrass suggests that size-dependent plant traits have a strong influence on the distribution and maintenance of tropical multispecies meadows. *PLoS ONE*, *9*(1), e86782.

Orth, R. J., Carruthers, T. I. M. J. B., Dennison, W. C., Duarte, C. M., James, W., Jr, K. L. H., … Williams, S. L. (2006). A global crisis for seagrass ecosystems. *Bioscience*, *56*(12), 987–996.

Orth, R. J., Heck, K. L., & van Montfrans, J. (1984). Faunal communities in seagrass beds: A review of the influence of plant structure and prey characteristics on predator-prey relationships. *Estuaries*, *7*(4), 339–350.

Paddack, M. J., Reynolds, J. D., Aguilar, C., Appeldoorn, R. S., Beets, J., Burkett, E. W., … Côté, I. M. (2009). Recent Region-wide Declines in Caribbean Reef Fish Abundance. *Current Biology*, *19*(7), 590–595.

Parrish, J. (1989). Fish communities of interacting shallow-water habitats in tropical oceanic regions. *Marine Ecology Progress Series*, *58*, 143–160.

Parrish, J., Callaham, M. ., & Norris, J. . (1985). Fish trophic relationships that structure reef communities. In *Proceedings of the 5th International Coral Reef Congress* (Vol. 4, pp. 73–78). Tahiti, PF: International Society of Reef Studies.

Pelletier, D., Leleu, K., Mallet, D., Mou-Tham, G., Hervé, G., Boureau, M., & Guilpart, N. (2012). Remote high-definition rotating video enables fast spatial survey of marine underwater macrofauna and habitats. *PLoS ONE*, *7*(2), e30536.

Pelletier, D., Leleu, K., Mou-Tham, G., Guillemot, N., & Chabanet, P. (2011). Comparison of visual census and high definition video transects for monitoring coral reef fish assemblages. *Fisheries Research*, *107*(1–3), 84–93.

Purkis, S. J., Graham, N. A. J., & Riegl, B. M. (2008). Predictability of reef fish diversity and abundance using remote sensing data in Diego Garcia (Chagos Archipelago). *Coral Reefs*, *27*(1), 167–178.

R Core Team. (2017). R: A language and environment for statistical computing. Vienna, AT: R Foundation for Statistical Computing.

Radford, C. a., Jeffs, A. G., Tindle, C. T., Cole, R. G., & Montgomery, J. C. (2005). Bubbled waters: The noise generated by underwater breathing apparatus. *Marine and Freshwater Behaviour and Physiology*, *38*(4), 259–267.

Ray, G. C. (1988). Ecological diversity in coastal zones and oceans. *Biodiversity*, 36–50.

Reef Check Malaysia. (2014). *Status of coral reefs in Malaysia , 2013*. Kuala Lumpur, MY: Reef Check Malaysia.

Reef Check Malaysia. (2015). *Status of coral reefs in Malaysia, 2015*. Retrieved June 15, 2015, from http://www.reefcheck.org.my/media-information/annual-survey-reports

Reese, E. S. (1981). Predation on corals by fishes of the family Chaetodontidae: Implications for conservation and management of coral reef ecosystems. *Bulletin of Marine Science*, *31*(3), 594–604.

Rice, E. L., & Kelting, R. W. (1955). The species-area curve. *Ecology*, *36*(1), 7–11.

Risk, M. J. (1972). *Fish diversity on a coral reef in the Virgin Islands.* Los Angeles, CA: Smithsonian Institution.

Robbins, B. D., & Bell, S. S. (1994). Seagrass landscapes: A terrestrial approach to the marine subtidal environment. *Trends in Ecology & Evolution*, *9*(8), 301–304.

Sale, P. F. (1971). Extremely limited home range in a coral reef fish , *Dascyllus aruanus* (Pisces; Pomacentridae). *American Society of Ichthyologists and Herpetologists*, *1971*(2), 324–327.

Sale, P. F. (1991). *The ecology of fishes on coral reefs*. London, UK: Gulf Professional Publishing.

Sale, P. F., Van Lavieren, H., Ablan Lagman, M. C., Atema, J., Butler, M., Fauvelot, C., … Stewart, H. L. (2010). *Preserving reef connectivity: A handbook for marine protected area managers*. Melbourne, QLD: Connectivity Working Group, Coral Reef Targeted Research & Capacity Building for Management Program, UNU-INWEH.

Sano, M., Shimizu, M., & Nose, Y. (1987). Long-term effects of destruction of hermatypic corals by Acanthaster plana infestation on reef fish communities at Iriomote Island, Japan. *Marine Ecology Progress Series*, *37*, 191–199.

Sasekumar, A., Leh, C., Chong, V. C., D'Cruz, R., & Audrey, M. L. (1989). *The Sungai Pulai (Johor): A unique mangrove estuary*. Kuala Lumpur, MY: Persatuan Sains Lautan Malaysia.

Schobernd, Z. H., Bacheler, N. M., Conn, P. B., & Trenkel, V. (2014). Examining the utility of alternative video monitoring metrics for indexing reef fish abundance. *Canadian Journal of Fisheries and Aquatic Sciences*, *71*(3), 464–471.

Short, F., Carruthers, T., Dennison, W., & Waycott, M. (2007). Global seagrass distribution and diversity: A bioregional model. *Journal of Experimental Marine Biology and Ecology*, *350*(1–2), 3–20.

Shulman, M. J. (1985). Recruitment of coral reef fishes: Effects of distribution of predators and shelter. *Ecology*, *66*(3), 1056–1066.

Smith, T. M., Hindell, J. S., Jenkins, G. P., & Connolly, R. M. (2008). Edge effects on fish associated with seagrass and sand patches. *Marine Ecology Progress Series*, *359*, 203–213.

Smith, T. M., Jenkins, G. P., & Hutchinson, N. (2012). Seagrass edge effects on fish assemblages in deep and shallow habitats. *Estuarine, Coastal and Shelf Science*, *115*, 291–299.

Spencer, M. L., Stoner, A. W., Ryer, C. H., & Munk, J. E. (2005). A towed camera sled for estimating abundance of juvenile flatfishes and habitat characteristics: Comparison with beam trawls and divers. *Estuarine, Coastal and Shelf Science*, *64*(2–3), 497–503.

Stobart, B., Díaz, D., Álvarez, F., Alonso, C., Mallol, S., & Goñi, R. (2015). Performance of baited underwater video: Does it underestimate abundance at high population densities? *PLoS ONE*, *10*(5), e0127559.

Stockwell, B., & Carpenter, K. E. (2012). Fish Fauna. In K. Kassem, B. W. Hoeksema, & Y. A. Affendi (Eds.), *Semporna Marine Ecological Expedition. WWF-Malaysia, NCB Naturalis, Universiti Malaysia Sabah* (pp. 43–64). Kota Kinabalu, Malaysia.

Stoner, A. W. (1980). The role of seagrass biomass in the organization of benthic macrofaunal assemblages. *Bulletin of Marine Science*, *30*(3), 537–551.

Syms, C., & Jones, G. P. (2000). Disturbance, habitat structure, and the dynamics of a coral-reef fish community. *Ecology*, *81*(10), 2714–2729.

Tan, C. H., & Heron, S. F. (2011). First observed severe mass bleaching in Malaysia, Greater Coral Triangle. *Galaxea, Journal of Coral Reef Studies*, *13*(1), 27–28.

Taylor, M. D., Baker, J., & Suthers, I. M. (2013). Tidal currents, sampling effort and baited remote underwater video (BRUV) surveys: Are we drawing the right conclusions? *Fisheries Research*, *140*, 96–104.

Thomas, C. R., & Heron, S. F. (2011). South-East Asia Coral Bleaching Rapid Response : Final Report (April). Townsville, QLD: CSIRO.

Thresher, R. E. (1991). Geographic variability in the ecology of coral reef fishes: Evidence, evolution, and possible implications. *The Ecology of Fishes on Coral Reefs*, 401–436.

Todd, P. A. (2008). Morphological plasticity in scleractinian corals. *Biological Reviews*, *83*(3), 315–337.

Townsend, D. (2015). First comprehensive list of the coral reef fishes of Tunku Abdul Rahman Park, Sabah, Malaysia (Borneo). *Check List*, *11*(7), 1762.

Tulevech, S. M., & Recksiek, C. W. (1994). Acoustic tracking of adult white grunt, *Haemulon plumieri*, in Puerto Rico and Florida. *Fisheries Research*, *19*(3), 301–319.

Tun, K., Chou, L. M., Low, J., Yeemin, T., Phongsuwan, N., Setiasih, N., … Bochove, J. V. (2010). Status of coral reefs in East Asian Seas region: 2010. In *A regional overview on the 2010 coral bleaching event in Southeast Asia* (pp. 9–26). Tokyo, JP: GCRMN.

Tuya, F., Vanderklift, M. A., Wernberg, T., & Thomsen, M. S. (2011). Gradients in the number of species at reef-seagrass ecotones explained by gradients in abundance. *PLoS ONE*, *6*(5), e20190.

Underwood, A. J. (1997). *Experiments in ecology: Their logical design and interpretation using analysis of variance*. Cambridge, UK: Cambridge University Press.

United Nations. (n.d.). Goal 14: Conserve and sustainably use the oceans, seas and marine resources. Retrieved January 20, 2018, from https://www.un.org/sustainable development/oceans/

Unsworth, R., De León, P., Garrard, S., Jompa, J., Smith, D., & Bell, J. (2008). High connectivity of Indo-Pacific seagrass fish assemblages with mangrove and coral reef habitats. *Marine Ecology Progress Series*, *353*, 213–224.

Unsworth, R. K. F., Bell, J. J., & Smith, D. J. (2007). Tidal fish connectivity of reef and sea grass habitats in the Indo-Pacific. *Journal of the Marine Biological Association of the UK*, *87*(05), 1287–1296.

Venables, W. N., & Dichmont, C. M. (2004). GLMs, GAMs and GLMMs: An overview of theory for applications in fisheries research. *Fisheries Research*, *70*(2–3), 319–337.

Vermaat, J. E., Agawin, N. S. R., Duarte, C. M., Fortes, M. D., Marbà, N., & Uri, J. S. (1995). Meadow maintenece, growth and productivity of a mixed Philippine seagrass bed. *Marine Ecology Progress Series*, *124*, 215–225.

Verweij, M. C., Nagelkerken, I., Hans, I., Ruseler, S. M., & Mason, P. R. D. (2008). Seagrass nurseries contribute to coral reef fish populations. *Limnology and Oceanography*, *53*(4), 1540–1547.

Vittinghoff, E., & McCulloch, C. E. (2007). Relaxing the rule of ten events per variable in logistic and cox regression. *American Journal of Epidemiology*, *165*(6), 710–718.

Warfe, D. M., & Barmuta, L. A. (2004). Habitat structural complexity mediates the foraging success of multiple predator species. *Oecologia*, *141*(1), 171–178.

Watson, D. L., Harvey, E. S., Anderson, M. J., & Kendrick, G. a. (2005). A comparison of temperate reef fish assemblages recorded by three underwater stereo-video techniques. *Marine Biology*, *148*(2), 415–425.

Watson, R. A., Coles, R. G., & Long, W. J. L. (1993). Simulation Estimates of Annual Yield and Landed Value for Commercial Penaeid Prawns from a Tropical Seagrass Habitat , Northern Queensland, Australia. *Australian Journal of Marine and Freshwater Research*, (44), 211–219.

Waycott, M., Duarte, C. M., Carruthers, T. J. B., Orth, R. J., Dennison, W. C., Olyarnik, S., … Williams, S. L. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences, USA*, *106*(30), 12377–12381.

Waycott, M., Mckenzie, L. J., Mellors, J. E., Ellison, J. C., Sheaves, M. T., Collier, C., … Payri, C. E. (2011). Vulnerability of mangroves , seagrasses and intertidal flats in the tropical Pacific to climate change. In J.D. Bell, J.E. Johnson & A.J. Hobday (Eds.) *Vulnerability of tropical pacific fisheries and aquaculture to climate change* (pp. 297–368). Noumea, NC: Secretariat of the Pacific Community.

Whitmarsh, S. K., Fairweather, P. G., Brock, D. J., & Miller, D. (2014). Nektonic assemblages determined from baited underwater video in protected versus unprotected shallow seagrass meadows on Kangaroo Island, South Australia. *Marine Ecology Progress Series*, *503*, 205–218.

Wilcoxon, F. (1945). Individual comparisons by ranking methods. *Biometrics Bulletin*, *1*(6), 80–83.

Wilkinson, C. C. R. (2004). *Status of coral reefs of the world: 2004*. Townsville, QLD: Australian Institute of Marine Science.

Williams, D. M. (1986). Temporal variation in the structure of reef slope fish communities (central Great Barrier Reef): Short-term effects of *Acanthaster planci* infestation. *Marine Ecology Progress Series*, *28*, 157–168.

Williams, D. M., & Hatcher, A. I. (1983). Structure of fish communities on outer slopes of inshore, mid-shelf and outer shelf reefs of the Great Barrier Reef. *Marine Ecology Progress Series*, *10*, 239–250.

Williams, S. L., & Heck, K. L. J. (2001). Seagrass community ecology. In M. D. Bertness, S. D. Gaines, & M. E. Hay (Eds.), *Marine Community Ecology* (pp. 317–338). Sunderland, MA: Sinauer Associates.

Willis, T. J., Millar, R. B., & Babcock, R. C. (2000). Detection of spatial variability in relative density of fishes: Comparison of visual census, angling, and baited underwater video. *Marine Ecology Progress Series*, *198*, 249–260.

Wilson, S. K., Burgess, S. C., Cheal, A. J., Emslie, M., Fisher, R., Miller, I., … Hugh, P. A. S. (2008). Habitat utilization by coral reef fish : Implications for specialists vs . generalists in a changing environment. *Journal of Animal Ecology*, (77), 220–228.

Wood, E. (1986). Ecological study of coral reefs. *Sabah Society Journal*, *VIII*(2), 310p.

Yeager, L. A., & Ariaz-Gonzalez, E. J. (2008). Preliminary survey of fish community composition in seagrass habitat in two back-reef lagoons of southern Mexican Caribbean. *Gulf and Caribbean Research*, *20*, 41–47.

Young, G. C., Dey, S., Rogers, A. D., & Exton, D. (2017). Cost and time-effective method for multiscale measures of rugosity, fractal dimension, and vector dispersion from coral reef 3D models. *PLoS ONE*, *12*(4), e0175341.

Zakaria, M. H., Bujang, J. S., Rizally, F., & Razak, A. (2003). Occurrence and morphological description of seagrass from Pulau Redang, Terengganu, Malaysia. *Jurnal Teknologi*, *38*(C), 29–39.

Zeller, D. C. (1997). Home range and activity patterns of the coral trout *Plectropomus leopardus* (Serranidae). *Marine Ecology Progress Series*, *154*, 65–77.

Zuur, A. F., Ieno, E. N., & Elphick, C. S. (2010). A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution*, *1*(1), 3–14.

LIST OF PUBLICATIONS AND PAPER PRESENTED

Publications:

Ho, N. A. J., Ooi, J. L. S., Affendi, Y. A., & Chong, V. C. (2018). Influence of habitat complexity on fish density and species richness in structurally simple forereef seagrass meadows. *Botanica Marina*, 61(6). Accepted on Oct 12, 2018. Published online on Nov 14, 2018. doi:10.1515/bot-2017-0115.

Conferences attended:

Oral presentation

Ho, N. A. J., Ooi, J. L. S., Affendi, Y. A., & Chong, V. C. (2014). Tropical fish habitat utilisation patterns: comparisons between adjacent habitats of coral reefs and seagrass meadows. *The 3rd Asia Pacific Coral Reefs Symposium*, 23-27 June 2014 at Kenting, Taiwan.

Ho, N. A. J., Ooi, J. L. S., Affendi, Y. A., & Chong, V. C. (2017). A study on tropical forereef seagrass meadows in South China Sea: the relative importance of habitat structural complexity and habitat configuration on fish community structure. *The 10th Western Pacific International Scientific Conference*, 17-20 April 2017 at Qingdao, China.

Ho, N. A. J., Ooi, J. L. S., Affendi, Y. A., Chong, V. C. & Then A. Y. H. (2018). Influence of habitat complexity and proximity to adjacent habitat on fish communities in tropical forereef seagrass meadows. *The World Seagrass Conference 2018*, 11-14 June 2018 at National University of Singapore, Singapore.

Poster presentation

Ho, N. A. J., Ooi, J. L. S., Affendi, Y. A., Chong, V. C. & Then A. Y. H. (2018). Caught in action: the rabbitfish Siganus guttatus (Bloch, 1787) feeding selectively on seagrass in a tropical seagrass meadow. *The 4th Asia-Pacific Coral Reef Symposium*, 4-8 June 2018 at Macro Polo Plaza Hotel in Cebu city, Philippines.

Conference paper:

Wong, S. L., Yu, Y. P., **Ho, N. A. J**., & Paramesran, R. (2014). Comparative analysis of underwater image enhancement methods in different color spaces. In *Intelligent Signal Processing and Communication Systems (ISPACS)*, 2014 International Symposium (pp. 034-038). IEEE.