1 Introduction

1.1 Coral reefs

Planet Earth is often called the “ocean planet” as more than 70 percent of earth’s surface is covered with seawater. About half the world’s coastlines are in the tropics and about 600,000 km² of tropical coastlines are made of coral reefs (Sapp, 1999). These unique systems are considered the most productive communities in the seas and they are home to thousands of different species of sea creatures (Birkeland, 1997). Although these complicated systems are known to be the biggest structures made by living organisms, they are very fragile and highly sensitive to water quality (Veron, 2000; Veron *et al.*, 2009)

Corals reefs benefit people and the environment in several ways. Coral reefs are among the most biologically productive ecosystems in the world (Birkeland, 1997). They have high economic value as hundreds of millions of coastal people in over 100 countries depend on the reef ecosystem and its harvestable marine resources such as fish and invertebrates for food and livelihoods (Edwards & Gomez, 2007). The total potential sustainable annual economic net benefits per km² of healthy coral reef in Southeast Asia is estimated to range from $23,100 to $270,000 (Conservation International, 2008). The value of the sustainable coral reef fisheries alone is US$2.4 billion per year in Southeast Asia (Burke *et al.*, 2002). Natural products from coral reefs are used as a treatment for many diseases such as cancer and AIDS. Coral reefs are natural barriers that protect nearby shorelines and prevent coastal erosion. They provide structural complexity and shelter for both fishes and invertebrates and as well as providing the shelter for herbivores, they can also control algal overgrowth (Birkeland, 1997; Edwards & Gomez, 2007). Furthermore, coral reefs play an important role in tourism industry

which is the largest industry in the world. One of the major tourists' destinations is attractive diving sites with high levels of biodiversity, especially coral reefs because of their natural beauty (Birkeland, 1997; Davenport & Davenport, 2006; Edwards & Gomez, 2007). For instance, the potential recreational value of the reefs in Pulau Payar Marine Park, Malaysia has been estimated to be $390,000 per year (Yeo, 1998).

Coral reefs have a wide range of distribution, they are mostly found in tropical and sub-tropical waters around the world especially shallow, warm tropical waters with water temperatures between 18°C and 30°C which is between latitudes 30° North and 30° South **(**Hoegh-Guldberg, 1999)

The marine zones containing at least 500 species of reef-building coral makes a triangle shape area, which is known as the "Coral Triangle" (Figure 1.1). It covers approximately 2.3 million square miles of ocean across all, or parts of, the seas of six countries in the South East Asia and the Pacific (Indonesia, Malaysia, Papua New Guinea, the Philippines, the Solomon Islands, and Timor-Leste) (Tun *et al.*, 2008; Hoegh-Guldberg *et al.*, 2009). According to the WWF report by Hoegh-Guldberg *et al.* (2009) this vast area with rich coral reef diversity has over 30% of the world's coral reefs, including 76% of the world's reef building corals and over 35% of the world's coral reef fish species. Malaysia is a country in Southeast Asia region, located in the Indo-West Pacific. This region has high biological significance, as it contains some of the most extensive coastlines and diverse coral reefs in the world. The coral reef area in Southeast Asia region itself is about 100,000 km², and about 4006 km² of the coral reefs in the region is in Malaysian waters (Tun *et al.*, 2008). Malaysia is one of the four countries (Indonesia, Malaysia, Philippines and Vietnam) in Southeast Asia with the

highest hard coral species. About 400 hard coral reefs species have been recorded in Malaysia (Tun *et al.*, 2008).

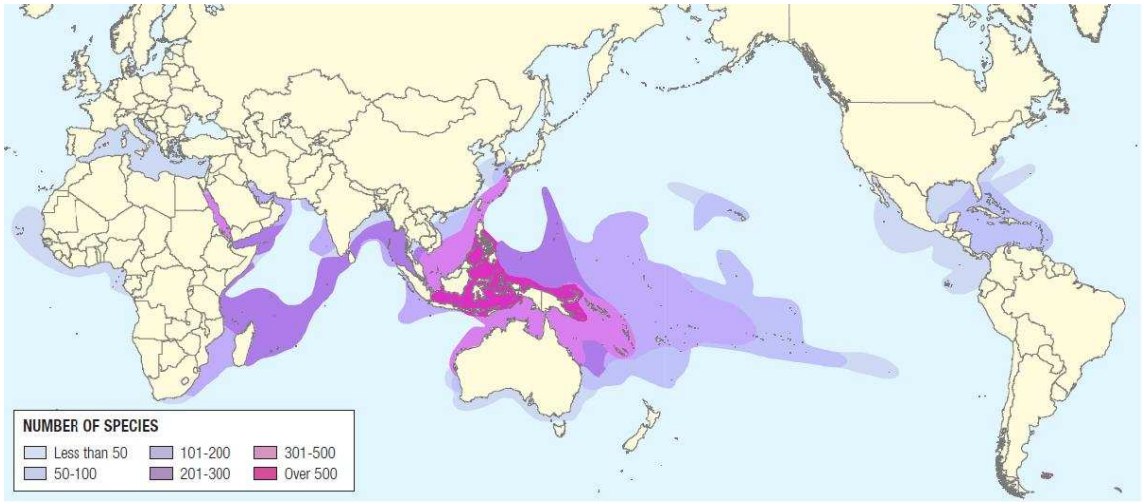


Figure 1.1 Diversity of the reef-building scleractinian corals of the world (Source: Burke *et al.*, 2002).

Coral reefs are classified into three main characteristic structures: Fringing, Barrier and Atoll. 'Fringing reefs', which are the most common, occur adjacent to coastlines and project seaward directly from the shore, forming borders along the shoreline and surrounding islands. They are usually unconsolidated where protected from wave action, and usually have a high component of non-carbonate sediment. 'Barrier reefs' typically develop 10 to 100s kilometres from the coastline and 'Atolls' typically consist of a string of narrow islands which may be vegetated and have a shallow central lagoon (Veron, 2000). Coral reefs in Malaysia are fringing and atolls (Tun *et al.*, 2004) while corals in east coast of Peninsular Malaysia, where the area of the study lies, are dominated by shallow fringing reefs (Harborne *et al.*, 2000; Morton & Blackmore, 2001).

1.2 Scleractinian corals

Corals are invertebrate animals in the Class Anthozoa, the largest class of organisms within the Phylum Cnidaria. Hard corals (scleractinians) make up the largest order of anthozoans, and are the group primarily responsible for laying the foundations of, and building up, reef structures. Each individual coral polyp has tentacles around its central mouth which sits in a limestone skeletal case, secreted by the polyp (Figure 1.2) (Veron, 2000).

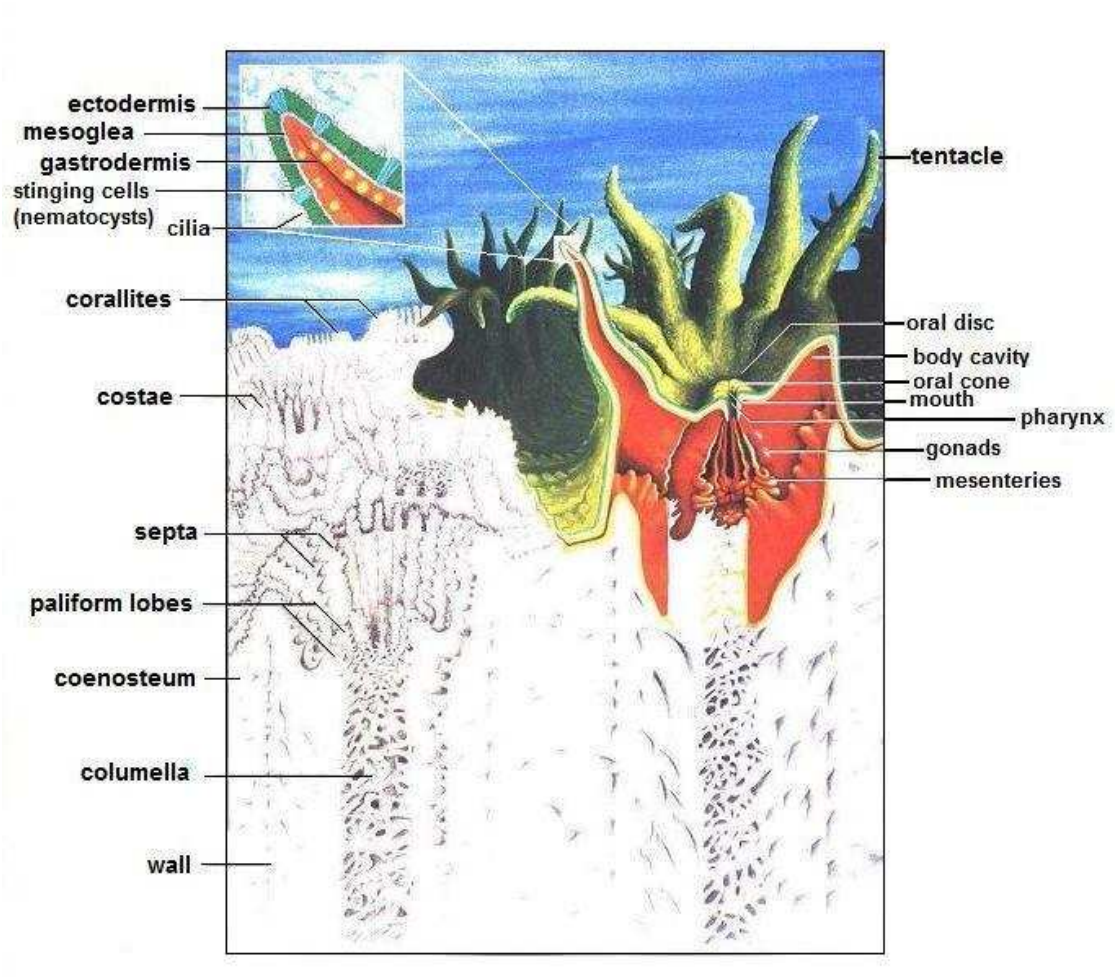


Figure 1.2 Coral structure. The general structure of the polyp and underlying skeleton (Veron, 2000).

Coral cover is a critical measure of habitat loss and degradation and hard coral (scleractinians) cover is one of the most usual indicators to habitat or to physical disturbance of habitat as it represents the most important component of the entire coral reef ecosystem (Gomez & Yap, 1988; Nugues & Roberts, 2003; Chabanet *et al.*, 2005; Al-Zibdah *et al.*, 2007; Bruno & Selig, 2007).

Colonies of reef-building (hermatypic) corals exhibit a wide range of shapes. According to Veron (2000) the most common growth-forms of corals are: 'Massive' which are solid and similar in shape in all dimensions; 'Encrusting' which grows as a thin layer against the substrate; 'Branching'; 'Columnar'; 'Laminar' (plate-like); 'Free-living' and 'Foliose' (= foliaceous, forming a whorl) (Figure 1.3). However, there are many other different shapes of corals from other researchers and authors. For example, 'Submassive' corals have knobs, columns or wedges protruding from an encrusting base (English *et al.*, 1997).

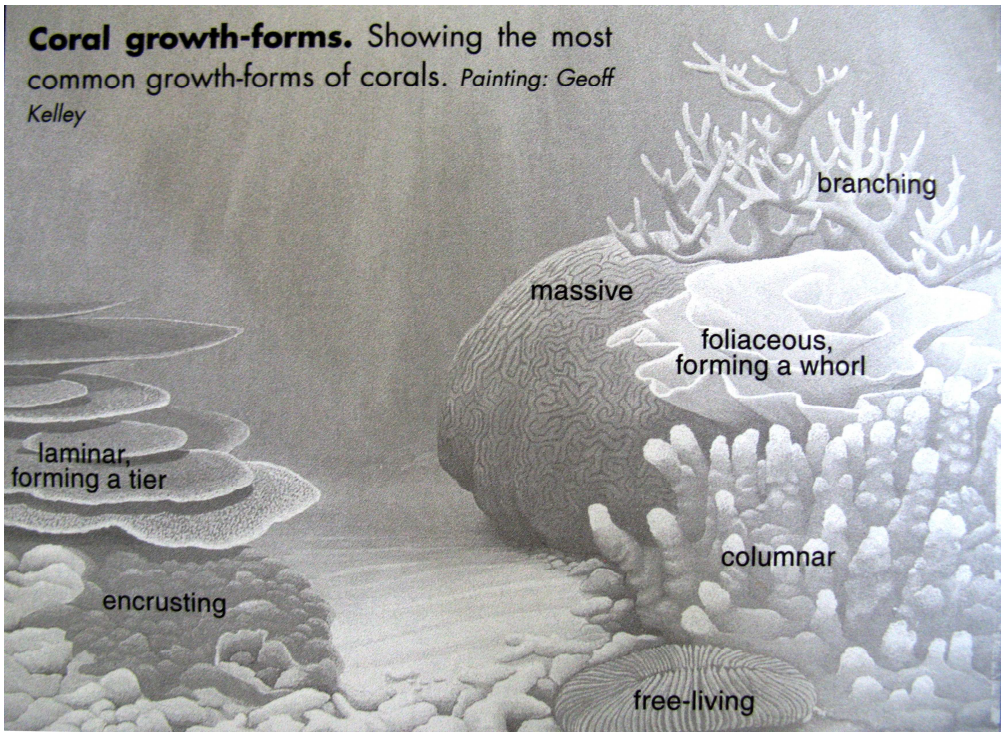


Figure 1.3 Coral growth-forms. Showing the most common growth-forms of corals (Veron, 2000).

Within gastrodermal cells of hermatypic (reef-building) corals there are brownish unicellular symbiotic algae called zooxanthellae. The algae produce energy and oxygen for corals through photosynthesis and help the coral to remove wastes while the coral, in return, provides the algae with a protected environment and the compounds necessary for photosynthesis (Muscatine & Cernichiari, 1969; Muller-Parker & D'Elia, 1997). Chlorophylls *a* and c_2 and selection of carotenoid pigments such as peridinin and diadinoxanthines are the photosynthetic pigments that can be found in the zooxanthellae (Barnes, 1987; Muller-Parker & D'Elia, 1997).

Zooxanthellae often are critical elements for reef-building corals health as they provide organic material of photosynthesis for the host coral tissue (Barnes, 1987). Most reef-building corals normally host between 1×10^6 and 5×10^6 zooxanthellae cm^{-2} of live surface tissue and 2-10 pg of chlorophyll a per zooxanthellae. However, the quantity of pigment per zooxanthellae differs among species and sometimes between colonies of the same species (Muller-Parker & D'Elia, 1997). Under conditions of stress, such as elevated temperature, the coral expels most, if not all, of the zooxanthellae, presumably to protect itself from damage. This is called ‘bleaching’, mainly because algal cells are expelled by the polyps and the loss of pigment (the zooxanthellae) causes the coral to appear white. When corals bleach they commonly lose 60-90% of their zooxanthellae and each zooxanthellae may lose 50-80% of its photosynthetic pigments (Glynn, 1996). In scleractinian corals some 50% or more of the total symbiont community must be lost before paling is typically visible to the naked eye (Fitt *et al.*, 2000). While the pale colour of bleached corals is mostly due to low numbers of zooxanthellae, they may also appear bleached when zooxanthellae lose their photosynthetic pigments (Hoegh-Guldberg & Smith, 1989; Muller-Parker & D'Elia, 1997). Coral bleaching is usually associated with elevated temperature, however other factors can cause bleaching such as

reduced salinity, increased or decreased light, increased solar radiation (both visible and UV) and increased sedimentation and toxins in the water due to coastal constructions (Hoegh-Guldberg, 1999; Baker *et al.*, 2008). However, each zooxanthellae species is likely to have different adaptive capabilities and tolerances to environmental extremes and because of this, corals containing different symbiont can vary in their sensitivity to bleaching. Coral can also modify their symbiont communities in response to environmental change (Muller-Parker & D'Elia, 1997; Baker *et al.*, 2004; Baker *et al.*, 2008; Fitt *et al.*, 2009).

Zooxanthella populations show distinct patterns in their density and photosynthetic characteristics within the host environment (Helmuth *et al.*, 1997). Studies performed by Shenker *et al.* (2006) showed the significant negative correlation between sea surface temperatures (SST) and zooxanthella density. According to his studies in Mediterranean coast of Israel, the reduction in zooxanhellae density in *Oculina patagonica* was 95% when the temperature rises above 26°C in summer, which is relatively high compared to tropical areas where there was a 72% decrease in zooxanthella density in *Montastraea franksi* from the Florida Keys, a 75% decrease in *Montastraea annularis* in the Caribbean and a 66 % zooxanthella decrease in *Acropora formosa* in the Great Barrier Reef. It should be noticed that the loss of zooxanthellae occurred in response to heat stress without a decrease in algal chlorophyll concentration (Hoegh-Guldberg & Smith, 1989; Stambler & Dubinsky, 2004). Fitt *et al.* (2000) suggested that all reef corals worldwide exhibit similar seasonal cycles (1) with lowest coral tissue biomass and densities of symbiotic dinoflagellates at the end of the season with the warmest seawater temperatures, (2) with rapid regrowth of symbionts only after seawater temperatures decrease, and (3) preceding a somewhat slower recovery of coral tissue biomass relative to the recovery rates of symbionts. Water temperature is

correlated with the decline of coral reefs and coral health is affected by the variety of other natural environmental factors and the combinations of different stressors (Veron *et al.*, 2009). Anthony & Connolly (2007) showed that coral mortality risk during bleaching events is a function of multiple environmental factors, such as temperature, sediment, and possibly light intensity, all of which will affect coral survival. Studies conducted on the Chlorophyll a and water temperature showed that they are negatively associated (Shenkar *et al.*, 2006; Anthony & Connolly, 2007; Rodolfo-Metalpa *et al.*, 2008). According to Stambler & Dubinsky (2004) light harvesting pigments such as chlorophyll a and c and peridinin concentrations per zooxanthellae increase with decreasing irradiance. Maximum photosynthesis per chlorophyll will decrease with depth but zooxanthellae cell numbers will increase. Obviously, reefs that are stressed by human activities such as with increased sedimentation are more likely to be unsuccessful in recovery and adaptation to natural environment than those which are not in disturbed regions and under stress (Fabricius, 2005; Carilli *et al.*, 2009).

Threats to the coral reefs can be divided into two main stressors: natural and anthropogenic disturbances (Table 1.1). Natural disturbances such as hurricanes, storms, monsoon, climate change, tsunamis, typhoons and cyclones had always caused changes to the coral's environment (Burke *et al.*, 2002; McClanahan *et al.*, 2008) (see Table 1.1). Increase in seawater temperature as a result of climate change during the 1998 El Niño Southern Oscillation (ENSO) caused a massive coral bleaching with the mortality of 50% to 99% throughout the Pacific and Indian Ocean (Glynn, 1996; Hoegh-Guldberg, 1999; Burke *et al.*, 2002). On the other hand, anthropogenic disturbances such as human development of tropical coasts, combined with changing land and water use, associated river discharge and sediments and changed seawater salinity, can induce ecological changes in coral reefs (McClanahan *et al.*, 2008).

Undoubtedly, the ability of reefs to recover from unusual warming events, tropical storms and other acute disturbances is profoundly affected by the level of chronic anthropogenic disturbance. In healthy and unstressed reefs, they can often recover quickly (sometimes in a short period of 5-10 years). Reefs that are already stressed by human activities often show poor ability i.e. they lack resilience to recover specially from large scale disturbances (Edwards & Gomez, 2007).

Table 1.1 Threats to coral reefs can be summarized as follows:

	Threats	**Harmful effect on corals**	**Source**
Anthropogenic	Coastal Development (Dredging)	Direct: - Reef substrate removal Indirect: - Increase sedimentation and nutrient runoff - Reduce water clarity	(Bryant *et al.*, 1998; Burke *et al.*, 2002; Chabanet *et al.*, 2005; Edwards & Gomez, 2007; McClanahan *et al.*, 2008)
	Damage by Tourists, Snorkelers and Divers	Direct: - Physical damage by clambering over corals and kicking them accidentally with the fins. Indirect: - Sewage and stirring up silt	(Davenport & Davenport, 2006; McClanahan *et al.*, 2008)
	Coral mining and Collection	Direct: - Physical damage - Reduce coral cover	(Burke *et al.*, 2002; Edwards & Gomez, 2007)
	Marine-based Pollution (Shipping)	Direct: - Groundings and anchor damage Indirect: - Pollution from ports, oil spills, ballast and bilge discharge, garbage and solid waste dumping from ships	(Burke *et al.*, 2002)
	Inland Sources (Runoff)	Indirect : - Increase erosion, sedimentation and pollution - High influx of nutrient	(Burke *et al.*, 2002)

	Overfishing and Destructive Fishing (e.g. poison fishing, blast fishing, ball-and-chain fishing)	Direct: - Coral bleaching (by poison fishing) - Coral mortality (by blast fishing) Indirect: - Change ecological state towards dominance by unused species with strong competitive ability such as coral-eating invertebrates and sea urchins (by overfishing) - Reduce reef resilient to natural and anthropogenic disturbances (by overfishing)	(Bryant *et al.*, 1998; Burke *et al.*, 2002; Edwards & Gomez, 2007) .
Natural	Climate change, Hurricanes, Tsunamis, Typhoons, Cyclones and etc.	Direct: - Physical breakage Indirect: - Mass coral bleaching by rising sea-surface temperatures - Increase in atmospheric CO_2	(Burke *et al.*, 2002; McClanahan *et al.*, 2008)
	Disease and Predation (e.g. Crown-of-thorns)	Direct: - Coral mortality and coral cover reduction	(Burke *et al.*, 2002; McClanahan *et al.*, 2008)

Table 1.1, continued

Most of the world's coral reefs have already been lost or are at high risk to be lost (Wilkinson, 2004). It has been estimated, 20% of the world coral reefs have been effectively destroyed and show no immediate prospects of recovery (Wilkinson, 2004). It is predicted that 24% of the world's reefs are under imminent risk of collapse through human pressures. The International Union for the Conservation of Nature (IUCN) in 1984-1989 indicated that people had significantly damaged or destroyed reefs in ninety-three countries. There were estimates that about 10% of tropical coral reefs were degraded beyond recovery, with another 30% likely to decline within the next two decades and reefs in Southeast Asia were identified as being at greatest risk (Sapp, 1999). Despite the rich biodiversity in SEA, unfortunately, 56% of reefs in Southeast

Asia are in a high-threat category (Bryant *et al.*, 1998). Coastal development, threatens about 25% of coral reefs in Southeast Asia, with 5% under high threat (Burke *et al.*, 2002).

Overall reef condition in Malaysia shows that almost one third of the reefs have between 25-50% live coral cover and very few reefs with more than 75% live coral cover (Tun *et al.*, 2004). Reefs in Malaysia are threatened by different anthropogenic impacts. Burke *et al.* (2002) estimated that 85% of the coral reefs in Malaysia are threatened of which 37% goes to the threat of sedimentation and pollution from coastal development and changes in land use. Unfortunately, reefs continued to show an overall decline in Malaysia from 2004 to 2008, considering the coastal development as a highest threat to coral reefs of Malaysia (Tun *et al.*, 2008). Reefs in East Malaysia in spite of the damaging fishing practices, is in much better condition than those of Peninsular Malaysia with higher coastal developments threat (Burke *et al.*, 2002; Tun *et al.*, 2004). Peninsular Malaysia has 30% lower coral cover percentage compared to East Malaysia (Burke *et al.*, 2002). According to the study done by Toda *et al.* (2007) on five islands (including Tioman Island) around peninsular Malaysia, live coral coverage in all study sites ranged from 17.9% to 68.6% and based on coral coverage classification, coral conditions in the study areas varied from “good” to “poor”. The percentage of live coral coverage at three reefs in Tioman (Tulai Reef, Manggo Reef and Renggis) was studied by Toda *et al*. (2007). Although Tulai Reef and Manggo Reef had the second highest number of genus diversity among other studied Islands in peninsular Malaysia, their coral cover was in fair condition with 31.1 and 34.6 % live coral cover. Only Renggis Island with 68.6% live coral cover was in good condition (Toda *et al.*, 2007).

1.3 Kampung Tekek, Tioman Island

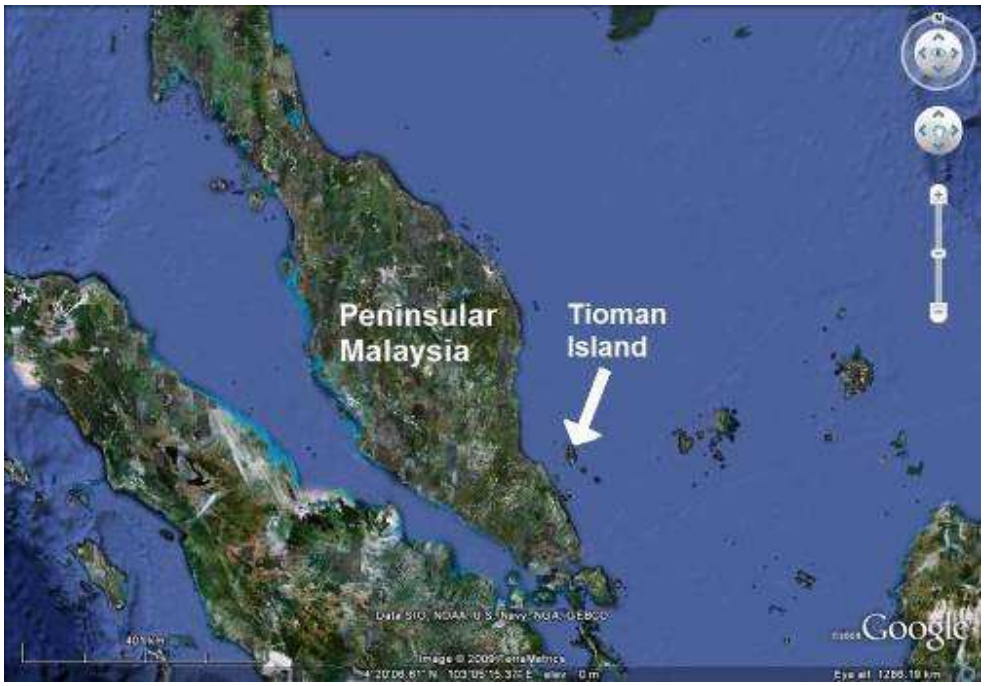
Tioman Island (locally called Pulau Tioman) is an island located in the South China Sea, 32 km off the east coast of Peninsular Malaysia in the state of Pahang, and is approximately 39 km long and 12 km wide. The densely forested island is surrounded by fringing coral reefs, making it one of the top diving locations in Malaysia (Vinsence, 2008). In year 2000 the Coral Cay Conservation Ltd (Harborne *et al.*, 2000) did a survey for the marine parks and found 183 species of hard corals in the waters of Tioman Island which was the highest compared to other marine parks in the east coast of their study. Their survey also had shown that 53 species of other invertebrates were present. Among the invertebrates are three species of giant clams; *Tridacna squamosa, maxima* and *crocea*, which are protected organisms in Malaysia. Harborne *et al.* (2000) also found a total of 233 coral reef fish species in the Pulau Tioman marine park area.

Tioman Island has been gazetted in 1994 by the Malaysian Government as a Marine Park. For Peninsular Malaysia, Marine Parks are managed by the Department of Marine Park Malaysia (DMPM). The main objectives of marine parks in Malaysia as DMPM had stated are conservation and protection of the marine community and natural habitats of endangered aquatic species. While the strategies for planning and management of Marine Protected Areas (MPAs) vary widely from country to country and among sites, the Global Representative System of Marine Protected Areas concluded that 90% of the MPAs in the East Asian Seas region generally fail to, or only partially, achieve management objectives (UP-MSI *et al.*, 2002). Unfortunately, only 16% of the MPAs in Malaysia were considered as MPAs with good management rating (Tun *et al.*, 2008).

Amongst eight main villages in Tioman, Kg. Tekek is the largest and most populous on the west coast of the Island. From Tioman Development Authority (TDA) report (Tioman TDA, 2007), Kg. Tekek has the population of 1,866 which is about half of the Tioman population. Recently, a marina located at Kg. Tekek in Tioman was constructed which covers an area of approximately 12.72 ha (EIA June 2006 monthly report) (Angkasa Jurutera Perunding Sdn Bhd, 2006). It includes a yacht marina and also a cargo jetty which extends 175 meters into the sea. Previous records have shown that the fringing reef adjacent to the marina had good corals, invertebrates and fish diversity. Previous studies specifically at Kg. Tekek (Affendi *et al.*, 2005) found a total of 221 hard coral species from 14 families. The dominant families were Acroporidae (59 species), Faviidae (52 species) and Fungiidae (27 species). In addition seventeen species that are categorized by Veron (2000) to be rare worldwide were found in the area. According to Yusuf *et al*. (2005), Tekek has the highest diversity of coral reef fish species in Tioman Island. A total of 192 species of coral reef fish from 41 families were observed in proposed marina site in Kg. Tekek.

The present study was conducted adjacent to where the marina is presently situated at Kampung Tekek, Tioman Island (Figure 1.4). The construction work on the marina was completed and handed over in February 2007, about one year prior to the present study.

a)



b)

c)

Figure 1.4 Satellite map (a) showing Peninsular Malaysia with Tioman island (=Pulau Tioman) on the east coast of Peninsular Malaysia (b) showing Kg. Tekek on the west coast of Tioman island (c) showing newly built marina in Kg. Tekek (Google Earth 2009).

Based on all the above studies done in Tioman and Kg. Tekek, it is believed that the study area is very unique with important resources such as corals, fish and invertebrates and needs to be managed with great care.

1.4 Coastal development

Coral reefs are threatened by human activities all over the tropics. Coastal development for recreation and infrastructure and shoreline development are the examples of human activities. As the population pressure and tourist activities on coastal areas increase, constructions such as land reclamation for airports, roads, ports, marinas, houses and hotels will also increase. This sacrifices reef areas, eliminates coastal habitats both on land and in the sea and exerts extreme pressure and stress onto the adjacent coral ecosystem (Chabanet *et al.*, 2005; Sale *et al.*, 2008).

According to Burke *et al.* (2002), coastal development can result in direct or indirect pressures on coral reefs. Some development projects such as dredging of harbours and shipping channels and the dumping of spoils directly result in disturbance to the topography of the seabed and the outright destruction of coral reefs through removal of reef substrate and increased sedimentation (Bryant *et al.*, 1998). Indirect impacts of construction in coastal areas are nutrient runoff, increased sedimentation and reduced water clarity (Burke *et al.*, 2002).

Polluted freshwater run-off from the island exerts a toxic effect on reef biota and would destroy the corals and its inhabitants. When pollutants are discharged, nutrient levels (nitrates and phosphates) in the water can increase. This can lead to an excessively

nutrient-rich environment (eutrophication), which encourages algae blooms and the growth of other organisms that can stifle corals or makes them to compete for space (Tomascik & Sander, 1985; Fabricius, 2005). It is estimated that recovery from eutrophication damage to reefs requires at least 10 years (Edinger *et al.*, 1998).

Increased sedimentation which is another indirect impact and one of the main effects of coastal development, was identified as the key pollutant generated by each construction process (Koskela *et al.*, 2003) and is a growing problem in most regions including Malaysia (Burke *et al.*, 2002). Over 20% of coral reefs are at risk from land-based sediment and pollution in South East Asia (Chou *et al.*, 2002). Sedimentation effects corals health in many different ways. Sustained high-level sedimentation (and nutrients) will switch off coral reef growth and reduce hard coral species richness and live-coral cover (Rogers, 1990; Dikou & Woesik, 2006). Direct sedimentation can smother a shoreline reef and corals have to spend more energy for sediment rejection, for example one of the mechanisms for coping with sediments is mucus production by coral, which is an energy-consuming process and this can weaken adult corals and prevent coral growth (Rogers, 1990). According to Fabricius (2005), sedimentation can also prevent coral recruitment by influencing pre-settlement stages of coral reproduction, as well as the ability of the coral larvae to settle and survive. This is because, coral larvae cannot successfully establish themselves in shifting sediments (Rogers, 1990) and also coral larvae use light quantity and quality to choose their settlement site (Fabricius, 2005). Even short exposure to sediments (few days) can cause long-term effects in populations, by removing cohorts of young corals and thus retarding reef recovery after a disturbance (Fabricius, 2005). In addition, sedimentation may increase the water's turbidity, which, in turn, changes the quality and the quantity of the light available for photosynthesis (Fabricius, 2005; James *et al.*, 2005). Therefore, zooxanthellae may not

get enough light to photosynthesize and feed corals and this ultimately will starve a coral, reduce the growth and tissue biomass or cause coral bleaching and death (Bryant *et al.*, 1998; Anthony & Connolly, 2007). According to Philipp and Fabricius (2003), sediment cover of 100 mg cm^{-2} reduces the available light by 75%. Their study showed that short-term exposure to sedimentation under laboratory conditions severely affected the quantum yield of photosystem II, chlorophyll a and c_2 concentrations, and zooxanthellae densities in *Montipora peltiformis*. In addition, zooxanthellae numbers, chlorophyll per unit surface area, and photosynthetic rates increase with increasing dissolved inorganic nutrients which is one of the effects of high sedimentation (Fabricius, 2005).

The effects of construction disturbances such as sedimentation, light reduction and physical damage are found to be depth-dependent (Fabricius, 2005). Fabricius (2005) indicated that stressors from land-based pollutions (sedimentation, runoff), affects corals in all depths with more effect on deep (10m) than shallow (3m). Mechanical damage (acute impacts) seemed to have lower effect on deep corals (Edinger *et al.*, 1998). In general, the effects of shading from turbidity are minimal in shallow water and progressively increase with increasing depth (Fabricius, 2005).

Philipp & Fabricius (2003) found that sedimentation stress increases linearly with increasing amounts and duration of sediment exposure. In addition, Edinger *et al.* (1998) stated that recovery from chronic stressors is much more difficult for corals than acute stress. Long term exposure to sedimentation, reduces coral cover and may also change species composition in communities. It would be dominated by a few well-adapted species to sedimentation.

The response to sedimentation differs between different species and different growth forms (Philipp & Fabricius, 2003; Sofonia & Anthony, 2008). For instance, the flattened or plate-like growth form of *Montastraea annularis* would be less efficient at removing sediments than a more rounded form and branching (Rogers, 1990). Although Acroporid corals may effectively escape deposition of sediment due to their branching morphology, they are poor sediment rejecters and appear intolerant to low light levels (Dikou & Woesik, 2006). Fabricius (2005) found that large colonies or those with branching growth forms or thick tissues are more tolerant of sedimentation, whereas small colonies or species with thin tissues and flat surfaces are often highly sensitive. Philipp & Fabricius (2003) suggested that sensitive corals to sedimentation were foliose corals or corals with relatively small polyps, such as *E. lamellosa*, *Montipora* spp., and massive *Porites*. These corals are unable to remove or shift the sediment because sediments lodge firmly on their concave or flat surface. On the other hand, Lam *et al*. (2007) showed that *Porites* can tolerate sediment deposition, rapidly regenerate tissue damaged by deposited sediment and trap sediments in mucus sheets, which are frequently discarded by currents. They suggested that *Porites, Favia and Favites* are less affected by smothering and tolerant to low-salinity and sedimentation stress.

It is suggested that normal sedimentation rates of coral reefs are in the order of 10 mg cm^{-2} day^{-1} or less, and typical suspended solids concentrations are less than 10 mg l^{-1} (Rogers, 1990; Fabricius, 2005). Studies done by Edinger *et al.* (2000) on the reefs of Indonesia showed that sedimentation rate in the most affected sites (with maximum depth range from 4 to 8 m) subjected to anthropogenic stress ranged from 26.19 to 57.50 mg cm^{-2} day^{-1}.

Coral damage appears to not only depend on the amount and duration of sedimentation, but also strongly depends on the sediment type. For example, tissue damage under a layer of sediment increases with increasing organic content and bacterial activity, and with decreasing grain sizes (Fabricius, 2005). Therefore, the composition of bottom sediments in term of particle size may even be more critical to sediment effects on corals than sedimentation rates (Weber *et al.*, 2006), because different species have different abilities in rejecting the fine particles (Nugues & Roberts, 2003). Specifically fine sediment less than 125μm in size was known to be the most harmful to coral and contributed to coral's stress (Nugues & Roberts, 2003). More coral species can tolerate areas with coarse-grained sediments than regions that silt-sized sediments are deposited (Fabricius, 2005). Sandy sediments can be removed more efficiently than silty sediments possibly due to the greater volume and stickiness of the silts (Weber *et al.*, 2006).

Another issue of concern which is an example of an acute impact is the barge moving in and out of the area during construction, which may have caused extremely high rates of sedimentation and coral breakage. Based on an EIA report on June 2006 (Angkasa Jurutera Perunding Sdn Bhd, 2006) the barge was reported landing on the beach south of the marina (Figure 1.5). This was the same area used for our study.

Figure 1.5 Barge beached on the south of marina which was the area of this study.

To our knowledge, there has been no monitoring or research done on the effects of the new marina construction on the reefs in Kg. Tekek, Tioman Island. Previous studies showed that coastal development and human activities such as dredging, beach reclamation, jetty and marina construction had negative effects on adjacent coral reef health (Philipp & Fabricius, 2003; James *et al.*, 2005). The situation would be more detrimental if coastal development is carried out on a small island such as Tioman, which has good but limited coral coverage. Therefore, this study is essential to investigate if the marina construction in Kg. Tekek had any harmful effects on its adjacent coral reef. This study is one of the first to scientifically document potential reef damage by marina construction in Malaysia.

1.5 Objectives

1) To compare the reef community before and after the marina was built.

2) To determine chronic impacts of the marina construction to the adjacent coral reef.

3) To determine coral growth form susceptibility to marina construction impacts.

To achieve the above objectives, a reef community survey was done during this study and was compared with reports prior to the marina construction (objective 1). In addition, monitoring was done quarterly through 12 months at two depths (shallow and deep) (objective 2). Four different growth forms of scleractinian corals were also studied at two depths (shallow and deep) and the effects of construction on the health of different coral growth forms were compared (objective 3).

2 Materials and Methods

2.1 Coral reef survey methods

In November 2007, after visiting the area where the marina had been constructed, the study site was determined (Figures 2.1 to 2.3). The study site is a coral reef area with the size of (150 m x 150 m=22500 m²) approximately 50 m southwest of the marina jetty. It was chosen to be as close as possible to the marina to be able to document the effects of the marina construction to the coral reef.

Figure 2.1 View of the marina jetty from land showing study site (red arrow).

Figure 2.2 Marina in Kg. Tekek, Tioman Island. The jetty is shown.

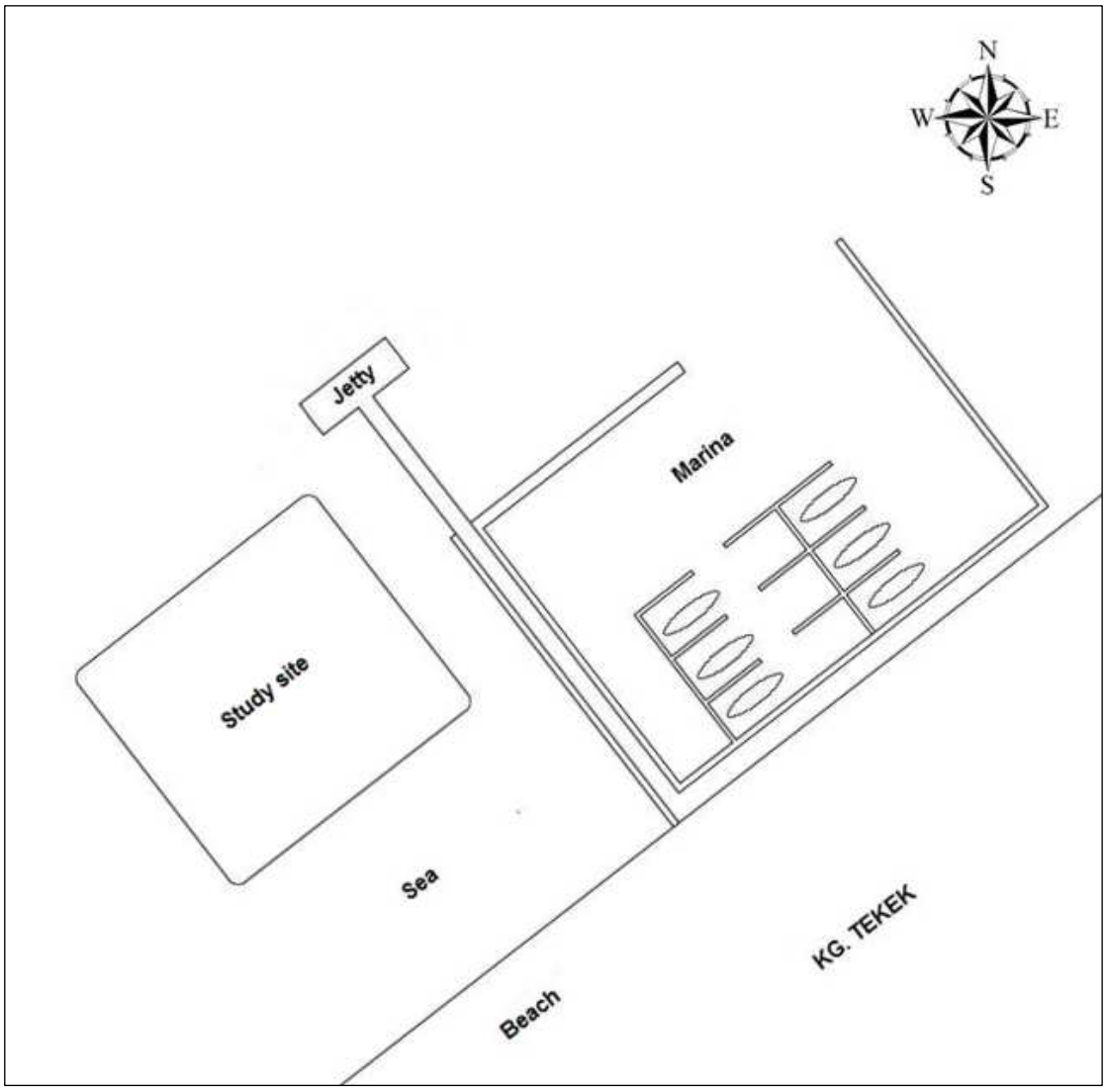


Figure 2.3 Diagram showing the location of the study site which is adjacent to marina (not to scale).

Water depth was used to divide the study site into two separate areas of 'Marina Deep' (MD) and 'Marina Shallow' (MS). Depth of <6 meters was considered as 'shallow' and the depth of 6 m to 12 m was considered as 'deep'. Transect line methods were used to monitor changes on the reef through time. In this study permanent transects were monitored to examine the processes responsible for long term effects on the corals reef with reference to Leujak & Ormond (2007). At each site, a 150-meter permanent transect (rope of 4mm thickness) was laid (Figure 2.4) and fixed to metal stakes (50 cm in height). The metal stakes with marker buoys were placed at every 50 meters and were

later used as reference points for future monitoring so that the same substrate would be covered at each time of sampling. Modified Line Intercept Transect (LIT) method as described in English *et al*. (1997) was used to study the coral cover and diversity of the study site.

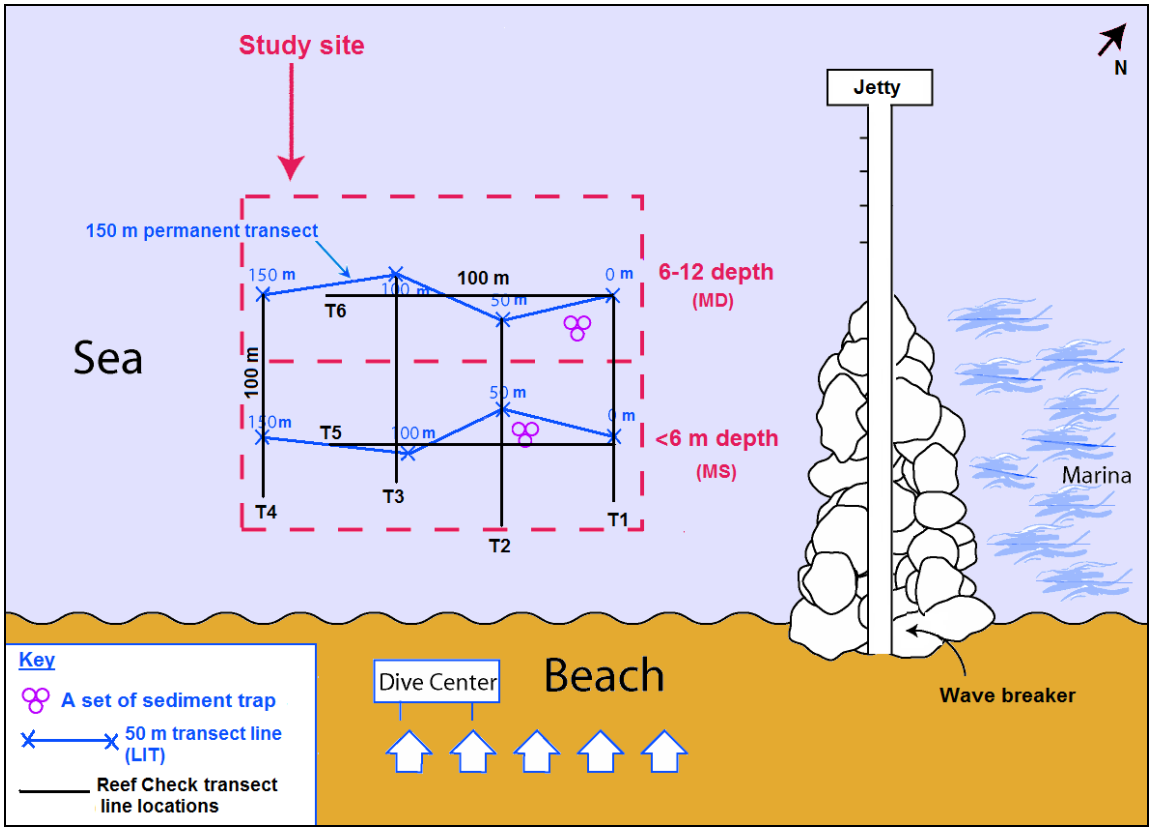


Figure 2.4 LIT (150 m transects) and Reef Check (100 m transects) survey locations with position of sediment traps (refer to Figure 2.7) in the study site. Note: MD= Marina Deep. MS= Marina Shallow. Transects T1 to T4 were used for profiling the substrate composition in the study site. Transects T5 and T6 were used for monitoring the changes before and after the marina construction.

To be able to distinguish the effects of the construction of the marina versus natural fluctuation, monitoring of two different study sites was needed. Therefore a control site was chosen as was recommended by Rogers *et al.* (2001). Pulau (=Island) Renggis was chosen as the control site (Figure 2.5) (~3 nm southwest of the marina site) as it has similar ecological parameters such as water quality and environmental factors.

Moreover, the fringing reef around Pulau Renggis has a good coral coverage of 68.6% (Toda *et al.*, 2007), and there has been no recent construction.

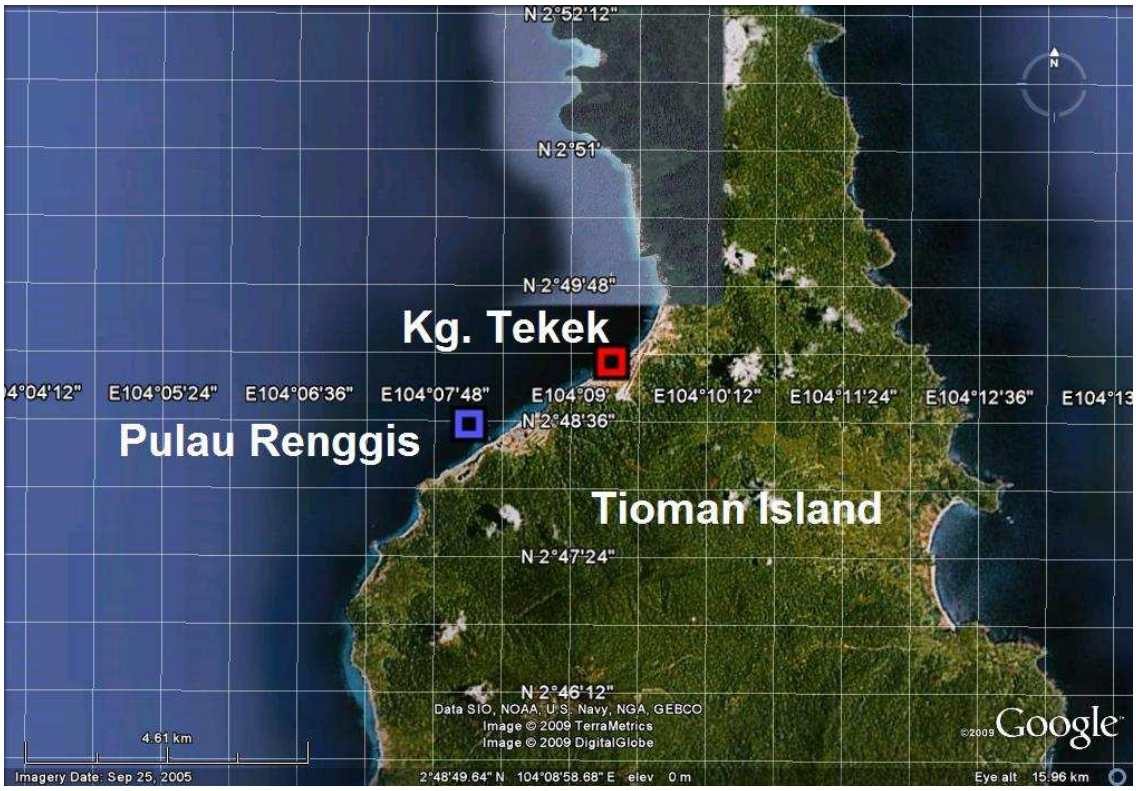


Figure 2.5 Close up view of the study site in Kg. Tekek and control site in Pulau Renggis, Tioman Island (Google Earth 2009).

In Renggis, (R) a 150 meter rope (rope of 4mm thickness) was laid (Figure 2.6) and metal stakes with marker buoys were laid at every 50 meters as it was done in the marina study site. Modified LIT method was used to study the substrate and coral cover of Pulau Renggis.

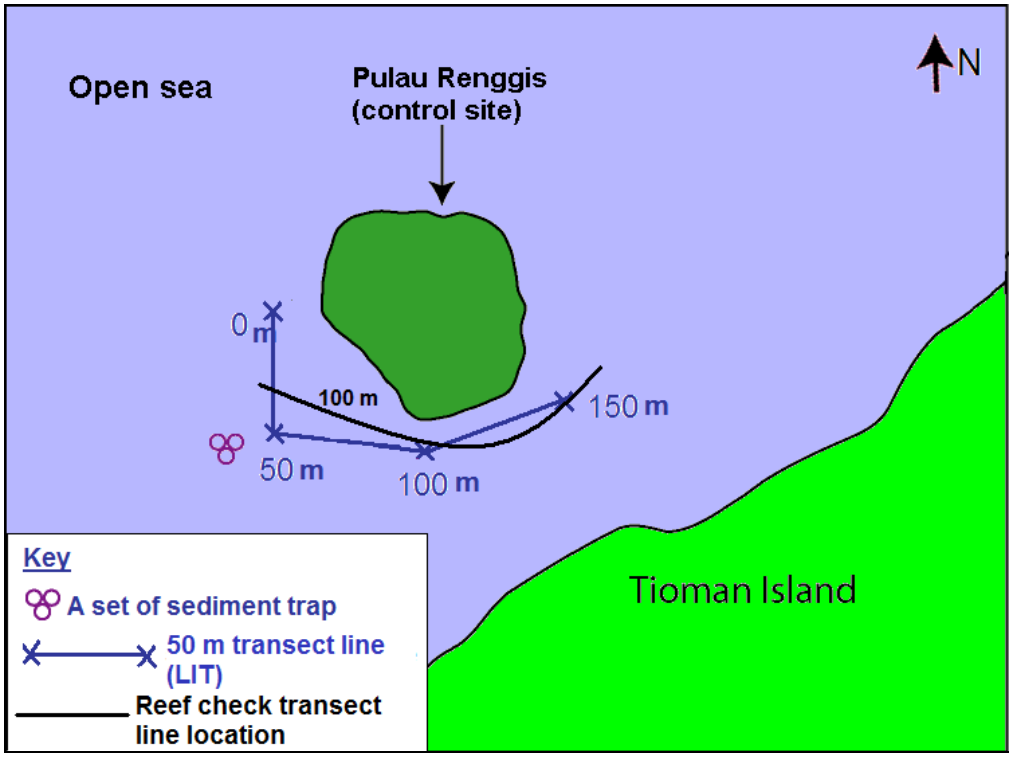


Figure 2.6 LIT (150 m transect) and Reef Check (100 m transect) survey locations around Pulau Renggis (control site) with position of sediment traps (refer to Figure 2.7).

2.1.1 Substrate and coral cover (%) determination using modified Line Intercept Transect (LIT) method

The percent cover of different substrates in the study sites was recorded in March 2008, June 2008, October 2008, March 2009 and June 2009 using self contained under water breathing apparatus (SCUBA). Modified LIT method was used by calculating the fraction of the length of the line that is intercepted by that life form with regards to the transect length (Loya, 1978; English *et al.*, 1997; Leujak & Ormond, 2007). Leujak & Ormond (2007) indicated that to detect a 20% relative change (with a power of 80%) in total hard coral cover, the LIT method requires 135 m of transect line. Therefore, in this study two 150 m transects (MD and MS) were laid along each permanent rope in the marina site and one 150 m transect was laid in the control site. Compass bearings of the

direction of each metal stake were recorded as a backup in case the permanent rope is lost. A Garmin GPS 76CSx was used to record the location (WGS84) of starting points for each transect in both study sites (shown as 0 meter in Figures 2.4 and 2.6):

Marina Deep (MD): 2°49'7.90"N and 104° 9'18.20"E.

Marina Shallow (MS): 2°49'8.80"N and 104° 9'22.60"E.

Renggis (R): 2°48'31.91"N and 104° 8'6.58"E.

To monitor each benthic category under the line transects through time, transects were laid out as precisely as possible during each survey. The percentage cover of each benthic category (Table 2.1) was calculated as follows:

$$\text{Percent cover of benthic category} = \frac{\text{Total length of category (cm)}}{\text{Length of transect (cm)}} \times 100\%$$

Table 2.1 Substrate categories and codes used for LIT method (English *et al.*, 1997).

CATEGORIES	**CODE**		**CATEGORIES**		**CODE**
Hard Coral:			**Other Fauna:**		
Dead Coral		DC	Soft Coral		SC
Dead Coral with Algae		DCA	Sponges		SP
Acropora	Branching	ACB	Zoanthids		ZO
	Encrusting	ACE	Others		OT
	Submassive	ACS			
	Digitate	ACD	Algae	Algal Assemblage	AA
	Tabular	ACT		Coralline Algae	AC
Non-*Acropora*	Branching	CB		*Halimeda*	HA
	Encrusting	CE		Macroalgae	MA

	Foliose	CF		Turf Algae	TA
	Massive	CM	Abiotic	Sand	S
	Submassive	CS		Rubble	R
	Mushroom	CMR		Silt	SI
	Heliopora	CHL		Water	WA
	Millepora	CME		Rock	RCK
	Tubipora			Missing Data	DDD

Table 2.1, continued

2.1.2 Profiling the coral reef of the study site using modified Reef Check method

The modified Reef Check method (Hodgson, 1999; Harborne *et al.*, 2000) was used in March 2008 and June 2008 to document the substrate status. A profile of the coral reefs in the study site was done using four separate 100 meter transects perpendicular to the shore (T1-T4, Figure 2.4). The previous studies on coral reefs in Kg. Tekek before the marina construction (April 2004 and September 2004) had been done by using the similar Reef Check method. Consequently, changes of coral reef coverage (acute impacts) were compared in the study site before and after the marina construction. Two 100 meter transects were laid in each study area parallel to the shore (T5 and T6, Figure 2.4) and a 100 meter transect was laid in Pulau Renggis (Figure 2.6). Substrate cover data was recorded on waterproof paper by aid of SCUBA. Substrate categories at 0.5 meter intervals beneath the transect were recorded based on the Reef Check description as shown in Table 2.2 (Hodgson, 2000).

Table 2.2 Indo-Pacific substrate categories and codes used for Reef Check method.

CATEGORIES	CODE
Hard Coral	HC
Recently Killed Coral	RKC
Sponge	SP
Rubble	RB
Silt/Clay	SI
Soft Coral	SC
Nutrient Indicator Algae	NIA
Rock	RC
Sand	SD
Other	OT

In addition, Before-After-Control-Impact-Pairs (BACIP) design (Underwood, 1991; Smith, 2002) was used to compare between Reef Checks done in Marina Shallow and Renggis. The design is considered useful for detecting changes in means associated with human activity. It involves collection of data prior to the activity and compares it with data after the activity both in control and impact sites.

2.2 Sedimentation rate

One set of sediment traps (Figure 2.7) was deployed in Marina Deep and Marina Shallow and in the Renggis (control site). Each sediment trap consisted of three plastic bottles mounted on a metal spike by cable ties (Figure 2.8). The traps were 8.5 cm diameter cylinders with a height to width ratio of 2.3 (Figure 2.8), which minimized the capture of sediment resuspension from the bottom, and maximized the particulate collection (English *et al.*, 1997; Ismail *et al.*, 2005). The baffles were not placed on top

of the trap because the traps were collected every 2-3 months and algal growth on the baffle may contribute significantly to the trapped organic material. The mouths of the traps lay approximately 25 cm above the seabed (Figure 2.8) to minimize the effect of water turbulence on the amount of sediment collected (Nugues & Roberts, 2003).

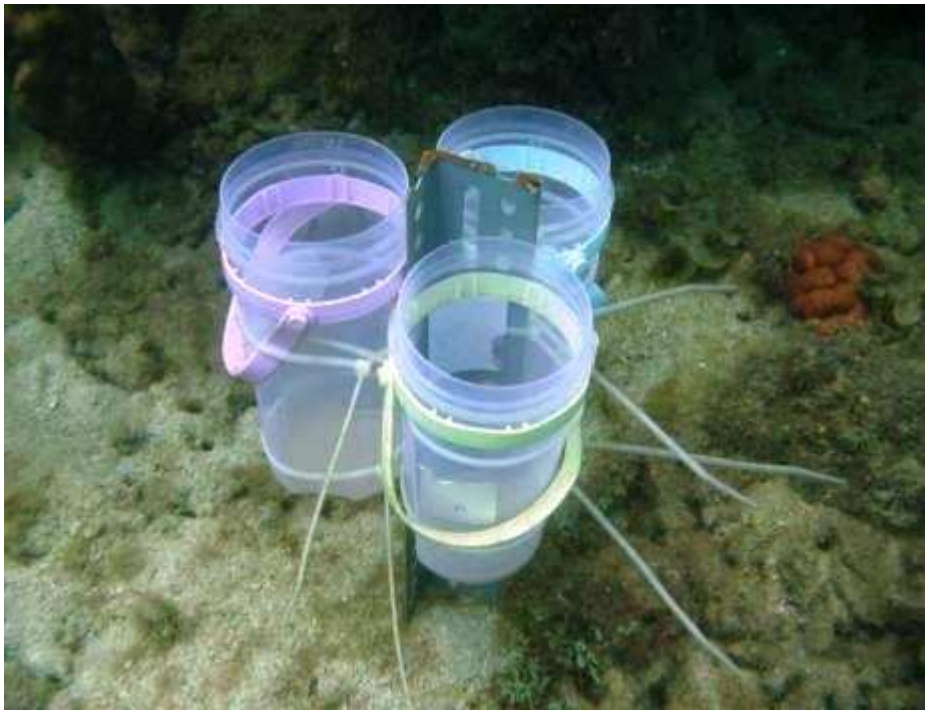


Figure 2.7 A set of sediment trap placed in the study site, also seen in Figures 2.4 and 2.6.

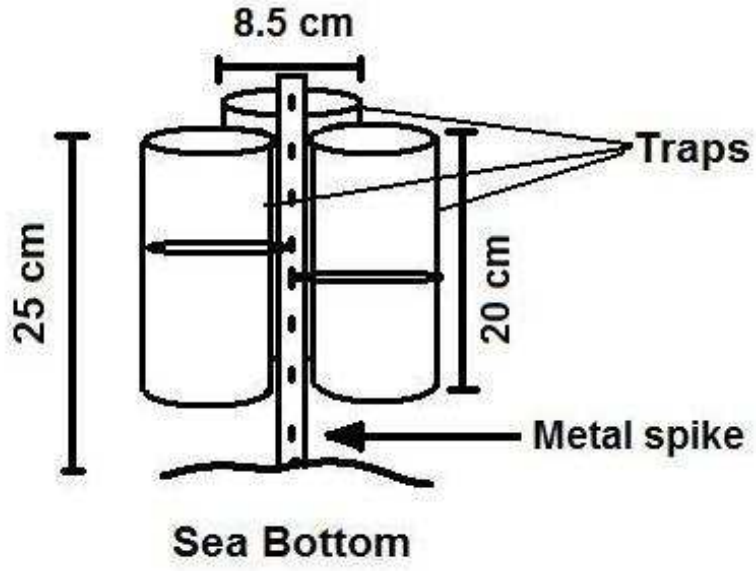


Figure 2.8 Diagram of a set of sediment trap showing the scale of the trap containers.

Sediment traps were removed every three months and replaced by a new set of traps using SCUBA. The plastic containers were first capped to prevent the loss of sediments collected while transporting the sample to the surface. The plastic containers containing the sediment and seawater were then kept in a refrigerator (at 4°C) at the Tioman Marine Research Station. The samples were kept on ice (at 4°C) for the journey to the laboratory at the Institute of Biological Sciences, University of Malaya. At the laboratory, they were kept in a refrigerator (at 4°C) for not more than one week until analysed for sedimentation rate, particle size and organic matter content.

Sediment trap contents were poured onto 0.45 μm filter papers placed in a glass funnel. The filter paper and sediment were dried in an oven at 70°C until a constant weight was obtained. Once samples were dry they were transferred to a desiccator and allowed to cool before it was weighed using Mettler Toledo AB204 balance to 4 decimal points. Sedimentation rate was calculated as milligram of sediment per cm^2 per day (Rogers, 1990; Nugues & Roberts, 2003; James *et al.*, 2005):

Sedimentation rate (mg $cm^{-2}day^{-1}$)=

$$\frac{\text{Sediment Weight (Total weight – Filter paper weight)}}{\pi r^2 \text{(Surface area of the trap opening}(cm^2)) \text{ X No. of days at site}}$$

2.3 Organic matter content in collected sediment

Small amounts of the dried sediment samples, derived from the sedimentation rate experiment (see subchapter 2.2), were placed into a pre-weighed ceramic bowl and weighed to 4 decimal places using ADAM PW124 balance. It was then combusted in a Heraeus® muffle furnace at 550°C for 5 hours to determine its ash free dry weight.

The samples were transferred to a desiccator and were allowed to cool before it was weighed again. Combustion of the sample was repeated until a constant weight was obtained (Baron *et al.*, 1993; Gleason, 1998; Dikou & Woesik, 2006). The weight loss was calculated as the total organic matter content of the sediment samples in terms of percentage as follows:

- Weight of ceramic bowl = *c* g
- Weight of dried sediment and ceramic bowl = *d* g
- Weight of ash free sediment and ceramic bowl after 550°C = *e g*

Percentage of organic matter in sediment = [(d – e) g ÷ (d – c) g] x 100

2.4 Particle sizing of sediment

A small part of the dried sediment samples (see subchapter 2.2) was used for sediment particle sizing. Small amount of 15% hydrogen peroxide (H_2O_2) was added to the dried sediment samples as a pre-treatment to remove organic matter through chemical means and at the same time to break up the sediment aggregate. The mixture of sediment and H_2O_2 was left for a minimum of 12 hours to ensure a complete reaction. It was then placed into a coulter particle size analyzer, which processed the sediment sample to make the various calculations for particle sizes. A Beckman Coulter LS 13 320 Particle Size Analyzer was used to analyze the particle size of the sediment samples. The instrument utilizes the refraction of laser light detected by multiple sensors as it bounces off particles suspended in liquid medium to analyze particle size (Hussein, 2004; Scott-Jackson & Walkington, 2005).

The size of sediment particle groups were classified into several categories according to the Wentworth grade scale, clay (<3.9*u*m), silt (3.9 to 62*u*m), very fine sand (63 to 125*u*m), fine sand (125 to 250*u*m), medium sand (250 to 500*u*m) and coarse sand (0.5 to 1mm) (Buchanan, 1984; Selley, 2000).

2.5 Water quality

At each time of sampling, water samples (from bottom and surface) were collected in a clean, plastic bottle with a screw cap at each permanent monitoring transect (Marina Deep, Marina Shallow and Renggis) by aid of SCUBA. Subsequently after reaching shore the water samples were analyzed immediately for: dissolved oxygen (DO), total dissolved solids (TDS), salinity, conductivity, and pH.

HOBO Pendant Temperature-Light data loggers were deployed on the metal stake near the permanent line (Figure 2.9) and were left at each site logging automatically every 30 minutes from June 2008 to June 2009. Since all the underwater light measurements were done at the same time of the day in both Marina site and control site and that the areas studied were close to each other, it was assumed that all sites had the same ambient light intensity above the water. Therefore, only the underwater light was measured in this study. The parameters shown in Table 2.3 were measured for the water quality data in this study. All the measurements were done in the morning (from 9 am to 11 am).

Table 2.3 Water quality parameters determined in the present study.

PARAMETER	UNIT	METHOD	DETECTABLE LIMITS / SENSITIVITY
Dissolved O_2	mg/L	YSI Probe 550 A (DO Meter)	± 0.3 mg/L
Salinity	ppt	Salinity Refractometer/ YSI Probe EC300	0.2 % Full Scale
pH	pH	YSI Probe pH 100	± 0.1 %
Total Dissolved Solids (TDS)	g/l	YSI Probe EC300	± 2.5 % of reading plus 0.5
Conductivity	mS	YSI Probe EC300	mS/cm
Seawater Temperature	°C	HOBO Temperature/Light Data Loggers	± 0.47°C at 25°C
Underwater Light	Lux	HOBO Temperature/Light Data Loggers	

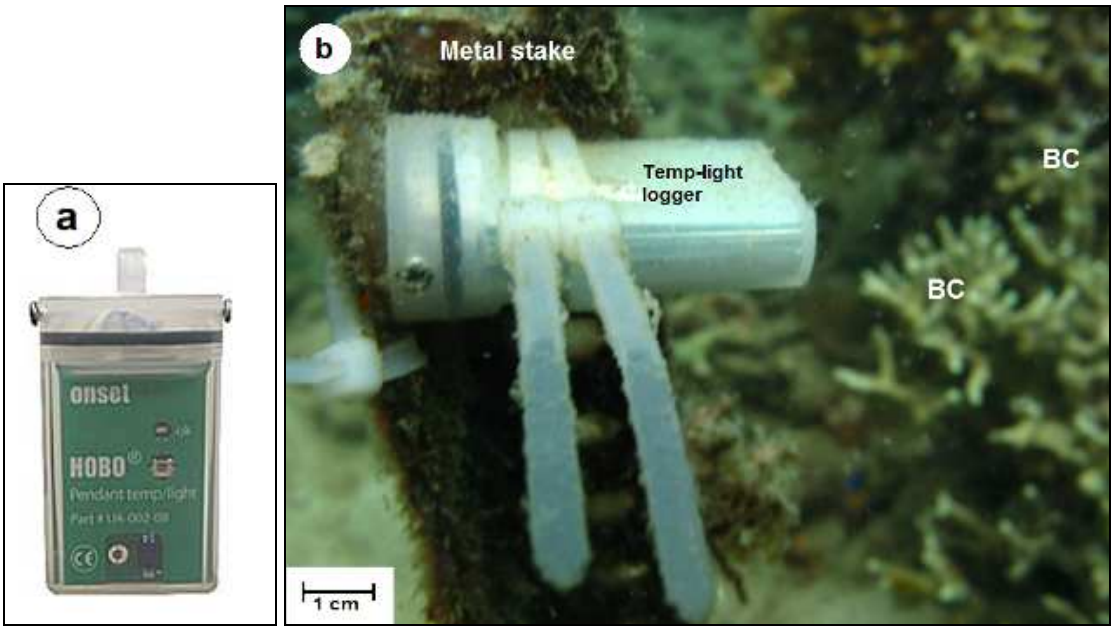


Figure 2.9 (a) HOBO temperature-light data logger as seen in Figure 2.9b; (b) A temperature-light data logger attached to a metal stake in the study site. Note presence of branching corals (BC).

2.6 Zooxanthellae of the selected scleractinian corals

For zooxanthella density and its chlorophyll content measurements, the scleractinian coral species with distinctly different growth forms that were abundant in the study sites were collected to be easily identified in the field. Four coral species with different growth forms (Submassive, Foliose, Branching and Free-living) were sampled from each study area (Marina Deep, Marina Shallow and Renggis) in June 2008, October 2008, March 2009 and June 2009 (Table 2.4; Figure 2.10). Corals with different growth forms were chosen, because each growth form has different sensitivity and responds differently to sedimentation (Rogers, 1990; Stafford-Smith & Ormond, 1992; Philipp & Fabricius, 2003; Fabricius, 2005; Sofonia & Anthony, 2008). The Coral ID programme by Veron (2002) was used for coral identification confirmation after sampling.

Table 2.4 Selected scleractinian coral species for this study.

CORAL SPECIES	**GROWTH FORMS**	**SITE**	
		Marina (Deep/Shallow)	Renggis
Pocillopora damicornis	Branching	√	√
Porites Family*	Submassive	√	√
Ctenactis echinata	Free living	√	√
Pachyseris speciosa	Foliose	√	
Echinopora lamellosa	Foliose		√

* Higher taxonomic category such as family was used rather than species to ensure accurate identification.

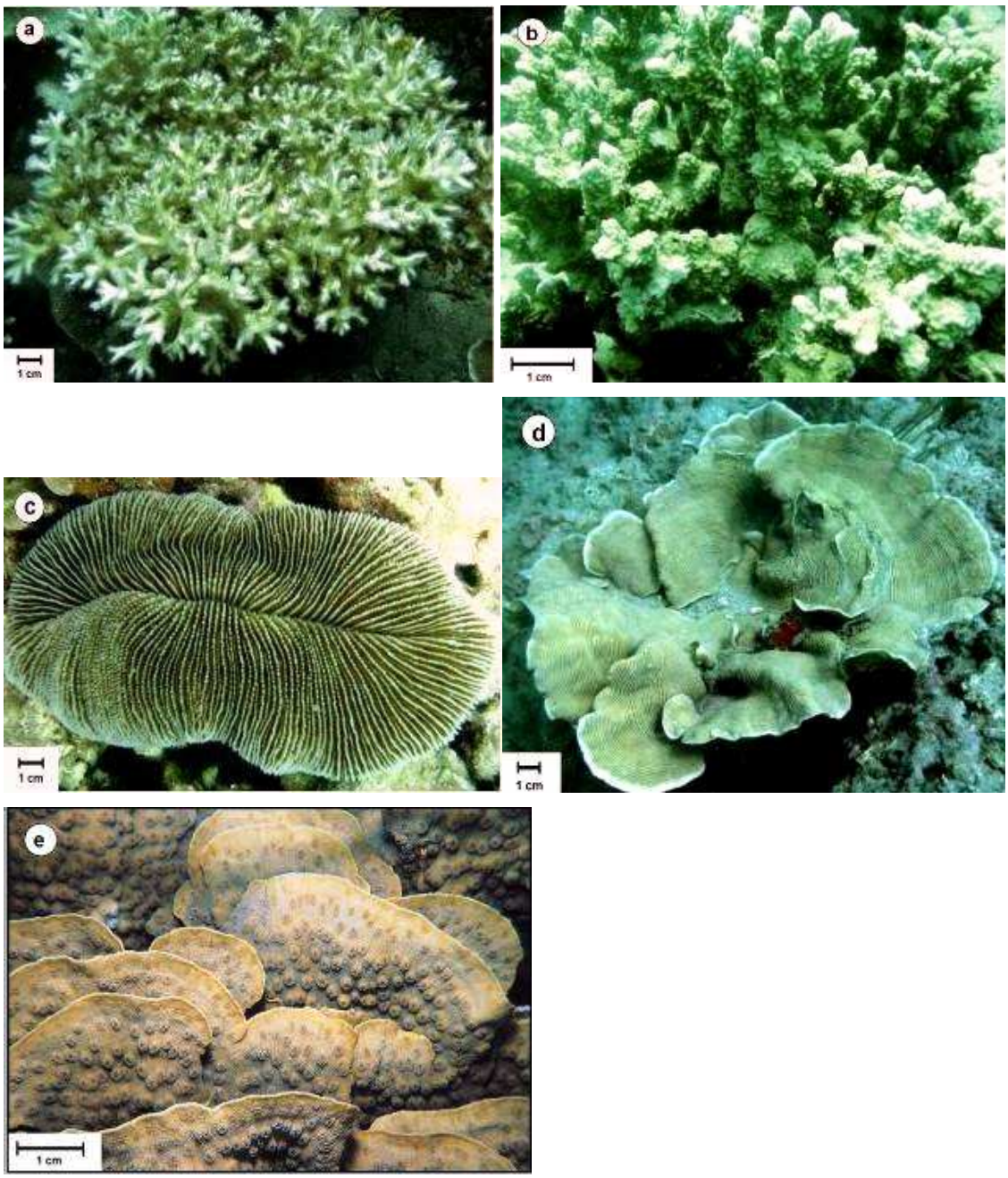


Figure 2.10 Pictures of the selected scleractinian coral species for this study (a) Branching e.g. *Pocillopora damicornis*; (b) Submassive e.g. *Porites rus;* (c) Free living e.g. *Ctenactis echinata;* (d) Foliose e.g. *Pachyseris speciosa;* (e) Foliose e.g. *Echinopora lamellosa.* All pictures are from this study except Figure 2.10 (e) which is from Veron (2000).

Small fragments (1 cm) were separated from three different healthy coral colonies of each species. A hammer and a chisel were used for the free living corals. As for the other growth forms, they were collected by breaking a small part of the colony by hand. Samples were then wrapped with aluminium foil to keep it in darkness and were kept in

a freezer (-17 ºC) immediately. To prevent zooxanthella and chlorophyll loss, the frozen samples were carried in an icebox filled with ice (~4ºC) and maintained frozen until separation of the zooxanthella in the laboratory at Institute of Biological Sciences, University of Malaya**.**

2.6.1 Coral tissue isolation

Coral tissue was removed from frozen samples using a WaterPik® and artificial seawater (25-30 ppt) and poured into a zipper bag (Johannes & Wiebe, 1970; Fitt *et al.*, 2000; Shenkar *et al.,* 2006). The liquid portion containing the coral tissue and artificial seawater was then transferred into a Phillips® Twist blender for homogenization by blending it for one minute twice. Then the homogenate was transferred into a measuring cylinder for volume measurement. The homogenous mixture was then kept in a container in the refrigerator (at 4ºC) until used for chlorophyll and zooxanthella analysis.

2.6.2 Zooxanthella density

The homogenate from coral tissue isolation (see subchapter 2.6.1) was inserted into 1.5 ml Eppendorf® tube using a glass pipette. One or two drops of 100% formalin were added into it and were kept in the refrigerator (at 4ºC) for zooxanthella counts. The zooxanthellae was then transferred to a haemocytometer and observed under a Leica® light microscope with magnification 40X and 100X (Figure 2.11). The zooxanthella cell counts was done with eight replicate cell counts using a Spencer® Bright-Line Improved Neubauer haemocytometer 1.0 mm^2 X 0.1 mm (Cervino *et al.*, 2003; Lasker, 2003). Only the healthy zooxanthellae were counted to measure zooxanthealla density

as degraded cells would have lost their chlorophyll pigments. The degraded cells differed from healthy zooxanthellae by the orange or dark-brown colour, smaller dimensions and irregular shapes (Titlyanov *et al.*, 1998).

Total amount of zooxanthellae in homogenate (cells) =

$$\frac{\text{Total volume of homogenate (cm}^3\text{)} \times \text{Number of counted zooxanthellae (cell)}}{\text{Volume of haemocytometer (cm}^3\text{)}}$$

The densities of the zooxanthellae of the coral samples were calculated from the haemocytometer counts and surface area determinations (see subchapter 2.6.4) (Fitt *et al.*, 2000; Lasker, 2003; Philipp & Fabricius, 2003).

Zooxanhellae density in coral samples (μcell cm^{-2}) =

$$\frac{\text{Total amount of zooxanthella in homogenate (cells}\times 10^6\text{)}}{\text{Coral surface area (cm}^2\text{)}}$$

Note: Coral surface area was determined in subchapter 2.6.4

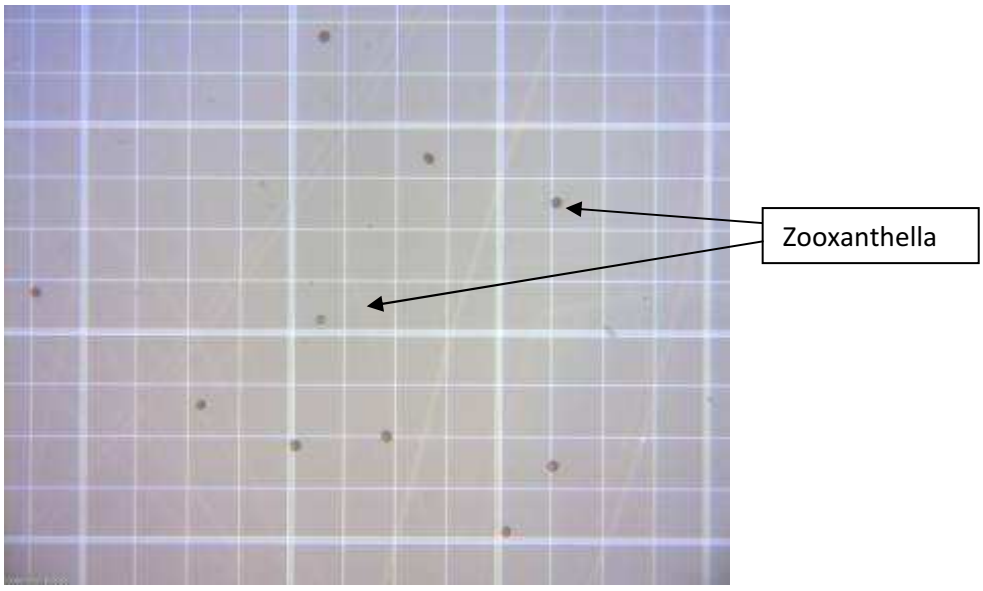


Figure 2.11 Zooxanthella cells on haemocytometer under the magnification of 100X.

2.6.3 Chlorophyll *a* & c_2 content in zooxanthellae

The homogenate from the coral tissue isolation (see subchapter 2.6.1) was placed into 1.5 ml Eppendorf® tubes. Three replicates were then centrifuged at 6000 rpm for 20 minutes at 10ºC using a Jouan MR 1812 refrigerated centrifuge. After centrifuging, the supernatant was discarded, leaving only the zooxanthellae pellet at the bottom of the Eppendorf tubes. The Eppendorf tubes were then fully filled with 100% acetone and the solution was mixed well using an auto vortex mixer. The samples were then wrapped with aluminium foil and kept in a refrigerator for at least 24 hours. After the chlorophylls *a* and c_2 were extracted in the 100% acetone in the dark in the refrigerator at 4ºC, the samples were then centrifuged again and the supernatant were transferred into a 1 cm light path quartz cuvette. Chlorophyll *a* and c_2 concentrations were determined by using a Shimadzu UV-1601 PC spectrophotometer that measures the amount of light absorbed by the extracted chlorophyll in the cuvette. Chlorophyll *a* and c_2 were calculated using the standard equation of Jeffrey & Humprey (1975). The chlorophyll extraction procedure was repeated by adding a fresh acetone to the zooxanthellae pellet for another 24 hours and measuring the chlorophyll content again. This procedure repeated until no chlorophyll pigment could be extracted from the zooxanthellae in the samples. The equation for chlorophyll extraction in 100% acetone is as follows (Jeffrey & Humphrey, 1975; Fitt *et al.*, 2000; Philipp & Fabricius, 2003; Moya *et al.*, 2008):

$$\text{Chlorophyll } a,\ Ca = 11.43\ E_{663} - 0.64\ E_{630}$$

$$\text{Chlorophyll } c_2,\ Cc_2 = 27.09\ E_{630} - 3.63\ E_{663}$$

Note: C*a* and Cc_2 represent the chlorophyll content (in 1µg ml^{-1} using 1cm light path cuvette)

Chlorophyll content per surface area (µg cm^{-2}) =

$$\frac{C\ (\mu g\ ml^{-1}) \times \text{Volume of acetone (ml)}}{\text{Coral surface area } (cm^2)}$$

Chlorophyll content per zooxanthellae (µg $cells^{-1}$) =

$$\frac{\text{Chlorophyll content } (\mu g\ cm^{-2})}{\text{Zooxanthellae density } (cells\ cm^{-2})}$$

Note: Coral surface area and zooxanthellae density was determined in subchapter 2.6.4

2.6.4 Surface area

The Aluminum foil method was used to determine the coral sample surface area (Marsh, 1970; Shu *et al.*, 2008). Firstly a standard curve graph was obtained using aluminium foils that were cut into known surface areas of 1 cm^2, 4 cm^2, 9 cm^2 up to 49 cm^2. The pieces were then weighed using Mettler Toledo AB204 balance to 4 decimal points. Finally, a standard curve graph was obtained by using the measured weights and surface areas of the aluminium foil pieces. The best linear line was drawn to determine the values of the equation $y=ax+b$ (Figure 2.12).

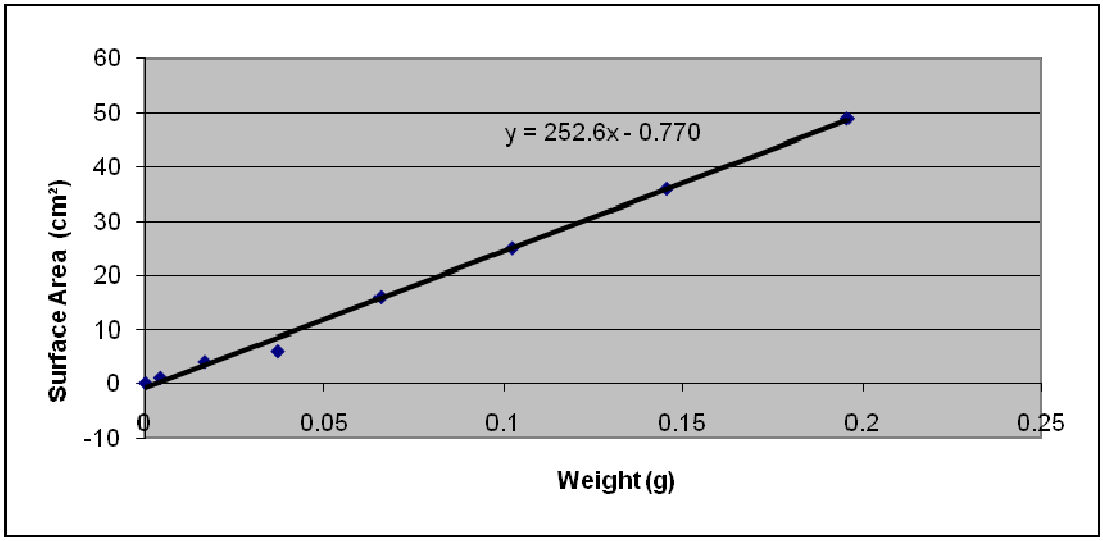


Figure 2.12 Graph showing the standard curve of known surface area against weight of aluminium foil for determination of coral surface area.

To determine the surface area of the living layer for each coral sample, the parts of each coral skeleton that had living tissue was wrapped with the Diamond® Heavy Duty aluminium foil which was moulded to fit into depressions and over projections with no overlap of aluminium foil. The aluminium foil was then peeled off and weighed using the Mettler Toledo AB204 balance to 4 decimal places. Finally, the surface area for each coral sample was determined by using this weight measurement with reference to the standard graph and equation (Figure 2.12).

2.7 Statistical analysis

SPSS programme was used for all statistical analysis. To determine whether there were any statistical difference in mean values of benthic community variables, zooxanthella density and chloroplyll a and c_2 content in each study site and between the reef sites, one-way ANOVA and its non-parametric equivalent, the Kruskal–Wallis test were used whenever the assumptions of normality and homogeneity of variance of ANOVA could not be met. Percent live coral cover data were arcsine square root transformed prior to the statistical tests being done (Zar, 1994). Where ANOVA and Kruskal–Wallis tests gave significant results, to determine which sites differed, the Post Hoc tests (Tukey HSD) were performed.

3 Results and Discussion

3.1 Acute Impacts

3.1.1 Substrate composition

Modified Reef Check method was used in this study in March 2008, to profile and document the substrate coverage in the study site. Substrate categories and the profiling results are shown in Figure 3.1.

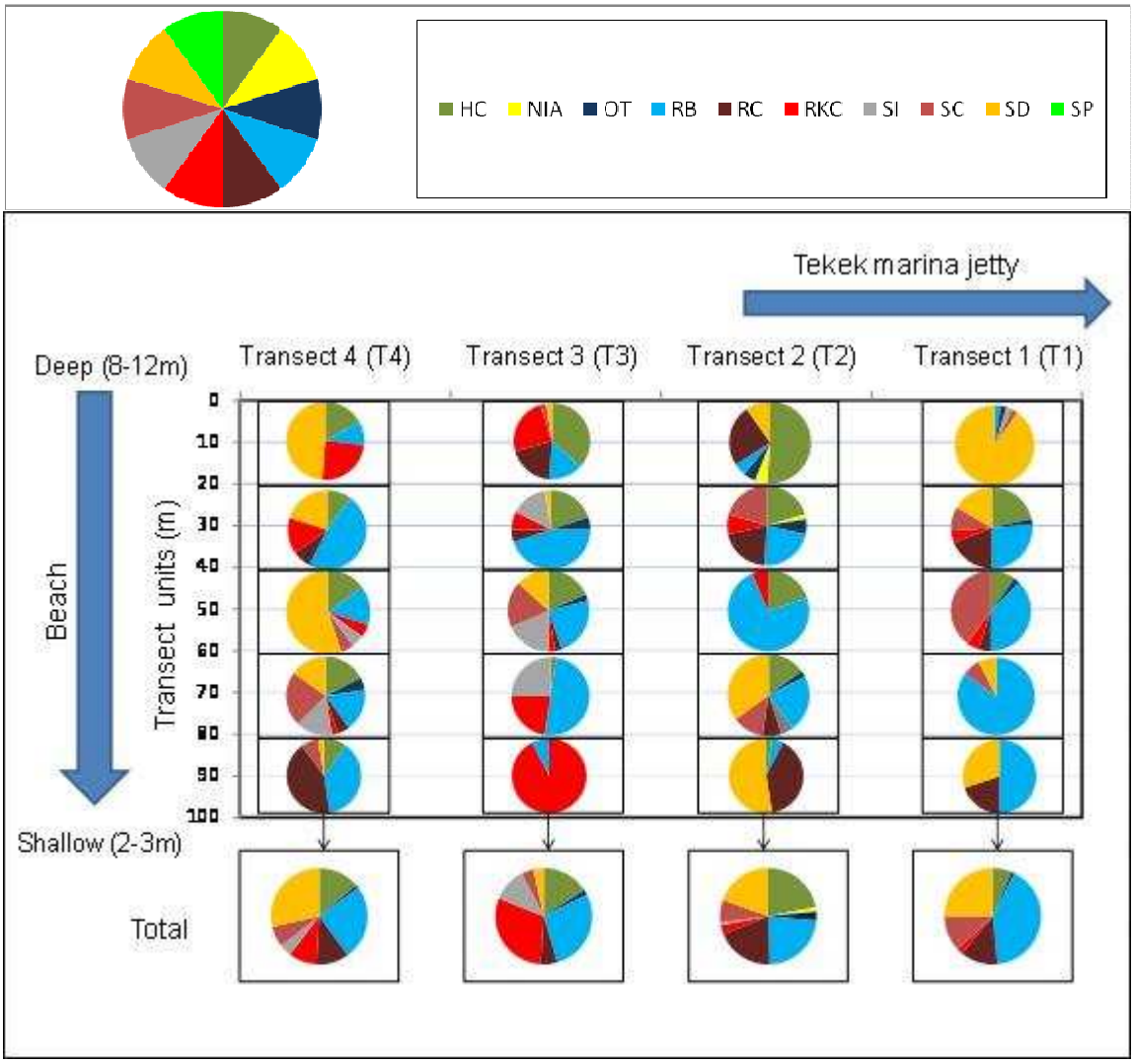


Figure 3.1 Profile transect and substrate composition (%) of the study site. Substrate categories and their colour codes are shown on top. HC= hard coral, NIA= nutrient indicator algae, OT= other biological organisms, RB= rubble, RC= rock, RKC= recently killed coral, SI= silt/clay, SC= soft coral, SD= sand, SP= sponge.

A significant difference (F: 4.659, $p<0.05$) was found in Silt (SI) cover % between shallow (40-100 m) and deeper parts (0-40 m) of transects with higher silt cover % in deeper parts. From Figure 3.2, the Transect 1 (T1), which was the closest transect to marina, had the highest Rubble (RB) % cover and the lowest Hard Coral (HC) % cover compared to other transects further from the marina.

Reef Check surveys were done for both Marina Shallow and Marina Deep areas in June 2008. The results were then compared (paired t-test) with Reef Check surveys done at the same area in April and September 2004 which were prior to the marina construction. As shown in Table 3.1 and Figure 3.2, mean percentage of Recently Killed Corals (RKC) (t: 10.288, $p<0.05$) and Silt (SI) (t: 11.831, $p<0.05$) cover in Marina Deep had significantly increased after the construction compared to the survey done in September 2004 (5-8 m depth). RB (S) % cover had also increased (t: 6.425, $P<0.05$) in Marina Shallow after the construction, compared to the survey done in the area (at 6 m depth) in April 2004.

Table 3.1 Mean percentage of substrate cover using Reef Check before and after marina construction in Marina Shallow (MS) and Marina Deep (MD). Note: * denotes significant difference was found. Refer to Table 2.2 for each substrate description.

Site	Time	HC	SC	RKC	NIA	SP	RC	RB	SD	SI	OT
MS	Before construction (Apr-04)	28.13	8.75	30.63	0.00	0.00	16.25	5.00	6.88	0.00	4.38
	After construction (Jun-08)	16.25	3.75	22.50	0.00	0.00	6.88	28.13*	22.50	0.00	0.00
MD	Before construction (Sep-04)	36.88	0.63	0.00	0.00	0.00	4.38	25.00	33.13	0.00	0.00
	After construction (Jun-08)	17.50	1.25	8.75*	0.63	1.88	16.88	10.63	22.50	16.25*	3.75

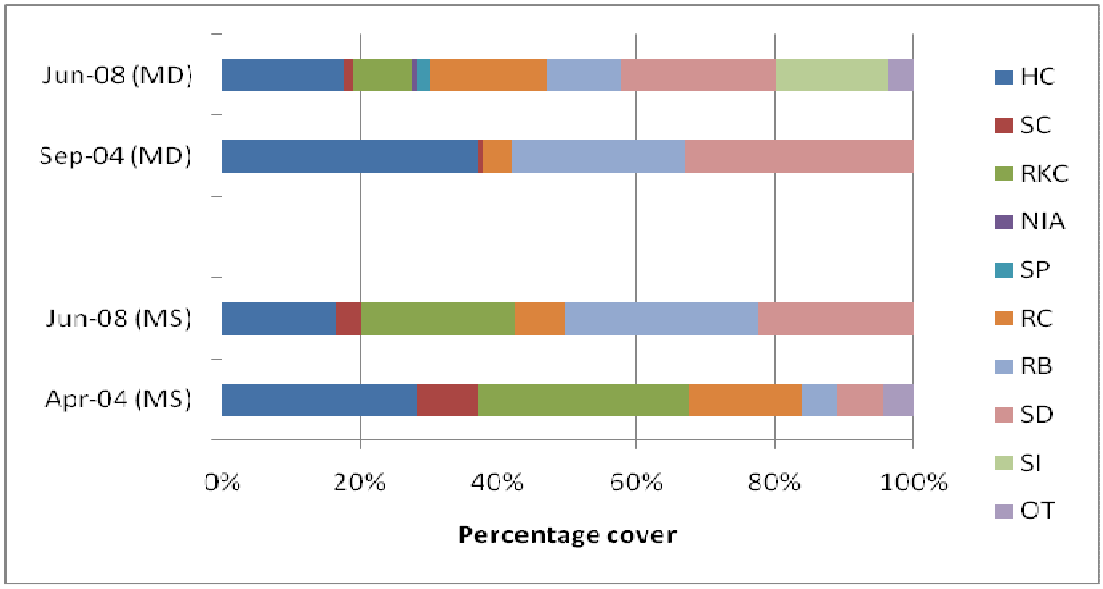


Figure 3.2 Percentage cover of different substrates before and after the marina construction in Marina Shallow (MS) and Marina Deep (MD) of the study site using modified Reef Check method. Refer to Table 2.2 for each substrate description.

Before-After-Control-Impact-Pairs (BACIP) design (Underwood, 1991; Smith, 2002) was used to compare between Reef Checks done in Marina Shallow and Renggis. Since for Renggis (control site) the only monitoring that has been done before the marina construction was at 6m depth, it only could be compared with MS at 6 m depth. T-test was used to compare the results in Marina Shallow before and after the construction with control before and after the construction and significant difference ($t: 3.21$, $p<0.05$) was found in Rubble (RB) % cover after the marina was built (Figure 3.3).

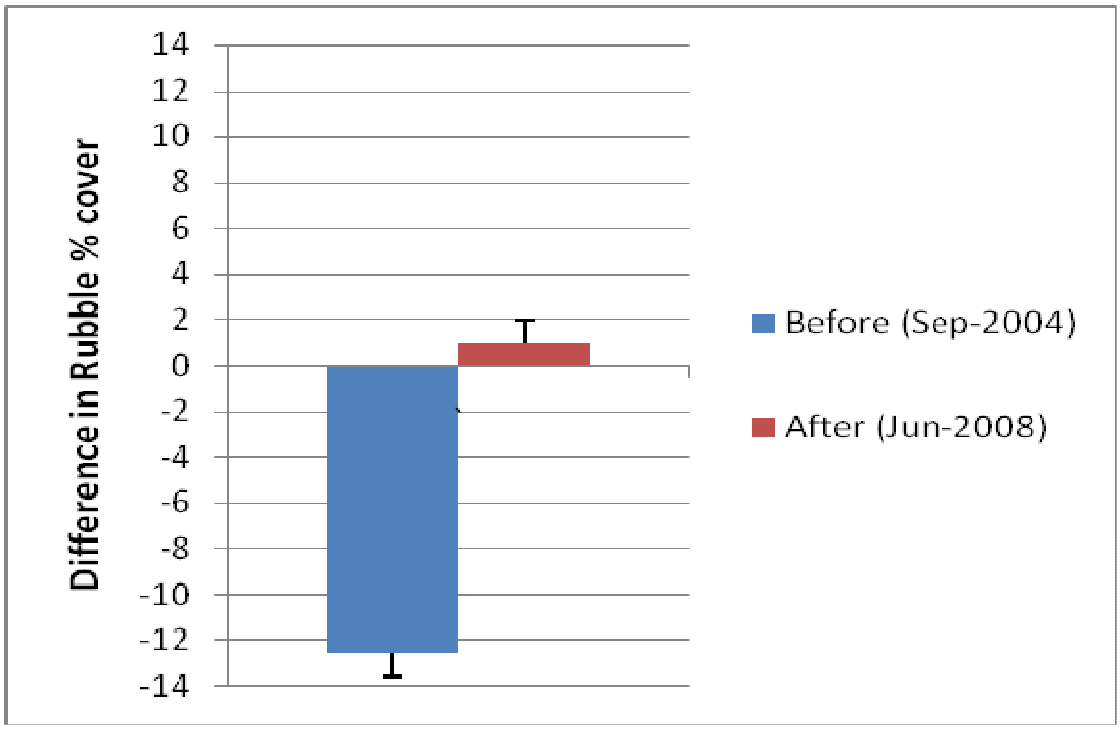


Figure 3.3 Difference in Rubble % cover before and after the construction in Marina Shallow. The blue column represents the difference in Rubble % cover between Control (R) and Impact (MS) before the marina construction which shows that R had more RB cover compared to MS before the construction. The more Rubble % cover in Renggis in Sep 2004 is probably because of the dominant branching *Acropora* species in the area. It is also one of the most famous tourist destinations in Tioman where the presence of tourists and anchoring of boats around the island may have caused more coral breakage compared to MS. The results in Jun 2008, shows that although Renggis was more susceptible to coral breakage, the rubble % cover increased much more in MS after the construction. The red column represents the difference in Rubble % cover between Control (R) and Impact (MS) after the marina construction which shows the difference has changed a lot after the construction and the RB cover has significantly increased in MS. Vertical Error bars denote Standard Deviation.

3.1.2 Discussion

Reef check method was used in this study in March 2008, to profile the study site (Figure 3.1) and get a better understanding of acute impacts of marina construction. Acute impacts were assumed as the study was done within the first year after the construction was completed. Due to logistical limitations, the earliest time the

monitoring could start was 9 months after the completion of the marina. This may underestimated the acute impacts of the marina construction in the results. To maximise the protection of habitats especially the highly sensitive ones such as coral reefs, it has been suggested that monitoring of construction activities should commence even during the pre-construction phase to allow intervention prior to construction (Koskela *et al.*, 2003).

By profiling the site some differences especially in Silt (SI) % cover (Figure 3.2) between shallow and deep parts of the study site were observed. This was one of the reasons that the study site were separated into Marina Deep (MD) and Marina Shallow (MS), as some differences in chronic impacts from construction were expected to be observed between MS and MD.

In addition, to be able to compare the coral reef coverage changes in the study areas before and after the marina construction (acute effects), Reef Check method was used in June 2008, as Reef Check was the only available data before the construction (Table 3.1). The increased Silt (SI) and Recently Killed Corals (RKC) % cover in MD (Table 3.1; Figure 3.2) after the construction could be one of the obvious effects of increased sedimentation due to the marina construction. As Fabricius (2005) indicated, sedimentation affects corals more in deeper depths compared to shallow parts which could explain the higher RKC in Marina Deep. Another explanation for higher RKC recorded in MD could be due to the longer term effects of construction. This happens when inorganic nutrients increase in sea water, bioeroding organisms such as microbes, algae, worms, sponges, bivalves will increase in density. This in turn, weakens the structure of coral reefs and they would be more susceptible to storm damage which can result in more RKC coverage (McClanahan, 2002; Fabricius, 2005). Direct physical

breakage of corals from the construction processes such as barge landings and piling of the jetty pillars can also increase the RKC percentage. Figure 3.4 shows the pillars that were constructed damaging the corals. Photos were taken 2-3 weeks after the pilling work.

Figure 3.4 Showing the pillars that were constructed damaging the corals during the marina construction (Photos taken by Serina Rahman, August 2005).

There seemed to be an increase in Sand (SD) % cover in MS (Table 3.1; Figure 3.2) could be from the sand used during the construction. It is reported by island locals (pers. comm.) that during the construction activity, after dredging and cleaning up the land in marina area, the voids areas had been filled with sand to stabilize the bottom of the marina area and levelling it for berthing. It was also reported by locals (pers. comm.)

that during the construction, the jetty pillars were temporary stored in the shallow part which could have caused coral breakage. Therefore, the direct physical breakage of corals from the construction process could have increased both the Sand % cover and Rubble % cover in marina site as seen in the results. The BACIP design showed that the Rubble had increased after the construction in MS (Figure 3.3). Moreover, the marina profiling (Figure 3.1) clearly shows that the highest Rubble (RB) cover was in the Transect 1 (T1=closest transect to the marina) compared to the other transects further from marina. This strengthens the idea that higher Rubble % after marina construction is most probably due to the construction. An EIA report in June 2006 (Angkasa Jurutera Perunding Sdn Bhd, 2006) documented that the regular barge berthing at the study site highly increased the chance of coral breakage in MS. This further caused an increase in Rubble cover (Figure 3.4) after the construction especially in MS where it is more susceptible to mechanical damage from the construction (Fabricius, 2005).

3.2 Chronic Impacts: Environmental Parameters

3.2.1 Sedimentation rate

The mean sedimentation rate in Marina Site (MD and MS) during the study was found to be significantly higher (F: 6.735, $p<0.05$) compared to Renggis (R, control site) (Figure 3.5). The mean sedimentation rate for Marina Deep (MD) was 11.69±7.04 SD (mg/cm^2day) and in Marina Shallow (MS) was 23.37±7.54 SD (mg/cm^2day), while in Renggis was 0.59±7.41 SD (mg/cm^2day).

For the temporal study of 12 months, significant differences in sedimentation rates were found in both Marina Deep (F: 10.754, $p<0.05$) and Marina Shallow (F: 579.799, $p<0.05$) only in October 2008 to March 2009 (second field trip) (Figure 3.5). This

increase in sedimentation rate coincided with the north-east (NE) monsoon during November to March. The results shows that increase in sedimentation rate during the monsoon was much higher in Marina Shallow (from mean of 6.99 mg/cm²day to mean of 60.05 mg/cm²day) compared to Marina Deep (from mean of 8.22 mg/cm²day to mean of 19.93 mg/cm²day) (Figure 3.5) and more bottom sediments had been moved by currents in Marina Shallow.

Total dissolved solids (TDS) measured during the study (subchapter 4.1.4) was found to be significantly correlated with sedimentation rate in Marina Shallow (Pearson correlation: 0.986, $p<0.01$) and Marina Deep (Pearson correlation: 0.655, $p<0.05$).

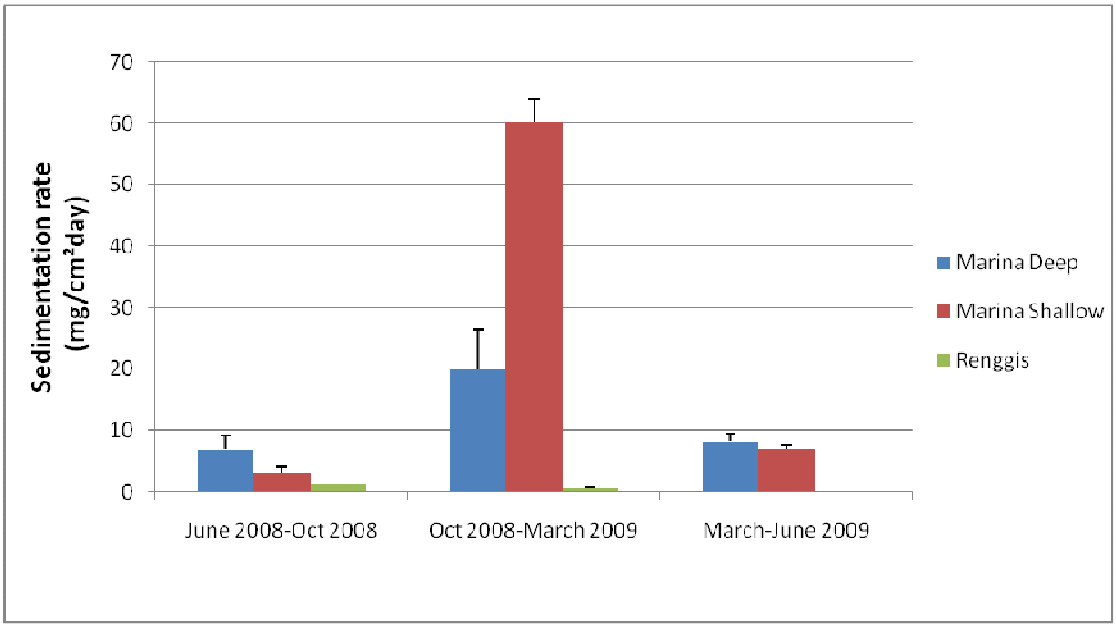


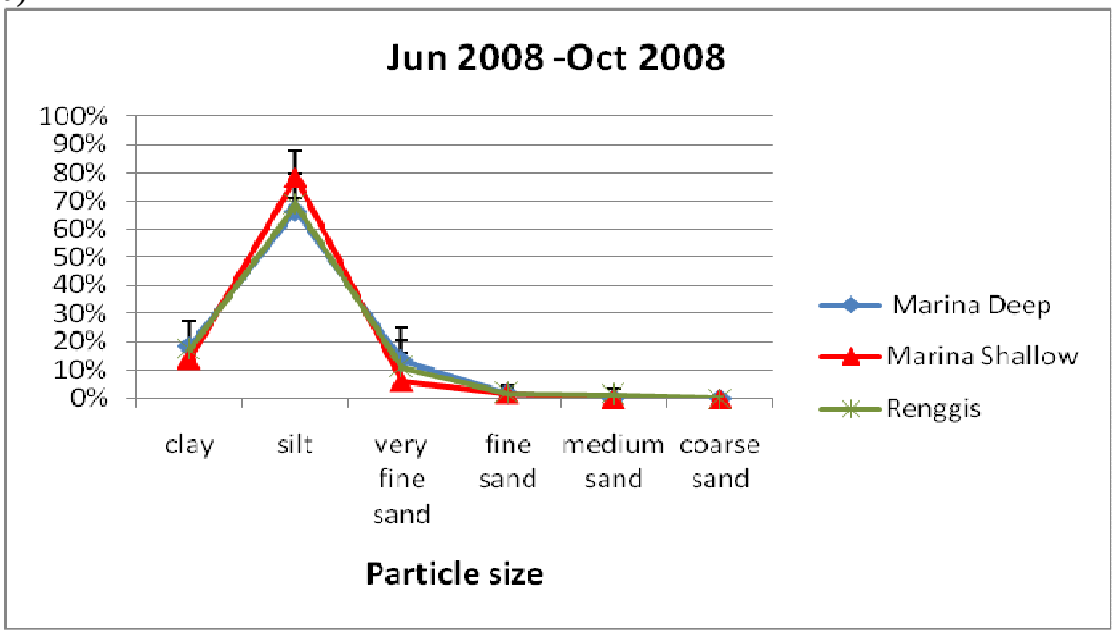
Figure 3.5 Sedimentation rates in Marina Deep, Marina Shallow and Renggis (control site) from June 2008 until June 2009. Vertical Error bars denote Standard Deviation.

3.2.2 Particle size of sediment

MS had the highest percentage (99.46%) of fine particle less than 125µm (clay, silt and very fine sand), while R had the lowest (84.66%). The "silt" content in MS was

significantly higher (F: 7.41, $p<0.05$) than MD and R. Sediment collected in sediment traps at the study site was dominated by silt component which exceeded 60% of the sediments collected at all sampling times (Figure 3.6).

a)



b)

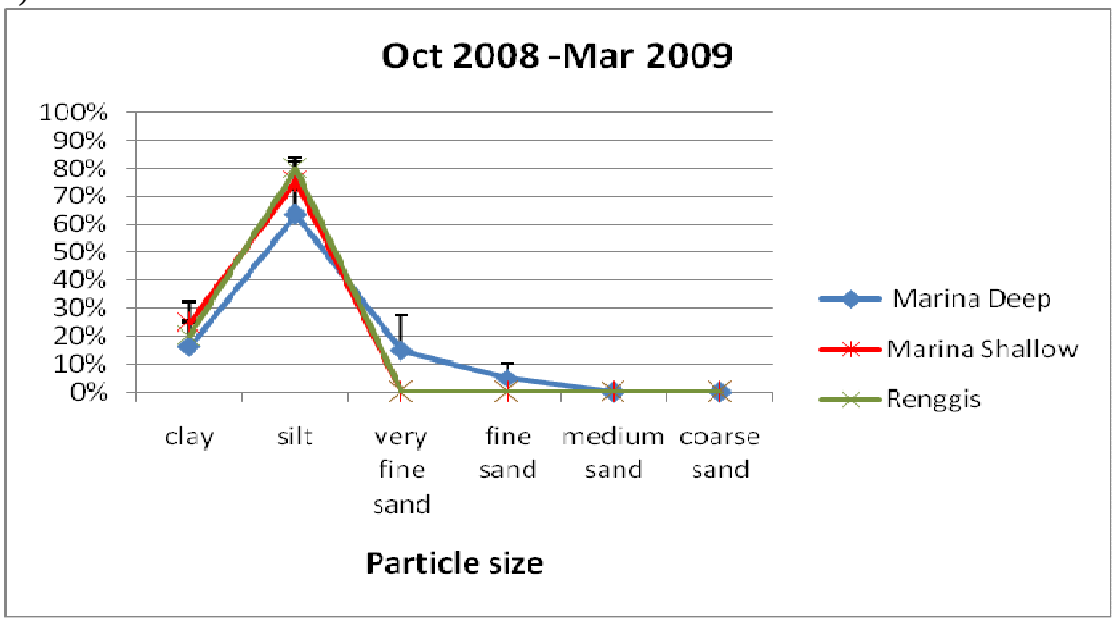


Figure 3.6, continued

c)

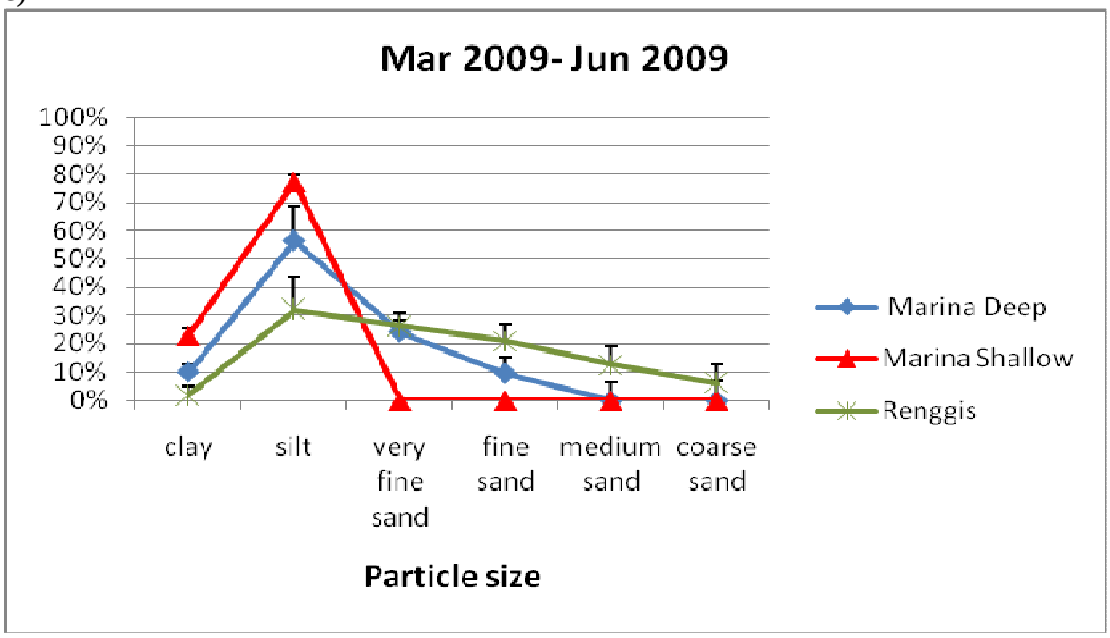


Figure 3.6 Line charts showing the changes of different sediment size particles (%) collected at MD, MS and R from (a) June 2008 to October 2008 (b) from October 2008 to March 2009 (c) from March 2009 to June 2009. The size of sediment particle groups were classified into clay (<3.9*u*m), silt (3.9 to 62*u*m), very fine sand (63 to 125*u*m), fine sand (125 to 250*u*m), medium sand (250 to 500*u*m) and coarse sand (0.5 to 1mm). Vertical error bars denote Standard Deviation.

In Marina Shallow the “clay” content increased after October 2008. In Marina Deep the “silt” content decreased in June 2009 while “very fine sand” and “sand” increased. In Renggis, sediments had the lowest “clay” and “silt” in June 2009 and highest for other particle size ranges in June 2009 (Figure 3.7).

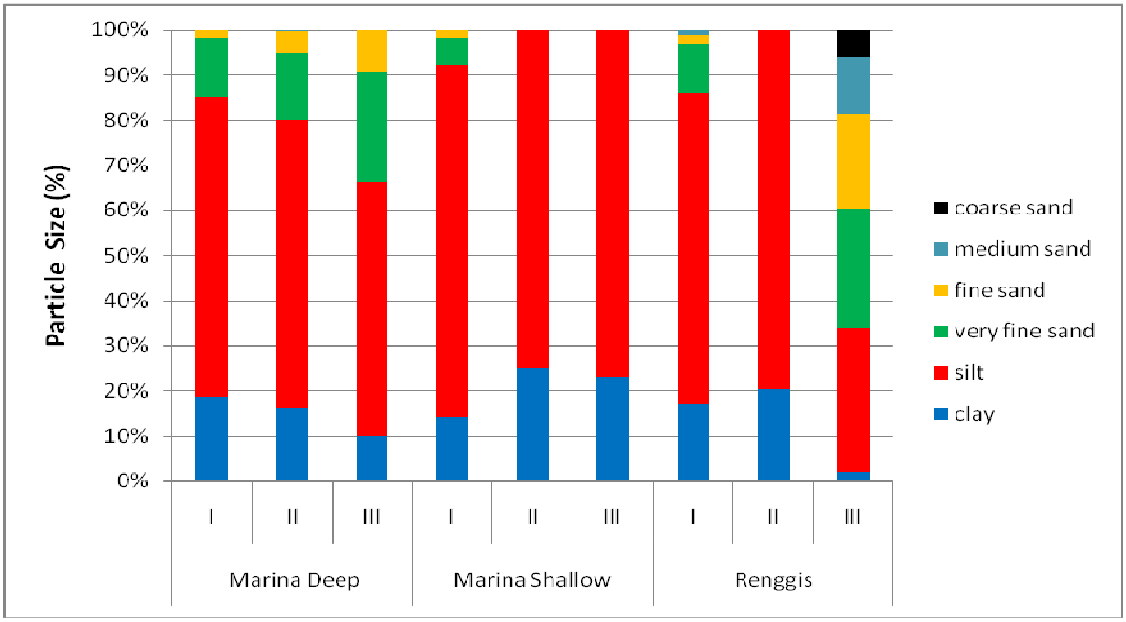


Figure 3.7 Changes of different sediment size particles collected in MD, MS and R throughout the study from June 2008 to June 2009. Note: I = First Sampling time (Jun08-Oct08), II = Second sampling time (Oct08-Mar09), III = Third sampling time (Mar09-Jun09).

3.2.3 Organic matter content in collected sediment

Percentage of organic matter content in the collected sediments was relatively low at Marina Deep and Marina Shallow compared to Renggis (Table 3.2) but no significant difference was observed between sites. In June 2008 until October 2008 the organic matter content was significantly higher than other sampling times in all MD (F: 360.24, $p<0.05$), MS (F: 531.34, $p<0.05$) and R (F: 20.81, $p<0.05$) sediments.

Table 3.2 Percentage of organic matter in trapped sediment at Marina Deep, Marina Shallow and Renggis from October 2008 to June 2009. (S.D= Standard Deviation).

Sampling period	Organic matter %					
	Marina Deep		Marina Shallow		Renggis	
	Mean	S.D	Mean	S.D	Mean	S.D
Jun08-Oct08	13.09	1.09	13.73	0.95	16.92	2.78
Oct08-Mar09	0.97	0.07	0.56	0.22	5.15	1.28
Mar09-Jun09	0.79	0.21	0.75	0.15	3.22	3.79

3.2.4 Water quality

All physical parameters measured in the study sites are shown in Table 3.3.

Table 3.3 Physical Parameters for all surveyed sites. Note: `N/A` = not available due to probe malfunction, `_` = no data. Underwater Light (Lux) and seawater temperature (ºC) shown in this table are daily mean for each period.

	Site	1st Field Trip (Mar-08)	2nd Field Trip (Jun-08)	3rd Field Trip (Oct-08)	4th Field Trip (Mar-09)	5th Field Trip (Jun-09)
Conductivity (ms)	**Marina Deep**	36.02	36.57	43.59	47.06	50.2
	Marina Shallow	38.35	36.25	44.1	44.8	50.1
	Renggis	46.44	N/A	42.5	44.06	49.73
Salinity (ppt)	**Marina Deep**	21.6	21	26.1	27.8	29.3
	Marina Shallow	23.1	20.07	26.5	28.1	29.2
	Renggis	28.7	N/A	25.2	27.3	29.7
TDS (g/L)	**Marina Deep**	22.47	21.91	26.62	28.14	29.6
	Marina Shallow	23.83	21.64	26.91	28.4	29.5
	Renggis	28.93	N/A	25.82	27.65	29.91
DO (mg/L)	**Marina Deep**	4.72	3.42	3.36	3.86	3.59
	Marina Shallow	5.92	3.75	3.5	4.04	3.51
	Renggis	6.61	4.72	3.48	3.2	3.49
pH	**Marina Deep**	_	7.89	7.38	7.12	7.28
	Marina Shallow	_	7.91	7.36	7.16	7.14
	Renggis	_	7.94	7.54	7.29	7.78
Underwater Light (Lux)	**Marina Deep**	–	_	275.15	270.47	609.83
	Marina Shallow	–	_	908.27	239.42	1056.24
	Renggis	_	_	1789.71	737.13	1832.36

Seawater Temperature (ºC)	**Marina Deep**	–	–	28.77	28.65	29.32
	Marina Shallow	–	–	28.76	28.60	29.49
	Renggis	–	–	28.64	28.51	29.31

Table 3.3, continued

By comparing the water temperature between MD, MS and R sites, no significant difference was found (Figure 3.8; Table 3.4). Nevertheless, there was a significant difference in light intensity recorded in MD, MS and R (Figure 3.7). Renggis had the highest light intensity (F: 176.77, $p<0.05$) when compared to Marina Shallow for the same depth (Table 3.5). Other physical parameters in Marina site were found to be similar to the control site (Renggis) (Table 3.3). Therefore, this strengthens the fact that Renggis is a good control site to be compared with the Marina site.

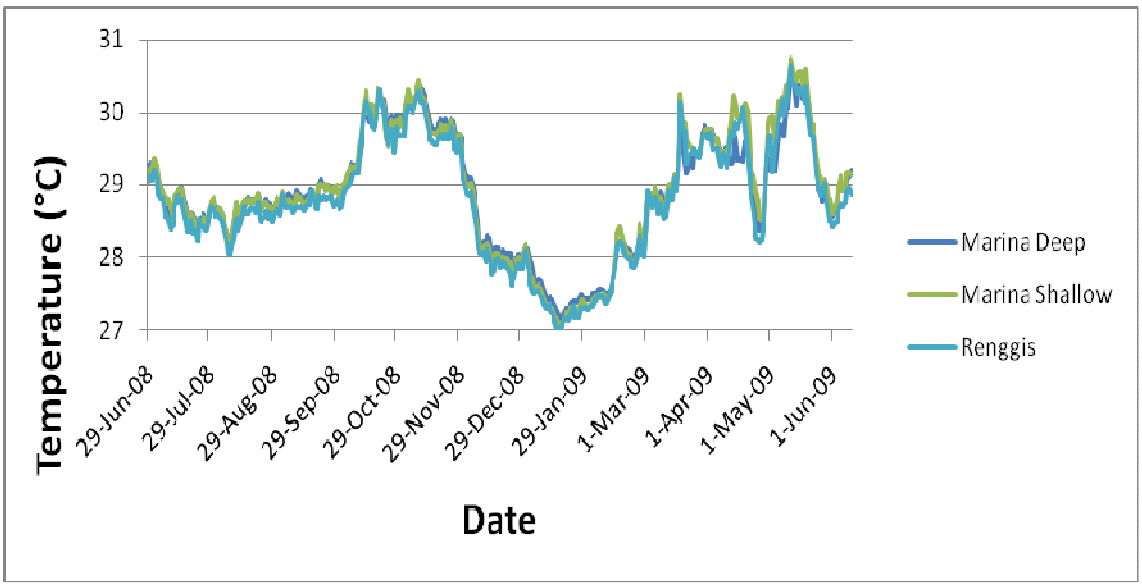


Figure 3.8 Daily mean seawater temperature (ºC) logged at Marina Deep, Marina Shallow and Renggis from June 2008 to June 2009 (12 months).

Table 3.4 Daily mean seawater temperature (ºC) logged at Marina Deep, Marina Shallow and Renggis from June 2008 to June 2009. (S.D= Standard Deviation).

	Temperature (ºC)					
	Marina Deep		Marina Shallow		Renggis	
	Mean	SD	Mean	SD	Mean	SD
Jun08-Oct08	28.77	0.21	28.76	0.22	28.64	0.21
Oct08-Mar09	28.65	1.06	28.60	1.08	28.51	1.06
Mar09-Jun09	29.32	0.51	29.49	0.58	29.31	0.60

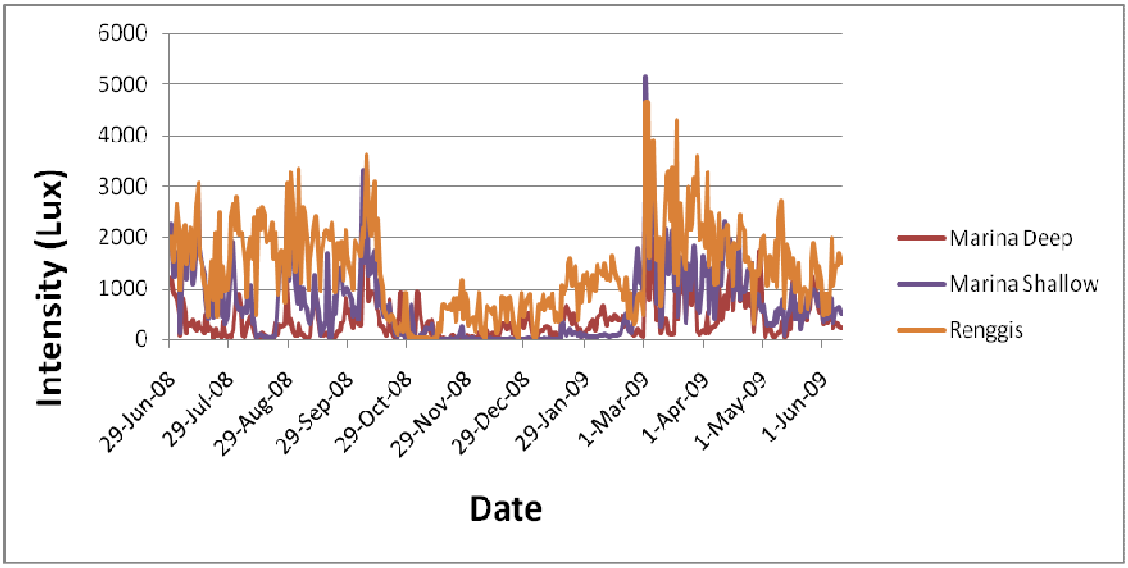


Figure 3.9 Daily mean underwater light (Lux) logged at Marina Deep, Marina Shallow and Renggis from June 2008 to June 2009 (12 months).

Table 3.5 Daily mean underwater light (Lux) logged at Marina Deep, Marina Shallow and Renggis from June 2008 to March 2009. (S.D= Standard Deviation).

	Light (Lux)					
	Marina Deep		Marina Shallow		Renggis	
	Mean	SD	Mean	SD	Mean	SD
Jun08-Oct08	275.2	267.9	908.3	662.0	1789.7	625.5
Oct08-Mar09	270.5	322.8	239.4	523.8	737.1	621.2
Mar09-Jun09	609.8	501.7	1056.2	792.5	1832.4	896.1

3.2.5 Discussion

The sedimentation rates in Marina site are considered high as Fabricius (2005) stated that mean sedimentation rate of less than 10 mg/cm²day for reefs would indicate that they are not subjected to human activities, while the chronic rates of greater than 10 mg/cm²day are considered high. From the results of this study, the Marina Deep and especially Marina Shallow are considered highly sedimented as their average sedimentation rates are more than 10 mg/cm²day. However, other studies on the effects of coastal development have shown higher sedimentation rates compared to the present study (mean ranged from 11.69 to 23.37 mg/cm²day). For example, Thomas *et al.* (2003), near a mining area that was subjected to a high sediment source at Lihir Island, Papua New Guinea, showed that the severe impact zone had sediment accumulation rates between 25 and 50 mg/cm²day. A study by Edinger *et al.* (2000) on the reefs of Indonesia showed that sedimentation rate in the most affected sites (with maximum depth range of 4 to 8 m) subjected to anthropogenic stress ranged from 26.19 to 57.50 mg/cm²day. In addition, Fabricius *et al.* (2007) showed that the sedimentation rate at the site affected by road construction and other coastal developments, averaged 39.6 mg/cm²day. However, the sedimentation rate observed in this study may have been underestimated. This is due to the collection efficiency of sediment traps in this study which might have been affected by many factors. For instance, sedimentation rate (1) decreases with increasing horizontal current speed at the trap mouth, (2) decreases with decreasing particle fall velocity, and (3) increases with increasing trap aspect ratio (Baker *et al.*, 1988; Bhaskar *et al.*, 2000). The height to diameter ratio of 5:1 in the present study, has been considered sufficient for minimising resuspension of trapped material by water turbulence entering the traps (Bhaskar *et al.*, 2000). As was recommended by English *et al.* (1997) sediments must be removed from the trap monthly but due to logistics problems and budget limitation the traps were collected

every three months. For further studies, it is suggested that a preliminary study be done to examine traps with different sizes and shapes in the study area to determine the best sediment trap size for each specific study site.

The high sedimentation rates recorded in Marina Shallow and Marina Deep (Figure 3.5) are most likely due to construction adjacent to the study site. This is supported by the study done by Koskela *et al.* (2003) who pointed out that sedimentation increase is a key pollutant generated by the coastal construction process. Furthermore, study by Ryan *et al.* (2008) on changes of sedimentation rate after coastal developments at the adjacent coral reef showed that there was a significant increase in sedimentation and decrease in coral cover caused by development over the last few decades. The most recent coastal construction adjacent to the study site was the marina construction. Even though there were no data on sedimentation before the construction in Marina site, the comparison of sedimentation rates in MD and MS with R (with no marina construction impact) after the jetty was built have supported the contention that sedimentation had increased. This is further strengthened by the fact that there was no change in sedimentation rate in the control site. Before the marina construction, the average sedimentation rates around Pulau Renggis was less than 10 mg/cm²day Yong (2007) and it had remained at that level in the present study. To have a better understanding on sedimentation rates and their impact on reef system for future studies and to better manage future construction projects, it is suggested that all marine parks should implement constant monitoring of sedimentation rates.

According to Nugues and Roberts (2003), sediments not only can cause direct coral mortality due to excessive energy expenditure from self-cleaning of sediment particles but also, it can affect corals indirectly by decreasing the light available to

photosynthesising symbiotic algae (zooxanthella) that lives in the coral. Lower light intensity recorded in Marina Shallow compared to Renggis (control site) (Figure 3.9; Table 3.5) in spite of the same depth, is probably due to high sedimentation and turbidity recorded in Marina site (Figure 3.5). This shading temporarily reduces photosynthesis by zooxanthellae. Many corals can adjust to lower light intensity by increasing the size and number of chloroplasts in zooxanthellae without altering zooxanthellae density per unit area (Sorokin, 1993). This process which is known as photoacclimation was observed in this study in the Foliose coral *(Pachyseris speciosa)* in Marina Shallow. Its chlorophyll *a* per zooxanthella ($F: 11.89$, $p<0.05$) significantly increased while zooxanthella density was not significantly different in March 2009 when the sedimentation rate increased (Figure 3.5). This photoacclimation process occurred only in the Foliose coral in this study as effects of low-light greatly vary between species (Fabricius, 2005). This is attributed to of its concave shape which promotes more sediment particles settling on its surface compared to other coral forms (Figure 3.10). This higher sediment settlement would have caused even lower light intensity available to the Foliose coral.

Figure 3.10 Foliose corals (*Pachyseris speciosa*) in Marina Deep and Marina Shallow. Note: the sediments stuck in the middle part of the coral.

There was a significant increase in sedimentation rates in second sampling time (Oct08-Mac09) in both MD (F: 10.754, $p<0.05$) and MS (F: 579.799, $p<0.05$), while the same increase was not observed in Renggis (control site) (Figure 3.5). This increase coincided with the NE monsoon (Oct- Mar) both in Marina Deep and especially in Marina Shallow with approximately 20 times higher sedimentation rate. The increase could be explained by the fact that the North East monsoon had caused an increase in suspended sediments in the Marina site which was affected by the marina construction and showed much higher sedimentation rate compared to Renggis. There was not such an increase in suspended sediments during the non monsoon season in the Marina site as the currents were not yet strong enough to resuspend the added sediment caused by the construction. The same increase was not observed in Renggis because the extent of sedimentation rate was low and consequently there was no significant increase of suspended sediments during monsoon. On the other hand, MS had more sedimentation due to marina construction and strong wave and currents during the monsoon season resuspended fine particles from the sea floor and caused an increase of suspended sediment (Bothner *et al.*, 2006). Bothner *et al*. (2006) indicated that the average sedimentation rates during the storm season were much higher than non-storm period. For instance, in Malokai, Hawaii a storm is able to cause 1000 times higher sedimentation rate than non-storm period.

From the results, sedimentation rates in MS and MD during monsoon shows that the water movements re-suspended sediments more in MS compared to MD (Figure 3.5). This can be described by the fact that the capacity for waves to re-suspend sediments increases as water depth decreases (Bothner *et al.*, 2006). Therefore, the sediments will re-suspend and settle down more at shallow parts compared to deep parts. Bothner *et al.*

(2006) also showed that the sedimentation rate in traps at 4.9 m water depth was 33 times higher than identical nearby traps at 10.1 m.

TDS is often correlated with turbidity as Fabricius (2005) had stated where any increase in terrestrial runoff (probably from the marina construction), would accelerate dissolved inorganic nutrients which in turn will increase turbidity. From the results (subchapter 3.2.1) the correlation between sedimentation rate and high TDS indicates that the Marina site has high turbidity.

The presence of high "silt" and "clay" content in the sediments of Marina Shallow (Figure 3.6) may threaten the coral species in the study site as silt-size sediments would be more detrimental than other grain size particles even after short exposures (Weber *et al.*, 2006). In addition, experimental studies (Nugues & Roberts, 2003; Fabricius, 2005; Weber *et al.*, 2006) have shown that fine particles less than 125μm (eg. "clay", "silt" and "very fine sand" components) in suspended sediment are most harmful to coral. "clay" and "silt" can easily be re-suspended from the sea floor and reduce the light intensity for prolonged periods (Fabricius, 2005) because they are the finest sediment components and fine-grain size particles that can be easily transported and dispersed throughout the reef (McCulloch *et al.*, 2003). In addition, removal of silt-sediments by corals is more difficult than sandy-sediments as the former has greater volume (greater surface area) and greater reactivity. Therefore, more nutrient and contaminant bind with sediment particles, making the sediment more sticky and fluffy (Weber *et al.*, 2006). From the Figure 3.11 which was taken during the construction it is shown that silt curtains used to trap silt and runoff from the construction were not properly deployed to prevent the effects of siltation. From this result in Marina site it is shown that the corals

are not only stressed by high sedimentation (subchapter 3.2.1), but also the situation was even made worse by the high amount of small grain size sediments.

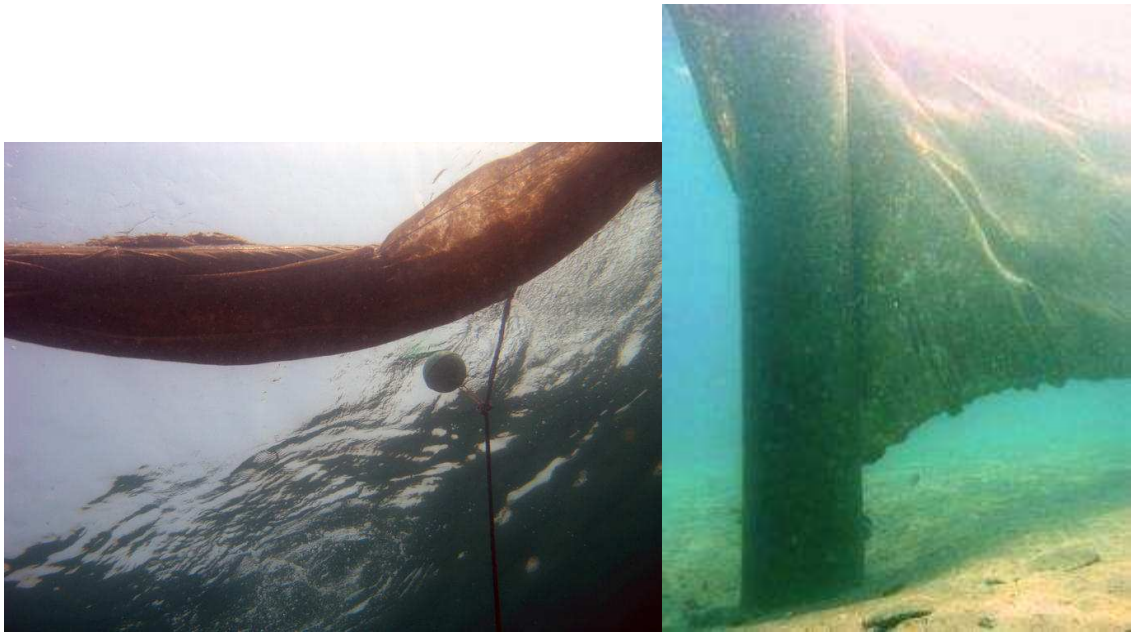


Figure 3.11 Showing the silt curtain used during the marina construction which was not properly deployed to trap silts and runoff from the construction (Photo taken by Serina Rahman).

Coral health is not only affected by the extent of sedimentation and grain size, but also the organic matter of the sediment. The quality of the sediment is a very important factor which can be more crucial than the sediment amount (Nugues & Roberts, 2003; Fabricius, 2005). It was suggested by Fabricius (2005) that low-level sediments with high organic content and bacterial activity and smaller grain size can kill newly settled corals, whereas the same amount of sediment with different quality would not have the same effect. Moreover, silt-sized minerals contain more organic matter content as they bind more nutrients and contaminants and harbour microorganisms. This makes the sediment more sticky and fluffy which makes the process of sedimentation removal more difficult for corals. Therefore, sediments with high concentrations of organic and nutrient-related matter (more ash-free dry weight) would have more effect on corals (Weber *et al.*, 2006). However, the results of organic matter content in this study, is

different from what was expected as the “silt” content in collected sediments was higher in Marina site (Figure 3.7), while according to Weber *et al.* (2006) silt-sediments have more AFDW than sandy-sediments. The lower organic matter content observed in this study could be explained by the low light intensity recorded in Marina site (Figure 3.9) that may have reduced the productivity of the reef and resulted in low organic contents in the sediment (Table 3.2). Lower organic matter observed in MD and MS also indicated that there are no other disturbances such as river discharge and sewage in Marina site (Nugues & Roberts, 2003).

The reason for higher organic matter content observed in pre-monsoon period (Jun 2008-Oct 2008) is not clear but it might be the effect of “flushing” of the sediments by strong monsoon currents. It seems that if the currents and water flow are strong enough, can cause the removal of accumulated organic matter in sediments. Strong storms and high wave energy can mix the bottom and surface water and will cause the perturbation of the sediments (Turner *et al.*, 2008). This may be the reason for the lower organic matter observed after monsoon season.

All water quality parameters that were measured in this study, were within normal ranges (Table 3.3). For example, the study by Lee *et al*. (2005) reported the physical parameters of the Langkawi archipelago area as having seawater temperatures in the range of 28.5°C-29.9°C, salinity between 28.5-30.50 ppt and DO between 4.58-6.64 mg/l. However, the TDS reported in the present study could be considered high because in the same study done by Lee *et al*. (2005) the study area was introduced as high turbid area with TDS ranging between 28.84-30.55 g/l. Seawater temperature between MS, MD and R was not significantly different, while light intensity was significantly different (in Figure 3.8 and 3.9). Light intensity recorded in Renggis was in the normal

range while Marina Deep and especially Marina Shallow at the same depth as Renggis had relatively low light intensity (Figure 3.9; Table 3.5). For instance, a study by Jitkue *et al*. (2007) showed that light intensity at tropical reefs (<5 m depth) of Racha Islands in Thailand on 30 June – 28 August 2007 had a mean of 2131.60 ± 3006.15 SD Lux. The difference in light intensity between Marina site and Renggis is probably resulted from sedimentation effects occurred in Marina Deep and Marina Shallow because increase sedimentation due to especially fine clay re-suspension from sea floor causes light reduction. In addition, increased nutrient run off will increase phytoplankton production which causes increase turbidity and reduction of light penetration (Fabricius, 2005).

3.3 Chronic Impacts: Substrate Cover

3.3.1 Substrate and coral cover (%)

The LIT surveys done from March 2008 to June 2009 showed that Renggis had the highest Hard Coral (HC) % cover. Mean Hard Coral (HC) % cover in Marina Deep was 24.74 (95% CI: ± 8.95), in Marina Shallow was 38.36 (95% CI: ± 2.3) and in Renggis was 53.27 (95% CI: ± 8.02) (Figure 3.12). Percentage data were arcsine square root transformed prior to the statistical test (Zar, 1994). From the One-way ANOVA ($F: 9.62$, $P<0.05$), the mean Hard Coral (HC) % cover values at Marina Deep were significantly lower than Marina Shallow and Renggis. The HC % cover did change slightly during the study period, but maintained the same trend during the study in all sites. No significant difference was observed in coral cover through 15 months monitoring (Figure 3.12).

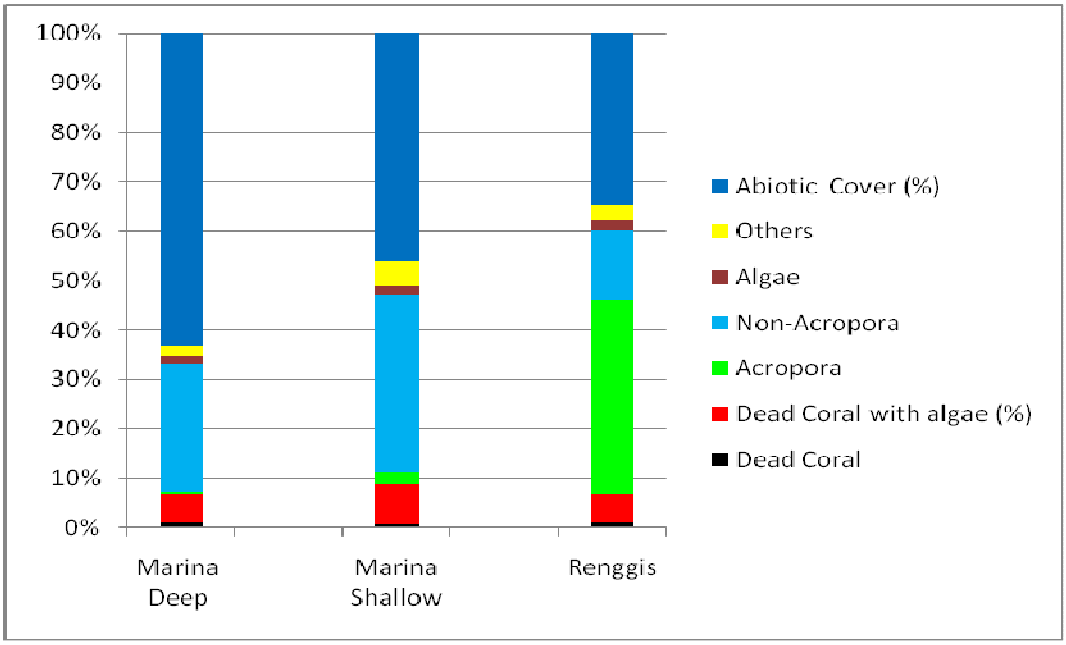


Figure 3.12 Mean percentage cover (n=5) of different substrates using LIT in Marina Deep, Marina Shallow and Renggis throughout the study from March 2008 to June 2009. Refer to Table 2.1 for each substrate description, "Others" category includes: Soft corals, Sponges, Zoanthids, Other living substrate organisms and Missing data.

As for coral reef status by using the linear quotes of live coral cover by Gomez and Yap 1988 (>75%: excellent, 50-75%: good, 25-50%: fair, <25%: poor), Renggis coral cover was in 'good' condition (53.27%) while Marina Shallow was in 'fair' condition (38.36%) and Marina Deep (24.74%) was in 'poor' condition (Figure 3.13).

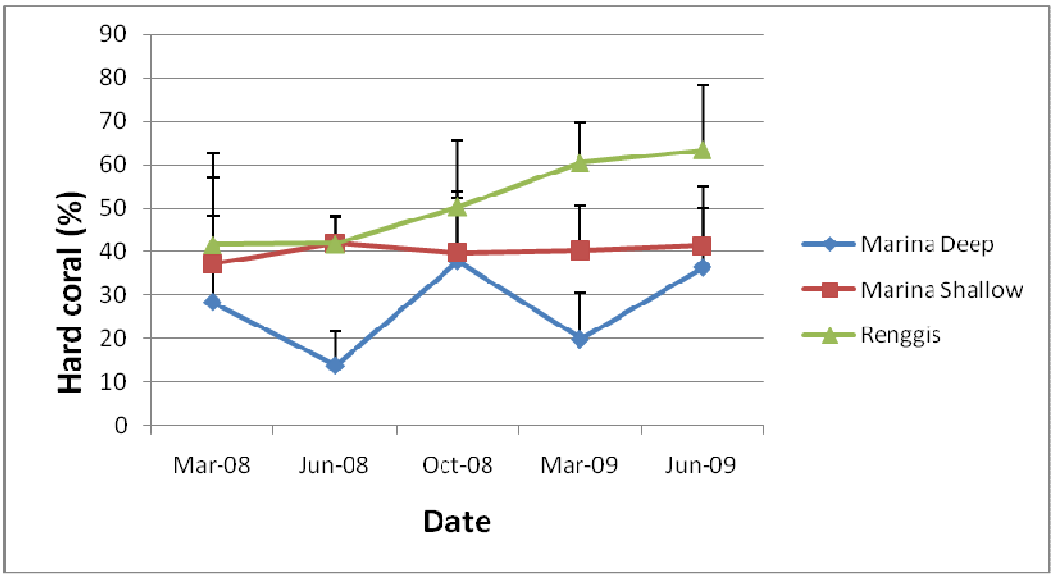


Figure 3.13 Hard coral cover % through time in MD, MS and R using LIT method. Vertical Error bars denote Standard Deviation.

The result from the 15 months monitoring also showed that the dominant coral growth form in Marina Deep and Marina Shallow was the submassive coral while the dominant coral growth form in Renggis was branching *Acropora* and there were no changes of the dominant coral growth forms throughout the study.

The results of LIT monitoring showed that in Marina Shallow *Acropora* encrusting (F: 9.451, $p<0.05$) and *Acropora* submassive (F: 6.350, $p<0.05$) had significantly the highest cover in March 2008 (first field trip) while the Rubble (R) % coverage increased through time and had significantly the highest value in the last field trip. It is probable that *Acropora* species may have been transformed to rubble. *Acropora* species are known to be a major rubble producer in the Great Barrier Reef (Woesik & Done, 1997). It has also been indicated that shallow reef areas (3 m depth) are more susceptible to mechanical damage caused by construction than deep areas (10 m depth) (Edinger *et al.*, 1998; Fabricius, 2005).

Percentage cover of Macroalgae (MA) (F: 3.829, $p<0.05$), Turf Algae (TA) (F: 7.248, $p<0.05$), and Dead Coral with Algae (DCA) (F: 3.641, $p<0.05$) among 5 sampling occasions, were all significantly highest (one-way ANOVA) in Marina Shallow at the start of the study in March 2008 (Figure 3.14).

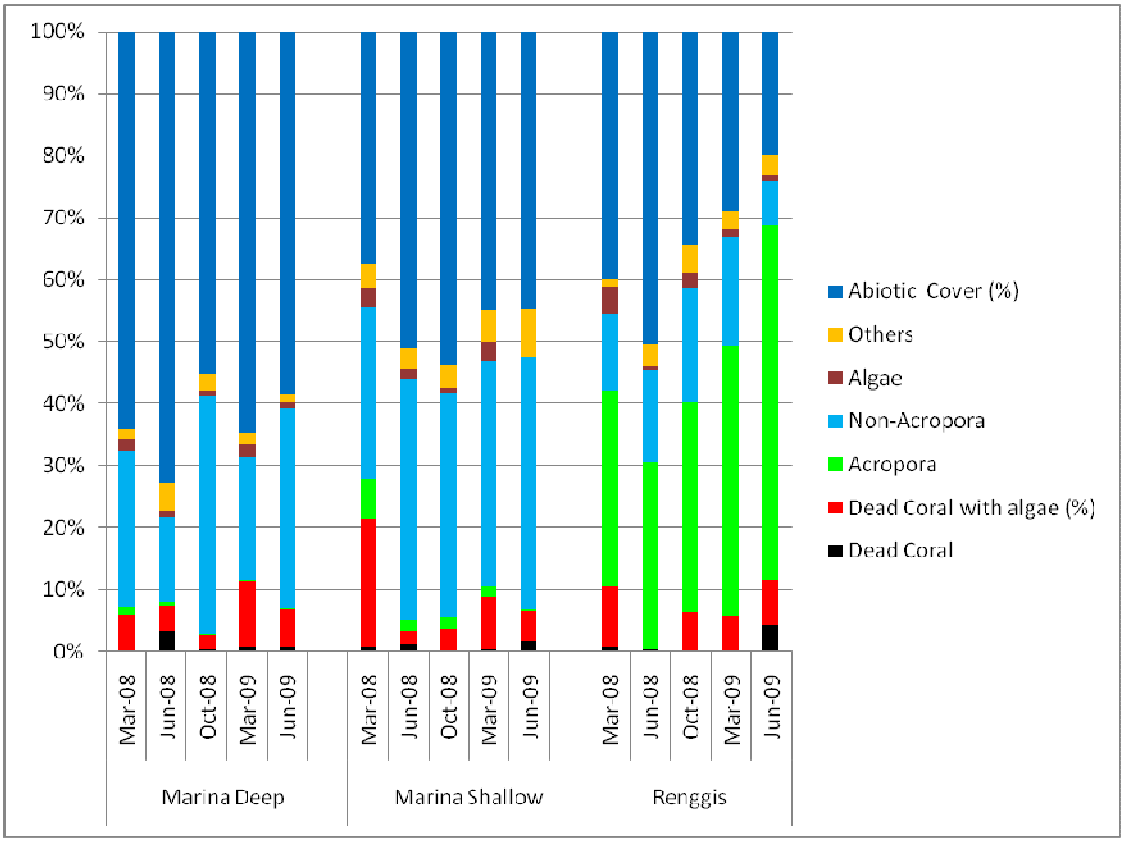


Figure 3.14 Percentage cover of different substrates in MD, MS and R using LIT monitoring for 15 months (Mar-08, Jun-08, Oct-08, Mar-09 and Jun-09). Refer to Table 2.1 for each substrate description, "Others" in this figure includes: Soft corals, Sponges, Zoanthids, Other living substrate organisms and Missing data.

3.3.2 Discussion

A survey on the reefs of Tioman in 2000 by Coral Cay Conservation (Harborne *et al.*, 2000) showed that mean coral coverage for Tioman was 45.3%. Another study done in 2001 by documented live coral coverage of Peninsular Malaysia ranging from 17.9% to 68.6% while live coral coverage in (Tulai Reef and Manggo Reef and Renggis) were 31.1 %, 34.6 % and 68.6 % respectively (Toda *et al.*, 2007). However, a study done by Bruno & Selig (2007) indicated that the average coral cover in the Indo-Pacific reefs was 22.1% in 2003. This means that although the reefs in the present study site are in normal range for Peninsular Malaysia, the recorded coral coverage (Figure 5.2) was less than what is expected for a reef in a marine park. Coral cover in protected areas should

be significantly higher than unprotected ones as was shown in the study by Selig & Bruno (2010) who compared coral cover in 310 MPAs to unprotected areas.

Coral % cover is a critical measure of habitat loss and degradation (Bruno & Selig, 2007) and hard coral represents the most important component of the entire coral reef ecosystem. In the studies done by Dikou & Woesik (2006), increase in sedimentation load (caused by anthropogenic impacts such as reclamation and dredging activities) was the apparent cause of live coral cover reduction. Monthly sedimentation rates in affected sites ranged from 5 to 20 mg/cm²day. In addition, Toda *et al.* (2007) suggested that one of the major reasons for the "fair" and "poor" conditions (Gomez & Yap, 1988) of corals in Peninsular Malaysia may be due to increase in sedimentation. So according to all these studies, low Hard Coral (HC) % cover (Figure 5.2) and higher Dead Coral (DC) % cover in Marina compared to Renggis is likely due to high sedimentation recorded in Marina site (Figure 4.1). The low coral cover during the study is another strong indication of the negative effects of the construction.

One of the reasons for the difference in coral growth form in the study sites can be the different tolerance to sedimentation between massive and branching corals. *Porites* massive is known to be slow growing while *Acropora* corals are capable of very rapid growth once established in a habitat (Edinger & Risk, 2000). Generally, under normal conditions where sedimentation rate is low, *Acropora* coral would be the dominant genus as fast growing corals become dominant more readily than slow growing coral like *Porites* massive (Toda *et al.*, 2007). Since *Acropora* species have lower tolerance to sedimentation, increases in sedimentation may cause a decline of *Acropora*. On the other hand, massive (or submassive) corals have more tolerance to sedimentation. This is supported by the work of Lam *et al.* (2007) where they showed that *Porites* can

tolerate sediment deposition, rapidly regenerate tissue damaged by deposited sediment and trap sediments in mucus sheets, which are frequently discarded by currents. Studies done in Cape Rachado of the Straits of Malacca on the west coast state in Malaysia also showed that massive coral forms of *Porites lutea*, *Faviid* species, *Goniastrea* and *Platygyra* are the most abundant species in the area influenced by several factors such as silt content and other particulate matter (Toda *et al.*, 2007). Other studies have also shown the disappearance of sediment-sensitive species (such as *Acropora* corals) over 12 months due to sedimentation from logging (Hodgson, 1999; Fabricius, 2005). It was indicated by Edinger & Risk (2000) that although sediment tolerant corals are abundant in all reefs, they would only be dominant as a result of sediment and pollution stress. Similarly in sediment stressed Marina site, massive form is the dominant coral. However, this sediment stress in marina may have occurred either by marina construction or by other factors even before the marina was built. Since there is a lack of study on coral growth form in Marina site before the marina construction, it is not possible to state the exact cause of sedimentation in Marina site and whether the difference in dominant coral growth forms in our study between Marina and Renggis is similar to what it was before the construction.

Macro Algae (MA), Turf Algae (TA) and Dead Coral with Algae (DCA), were all highest in Marina Shallow at the start of the study in March 2008. Run off from the construction could have caused nutrient enrichment which increased algae assemblage and more algae would have settled on coral surfaces. This would cause light reduction and shading which would become even worse when high sedimentation occurred in the area (Fabricius, 2005). The reason of not observing the same results in MD is because nutrient enrichment would be highest in the more productive inshore environments (shallow) than offshore (Fabricius, 2005). It was indicated by Edinger *et al*. (1998) that

the reef can recover from chronic stresses such as increased sedimentation and nearshore eutrophication, only when the stressor is removed. Since this study was done one year after the marina was completed, decreasing coverage of MA, TA and DCA throughout the study indicated that the recovery might have already started in Marina Shallow after the source of stress (marina construction) had stopped. This demonstrates that to monitor the recovery process, apart from monitoring the acute construction impacts it is also important to do long-term monitoring to observe chronic effects of the construction.

3.4 Chronic Impacts: Zooxanthellae of Selected Scleractinian Corals

3.4.1 Zooxanthella density and chlorophyll content

The zooxanthella densities were determined for four species of corals with different growth forms (Branching, Foliose, Submassive and Free-living) in June 2008, October 2008, March 2009 and June 2009. The mean zooxanthella density of all selected scleractinian corals in four times sampling through 12 months in Marina Deep, Marina Shallow and Renggis is shown in Table 3.6.

Table 3.6 Mean zooxanthella density in selected scleractinian corals in this study (Values are presented as means ±SD). Branching was *Pocillopora damicornis*, Submassive was *Porites* spp., Free-living was *Ctenactis echinata* for all MD, MS and R. Only Foliose in Marina Deep and Marina Shallow was *Pachyseris speciosa* while in Renggis was *Echinopora lamellose*.

Colony form	Site	Depth (m)	Zooxanthellae density (x 10^6cells cm^{-2})	Species
Branching	Marina Deep	6-12	0.53±0.104	*Pocillopora damicornis*
Branching	Marina Shallow	<6	0.66±0.257	*Pocillopora damicornis*
Branching	Renggis	<6	0.72±0.173	*Pocillopora damicornis*
Foliose	Marina Deep	6-12	0.93±0.149	*Pachyseris speciosa*
Foliose	Marina Shallow	<6	1.21±0.239	*Pachyseris speciosa*
Foliose	Renggis	<6	1.25±0.179	*Echinopora lamellosa*
Submassive	Marina Deep	6-12	1.36±0.369	*Porites* spp.
Submassive	Marina Shallow	<6	1.50±0.355	*Porites* spp.
Submassive	Renggis	<6	2.19±0.454	*Porites* spp.
Free living	Marina Deep	6-12	1.43±0.719	*Ctenactis echinata*
Free living	Marina Shallow	<6	1.83±0.487	*Ctenactis echinata*
Free living	Renggis	<6	1.44±0.597	*Ctenactis echinata*

Zooxanthellae density in Submassive, Foliose and Branching corals in Marina Deep and Marina Shallow were lower than in Renggis (Figure 3.15 to Figure 3.18). The differences found were significant for Submassive ($F: 5.69$, $p<0.05$) in both MD and MS, while for Foliose coral it was significantly lower ($F: 4.01$, $p<0.05$) only in Marina Deep.

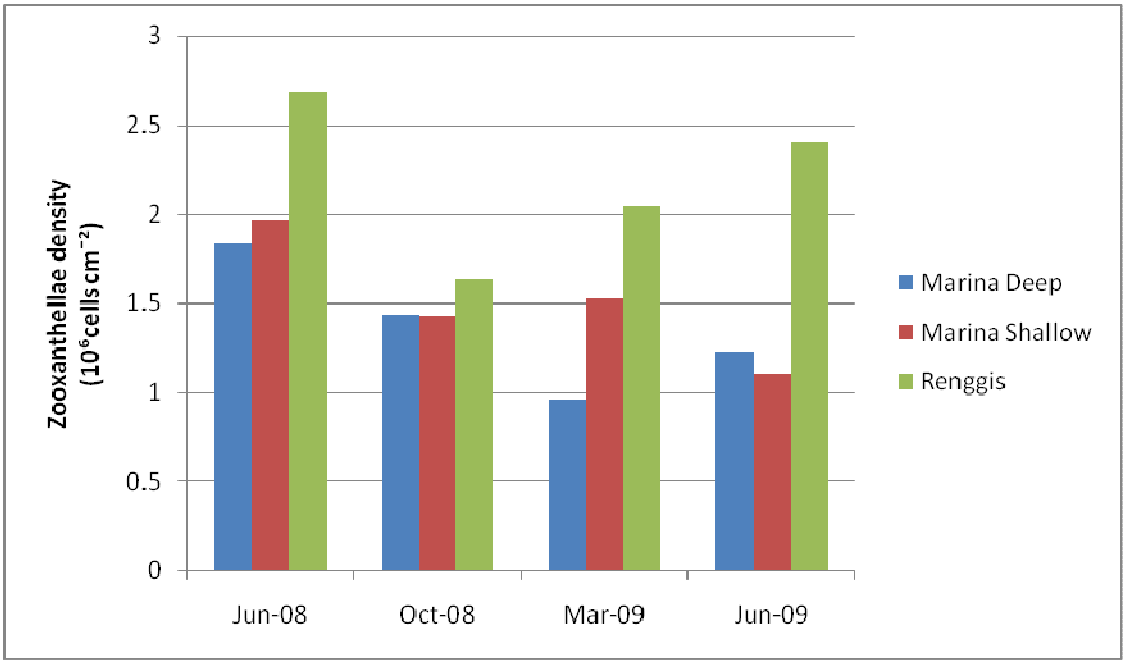


Figure 3.15 Zooxanthellae density in Submassive coral (*Porites* spp.) in MD, MS and R.

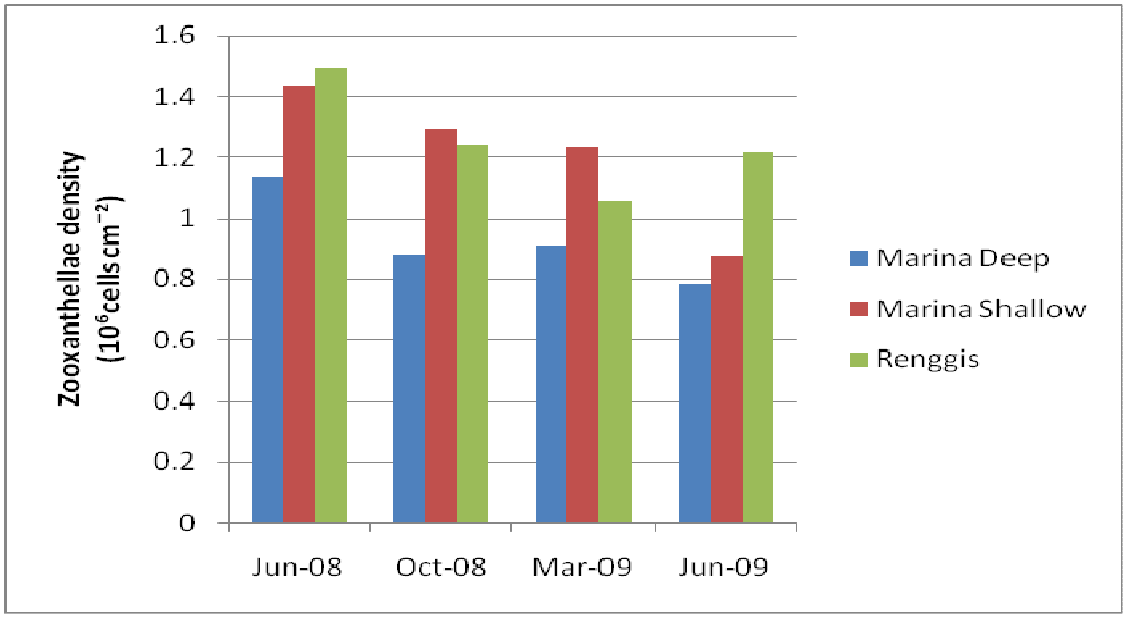


Figure 3.16 Zooxanthellae density in Foliose coral (*Pachyseris speciosa* and *Echinopora lamellosa)* in MD, MS and R.

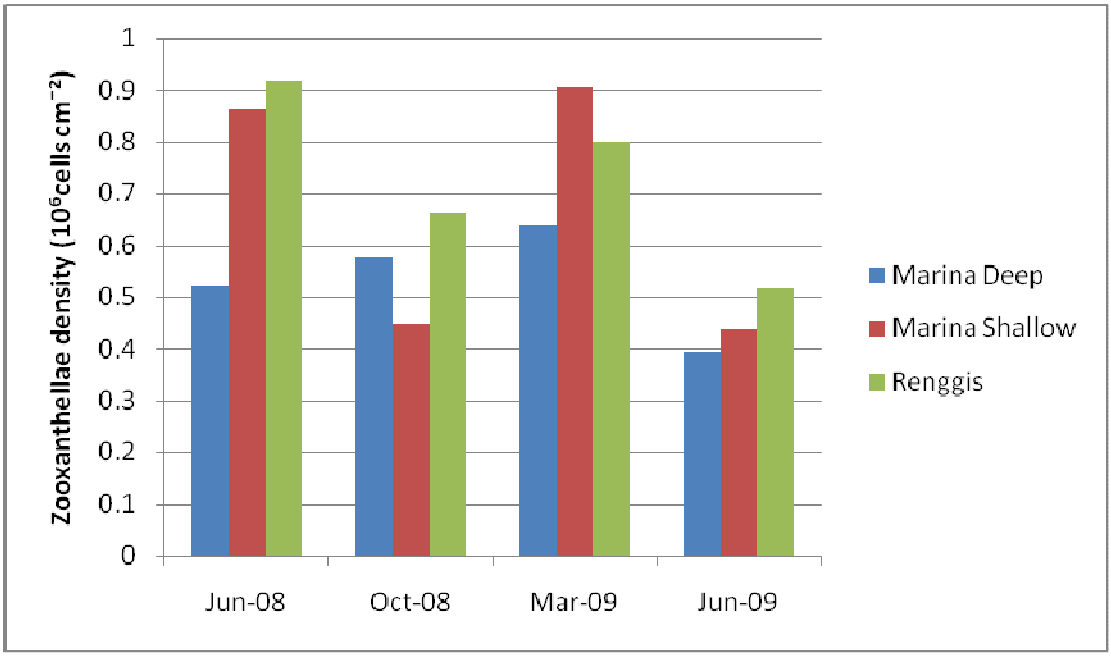


Figure 3.17 Zooxanthellae density in Branching coral (*Pocillopora damicornis)* in MD, MS and R.

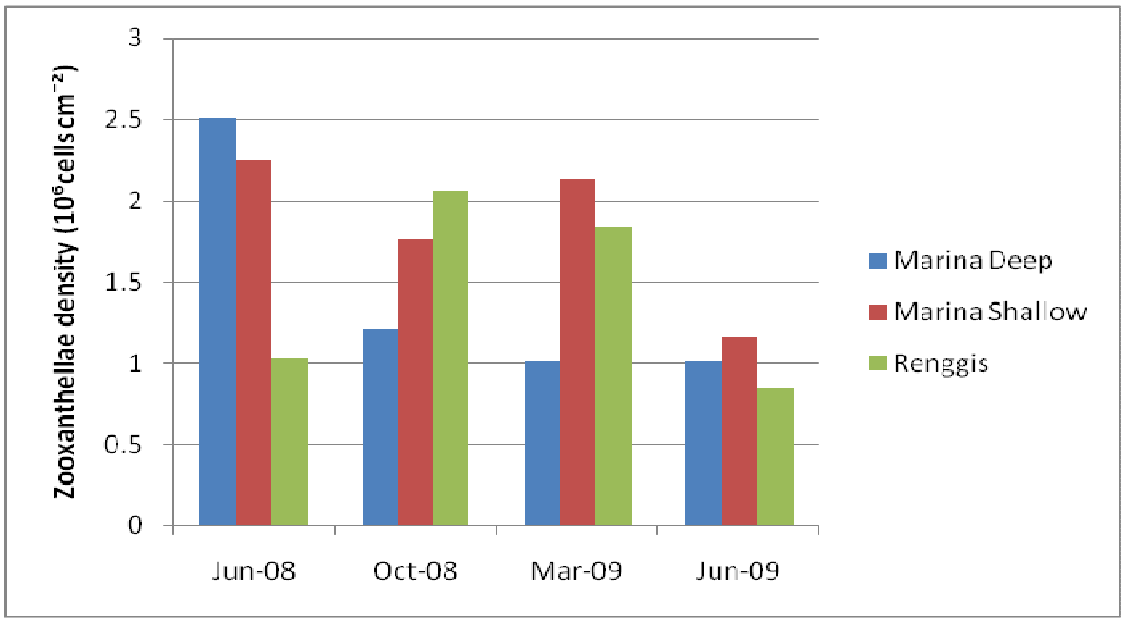


Figure 3.18 Zooxanthellae density in Free-living coral *(Ctenactis echinata)* in MD, MS and R.

The mean value of zooxanthella density and its chlorophyll *a* per unit surface area ($\mu g.cm^{-2}$) for selected species collected at different study sites in four times sampling through 12 months are shown in Table 6.2 and 6.3. Mean zooxanthella density in Branching corals was lower than other growth forms in MD, MS and R (Table 3.9). In Marina Deep all growth forms of scleractinian corals had lower zooxanthella density

and chlorophyll *a* content compared to Marina Shallow and Renggis (<6 m depth). In contrast, the chlorophyll c_2 pigment content in Marina Deep was the highest in almost all the growth forms (Table 3.9).

In Marina Shallow zooxanthella density of all the studied species except Free-living coral was lower than the zooxanthella density of the corals in the control site (Renggis).

Table 3.7 Mean zooxanthella density of corals monitored quarterly from June 08 to June 09. Branching was *Pocillopora damicornis*, Submassive was *Porites* spp., Free-living was *Ctenactis echinata* for all MD, MS and R. Only Foliose in Marina Deep and Marina Shallow was *Pachyseris speciosa*, while in Renggis *Echinopora lamellose* was used for comparison.

	Zooxanthella density (x 10^6cells cm^{-2})											
	Foliose						**Submassive** *(Porites* spp.)					
	Pachyseris speciosa				*Echinopora lamellosa*							
	MD		**MS**		**R**		**MD**		**MS**		**R**	
	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI
Jun-08	1.14	0.21	1.44	0.48	1.49	0.46	1.83	1.36	1.96	0.11	2.68	1.15
Oct-08	0.88	0.11	1.29	0.14	1.24	0.14	1.43	0.40	1.42	0.68	1.63	0.38
Mar-09	0.91	0.42	1.23	0.29	1.06	0.27	0.96	0.12	1.52	0.95	2.04	0.46
Jun-09	0.78	0.51	0.87	0.25	1.22	0.38	1.23	0.27	1.10	0.24	2.40	0.93
	Branching *(Pocillopora damicornis)*						**Free-living** *(Ctenactis echinata)*					
	MD		**MS**		**R**		**MD**		**MS**		**R**	
	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI
Jun-08	0.52	2.69	0.86	0.56	0.92	0.04	2.50	0.02	2.25	0.71	1.03	1.03
Oct-08	0.58	0.23	0.45	0.11	0.66	0.15	1.21	0.74	1.76	0.81	2.07	1.09
Mar-09	0.64	0.30	0.91	1.04	0.80	0.84	1.01	0.58	2.13	0.65	1.84	1.19
Jun-09	0.39	0.19	0.44	0.23	0.52	0.24	1.02	0.16	1.17	0.45	0.85	0.28

Table 3.8 Mean chlorophyll *a* content of corals monitored quarterly from June 08 to June 09. Branching was *Pocillopora damicornis*, Submassive was *Porites* spp., Free-living was *Ctenactis echinata* for all MD, MS and R. Only Foliose in Marina Deep and Marina Shallow was *Pachyseris speciosa*, while in Renggis *Echinopora lamellose* was used for comparison.

	Chlorophyll *a* content (x 10^{-2} µg cm^{-2})											
	Foliose						**Submassive** *(Porites* spp.)					
	Pachyseris speciosa				*Echinopora lamellosa*							
	MD		**MS**		**R**		**MD**		**MS**		**R**	
	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI
Jun-08	1.0	0.6	1.6	0.9	1.6	0.9	0.8	0.8	1.6	0.06	1.7	0.8
Oct-08	0.8	0.1	1.2	0.1	1.5	0.5	0.8	0.4	1.2	0.43	1.4	0.5
Mar-09	2.2	0.7	2.4	0.6	1.5	0.4	2.0	0.5	1.7	0.37	2.1	0.6
Jun-09	1.5	0.7	2.0	0.9	2.4	0.9	2.3	0.2	2.1	0.48	4.9	1.8
	Branching *(Pocillopora damicornis)*						**Free-living** *(Ctenactis echinata)*					
	MD		**MS**		**R**		**MD**		**MS**		**R**	
	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI	Mean	CI
Jun-08	0.5	0.5	1.0	0.0	0.6	0.2	2.4	1.5	1.5	0.5	2.1	NA
Oct-08	0.6	0.6	1.3	0.7	3.0	2.6	1.0	0.3	1.8	0.4	2.4	0.9
Mar-09	2.3	2.3	1.5	0.5	2.4	2.7	1.3	0.4	2.5	1.3	2.2	1.4
Jun-09	1.7	1.7	2.1	0.9	1.7	0.7	1.3	0.3	1.2	0.2	2.8	1.9

Table 3.9 Mean zooxanthella density, chlorophyll *a* and chlorophyll c_2 content in corals studied in MD, MS and R. Branching coral was *Pocillopora damicornis*, Submassive coral was *Porites* spp., Free-living coral was *Ctenactis echinata* for all MD, MS and R. Foliose coral in Marina Deep and Marina Shallow was *Pachyseris speciosa*, and in Renggis was *Echinopora lamellose*.

	Zooxanthella density in corals studied (x 10^6cells cm^{-2})					
	MD		**MS**		**R**	
	Mean	SD	Mean	SD	Mean	SD
Free-living	1.43	0.719	1.83	0.487	1.44	0.597
Submassive	1.36	0.369	1.50	0.355	2.19	0.454
Branching	0.53	0.104	0.66	0.257	0.72	0.173
Foliose	0.93	0.149	1.21	0.239	1.25	0.179

Table 3.9, continued

	Chlorophyll *a* content (µg cm^{-2})					
	MD		**MS**		**R**	
	Mean	SD	Mean	SD	Mean	SD
Free-living	0.015	0.006	0.018	0.006	0.024	0.003
Submassive	0.015	0.008	0.017	0.004	0.025	0.016
Branching	0.013	0.008	0.015	0.005	0.019	0.010
Foliose	0.014	0.006	0.018	0.005	0.018	0.004

	Chlorophyll c_2 content (µg cm^{-2})					
	MD		**MS**		**R**	
	Mean	SD	Mean	SD	Mean	SD
Free-living	0.009	0.002	0.016	0.009	0.017	0.005
Submassive	0.019	0.011	0.012	0.003	0.018	0.012
Branching	0.015	0.010	0.013	0.003	0.018	0.011
Foliose	0.011	0.009	0.010	0.006	0.012	0.004

Free-living coral (*Ctenactis echinata)* was the only growth form that had shown no significant changes in chlorophyll *a* (Table 3.8) and c_2 content in Marina Deep through time.

In Foliose coral *(Pachyseris speciosa)*, chlorophyll *a* per zooxanthella (F: 11.89, $p<0.05$) had significantly increased in March 2009 and chlorophyll c_2 per zooxanthella significantly increased (F: 4.25, $p<0.05$) in June 2009 both in Marina Shallow and Marina Deep, while the same results were not observed in Renggis (control site). Although different species were examined in Marina and Renggis, it was presumed that both species should react to stress in a similar way as they have the same growth form and skeletal morphology (Stafford-Smith & Ormond, 1992). Furthermore, it was expected to observe more sedimentation effect on *Echinopora lamellosa* (in control site) compared to *Pachyseris speciosa* (Marina site), as the study done by Stafford-

Smith and Ormond (1992) showed that *Pachyseris speciosa* can manipulate silt and fine sand easier than *Echinopora lamellosa.* In addition, the Pearson correlation for Foliose coral showed a positive correlation between chlorophyll *a* per zooxanthella and sedimentation in Marina Shallow (Pearson correlation: 0.858, $p<0.01$), while zooxanthella density had negative correlation with sedimentation in Marina Shallow (Pearson correlation: -0.697, $p<0.05$).

3.4.2 Discussion

According to Sorokin (1993), most reef-building corals normally host between 1 x 10^6 - 5 x 10^6 zooxanthella cm^{-2} of live surface tissue. However, zooxanthella density may differ greatly between different species. In other studies (Stimson *et al.*, 2002; Yong, 2007; Shu *et al.*, 2008) zooxanthella density for *Porites* spp. ranged 2 - 10 (x10^6 zooxanthellae cm^{-2}), for *Pocillopora damicornis* ranged 0.4 - 1.86 (x10^6 zooxanthella cm^{-2}), for *Pachyseris* spp. was 0.88 x 10^6 zooxanthella cm^{-2} and for *Echinopora lamellosa* ranged 0.59-2.59 (x 10^6 zooxanthella cm^{-2}). The zooxanthella density recorded in this study for *Porites* spp. (Submassive) did not appear to be in normal range in Marina Deep and Marina Shallow (Table 3.9). The significant difference of zooxanthella density in Submassive corals between Marina site and control site (R) (Table 3.9) also supports the fact that these species was under sedimentation stress in Marina site. The studies done by Stafford-Smith (1993) on 22 species of Australian scleractinian corals showed that, although these species are known as sediment-tolerant species, bleaching (loss of zooxanthella) were observed in these massive *Porites* species after exposure to sedimentation.

It was indicated by Shu *et al.* (2008) that the *Pocillopora* species would be more likely to bleach and die from stress compared with the massive *Porites* and it is known that branching corals are the most sensitive among all growth forms (Shenkar *et al.*, 2006; Shu *et al.*, 2008). This can be the reason of lower zooxanthellae density observed in *Pocillopora* branching in this study (Table 3.9).

Previous studies (Titlyanov *et al.*, 2001; Anthony & Hoegh-Gulberg, 2003) showed that zooxanthella density and its pigments in coral colonies will increase by increasing depth or lower light levels while in this study all growth forms of scleractinian corals in Marina Deep had lower zooxanthellae density and chlorophyll a content compared to Marina Shallow and Renggis (<6 m depth) (Table 6.4). This may be due to zooxanthellae loss caused by the stress from high sedimentation (Figure 3.5). In contrast, the chlorophyll c_2 pigment content in Marina Deep was the highest in almost all the growth forms (Table 3.9) which could be an adaptative mechanism (photo adaptation) to the lower light intensity (Figure 3.9) (Iglesias-Prieto & Trench, 1994). The higher content of chlorophyll c_2 allows higher efficiency in utilization of light in low light condition. This is because chlorophyll c_2 has the ability to absorb higher blue portion of PAR compared to chlorophyll *a* (Battey & Patton, 1988). Therefore, the increase in the content of chlorophyll c_2 is one of the adaptative mechanisms to utilize the blue portion of PAR to compensate for the low light condition due to both depth and increased sedimentation.

Zooxanthella density of all the studied species except Free-living coral in Marina Shallow was lower than the zooxanthella density of the corals in the control site (Renggis) (Table 3.9). According to Titlyanov *et al.* (2001), zooxanthellae density is usually lower for the photosynthetic capacities of zooxanthellae acclimated to dim light

compared to those acclimated to bright light. This can also explain the difference between zooxanthella density in Renggis which had more light intensity and Marina Shallow which had high sedimentation and less light although both were at the same depth (Figure 3.9). Hence, the zooxanthellae density of the corals in Marina Shallow may have increased more than Renggis because of the low light intensity (dim light) due to higher sedimentation in the area (Figure 3.5).

Free-living coral (*Ctenactis echinata*) was the only growth form that had shown no significant changes in chlorophyll *a* or c_2 content in Marina Deep through time (Table 3.8). This may be due to the higher tolerance of this species to sedimentation and mechanical stress. Solitary corals of the family Fungiidae were introduced as impressive examples of morphological and physiological adaptations to high sedimentation (Dikou & Woesik, 2006). The studies done by Rachello-Dolmen & Cleary (2007) in the Jakarta Bay reefs, Indonesia showed that fungiids such as *Ctenactis echinata* are less affected by sedimentation and mechanical stress because of their small oval surface area that helps them to remove the sediment and also to their ability to rest upon dead basal parts of coral colonies or on coral rubble. In addition, it seems that these species are more adapted to shaded areas with less light and less water temperature. This can explain why the same results in Marina Shallow were not observed which is due to the difference in light exposure and water temperature between shallow and deep water. In the study done by Hoeksema (1991), the majority of bleached fungiids in the shallow part (2 and 3 m depth) were completely bleached, whereas only partial discoloration was observed in fungiids at 9 m depth with more shaded areas.

For Foliose coral (*Pachyseris speciosa*) in both MS and MD, the increase of chlorophyll *a* per zooxanthella in March 2009 and chlorophyll c_2 per zooxanthella in June 2009

(Table 3.8) could be some kind of adaptation. Foliose corals can barely tolerate the sedimentation because of their shape. Corals with concave shape or flattened and plate-like corals are less efficient at removing sediments than more rounded form (Figure 3.10) (Rogers, 1990; Weber *et al.*, 2006). The coral had increased its chlorophyll *a* as it was covered under sediment especially after high sedimentation in monsoon (Figure 3.5) and thus needed more chlorophyll *a* pigments so that photosynthesis would be optimised. Furthermore, increase in the amount of pigment can also be the adaptation response to self-shading induced by the growing algae in Marina Shallow which was described earlier (subchapter 3.3) (Rodolfo-Metalpa *et al.*, 2008).

Table 3.10 shows the summary of the zooxanthella density, chlorophyll *a* content and chlorophyll c_2 content changes through 15 months of monitoring.

Table 3.10 Synthesis of changes in (a) zooxanthella density (b) chlorophyll *a* content (c) chlorophyll c_2 content of four growth forms in Marina Deep, Marina Shallow (MD and MS) and the control site (R) through time (15 months). Note: Black arrow shows the direction of the change (higher or lower). Foliose coral was the most sensitive growth form as the physiological parameters changed the most in this growth form. On the other hand, Free-living coral was the least sensitive. Among all sites, Marina Deep (MD) was the most affected site by the construction.

a)

Site / Growth form	MD	MS	R
Submassive	–	–	–
Foliose	–	–	–
Branching	–	–	–
Free living	↓	–	–

Table 3.10, continued

b)

Growth form \ Site	MD	MS	R
Submassive	↑	–	↑
Foliose	↑	↑	–
Branching	↑	–	–
Free living	–	–	–

c)

Growth form \ Site	MD	MS	R
Submassive	↑	–	↑
Foliose	↑	↑	–
Branching	–	–	–
Free living	–	–	–

The construction impacts on marine ecosystems could be irreversible and it is unfortunate that these effects are more noticeable when there is a failure in the management of coastal constructions (McClanahan *et al.*, 2008; Sale *et al.*, 2008). Monitoring, management and predicting the impact of construction programs should be undertaken before the commencement of the construction so that it would be possible to take the necessary actions before the measurable impact occurs (Koskela *et al.*, 2003). Furthermore, construction activities are essentially unmanaged because the management agencies in most countries lack the resources of skilled scientists and efficient data collection, Therefore, more interaction between managers and scientists would help to effectively manage construction projects such as the marina construction in Tioman Island (McClanahan *et al.*, 2008; Sale, 2008).

4 Summary and Conclusion

One of the inevitable effects of any coastal construction is its direct impact on the adjacent marine habitats such as coral reefs. In this study acute impacts of the marina construction process, were documented on the adjacent coral reef. Some of the acute impacts found were breakage of the corals, increased rubble and silt/sand cover in the area. Furthermore, from the results, the marina construction certainly had led to some chronic changes in Marina site in terms of increased sediment load and turbidity in both Marina Deep (MD) and Marina Shallow (MS). In general, the increased sedimentation had negatively impacted the substrate cover especially the hard coral cover %. In addition, high turbidity associated with high suspended sediments had decreased water quality by changing the light penetration which caused some negative effects on the adjacent corals especially in MD with lower light intensity. Foliose coral was the most sensitive growth form and had the least tolerance to sedimentation as the physiological parameters such as zooxanthella density and chlorophyll content changed the most in this growth form. On the other hand, Free-living coral was the least sensitive among other growth forms and showed more tolerance to sedimentation and light reduction. These results also show that the response of corals to stress depends on their species, growth forms and water depth.

All these construction impacts that were observed in this study can be prevented or at least reduced by proper management of constructions. Mitigation actions should have been taken by relevant authorities and monitoring the area should have been strongly recommended by the management consultants even before the construction phase. In fact, a complete BACIP study would provide very useful information for such future developments at the vicinity of highly sensitive habitats such as coral reefs.