1.0 INTRODUCTION AND SCOPE OF RESEARCH

It is well documented that coral reefs play a crucial role in maintaining the local fisheries industry, ecotourism and adjacent shoreline protection. It is surprising then that coral reef research in Peninsular Malaysia has mainly been concentrated on the east coast with little emphasis on the Straits of Malacca (SOM) of the west coast. The coral reefs of this area are extremely important, more so than their east coast counterparts. This is due to the fact that they are only a few viable coral reef ecosystems in SOM. Reports on the status of coral reefs in SOM are for Pulau Langkawi (Affendi, 2005; Jonsson, 2003; Lee et al., 2005), Pulau Payar (Lee et al., 2000; Lim, 1998), Pulau Pangkor (Affendi, unpublished), Pulau Sembilan (Mohamed Pauzi & Mohd Najib, 2002; Ridzwan, 1994) and Teluk Kemang, Port Dickson (Goh & Sasekumar, 1981). Nevertheless reports on coral reef status for Pulau Perak are scarce.

Pulau Perak received its first scientific attention in 1958 with the 2nd 'Xarifa' expedition (Gopinadha-Pillai & Scheer, 1974). After a huge gap of about 46 years the next scientific study was done during the Scientific Expedition to the Seas of Malaysia (SESMA) in August 2004 (Affendi, 2007; Affendi et al., 2008) and subsequently by the ROSES Expedition in September 2004. After the tsunami of December 2004, two expeditions for Post Tsunami Impact Reef Surveys (POSTIARS) were done in January 2005 (Affendi et al., 2008; Affendi et al., 2005a; Affendi et al., 2005b; Tun et al., 2006; Yusuf et al., 2005) and in February 2006 (Affendi & Tajuddin, 2006; Affendi et al., 2008; Yusuf et al., 2007).

Since the second 'Xarifa' expedition in 1958 the Straits of Malacca has gone through a lot of changes where developments on its adjacent shorelines and shipping activities have dramatically increased. With all this development and other present anthropogenic factors the water quality in Straits of Malacca has significantly decreased (Chua et al., 2000). It is feared that with severe stress levels from pollution, resource exploitation and global climate change the reefs in Straits of Malacca especially Pulau Perak could be damaged beyond repair.

During the earlier surveys of SESMA in 2004 and POSTIARS in 2005 and 2006 as mentioned before, Pulau Perak’s reef structure was found to be very unique if compared to other coral reefs in Peninsular Malaysia. It is basically a sheer 90 degrees ‘drop off’ (**Figure 1.1**) to about 34m, where it levels off for around 5m before dropping off again. It is one of the only three island reef areas in Malaysia which has a ‘drop off’ or ‘reef wall’; the other is Pulau Sipadan and Pulau Layang-Layang, both are in Sabah waters. Nevertheless they are ‘oceanic islands’ compared to Pulau Perak which is a ‘continental island’. The typical reef ecosystems found elsewhere in Malaysia are ‘fringing reefs’ which usually start with a shallow reef flat which then extends into deeper waters on a gentle slope not exceeding 30m. This is in contrast to Pulau Perak which has corals even at 40m depth.

Figure 1.1: Picture of a typical coral reef scenery at Pulau Perak where surveys were done on reef walls. Photo by Affendi Yang Amri.

A usual continental island has fringing reefs which comprises of a back reef, lagoon, reef flat, reef crest and an outer reef slope (Veron & Stafford-Smith, 2000). The corals distribution, growth and growth shape would be affected by the amount of light, temperature and physical energy (e.g. waves & currents) it is exposed to according to where it is on the fringing reef. Nevertheless for a continental island like Pulau Perak with its vertical reef walls, the coral ecology is totally different. The corals on the reef walls are more prone to self shading, breakage from falling rocks/corals, and exposed to a more high energy environment where risk of physical damage is high. The vertical reef walls are unlike their fringing reef continental island counterpart which usually encounters stress from sedimentation or resuspension of sediments from bottom substrate such as silt. This is supported by the study on a Belize reef wall by Bosscher & Schlager (1992) where they reported that the steep seaward wall allows excess sediment to be shed to greater depths and therefore sediment did not smother reef growth.

Pulau Perak (5^{o}41'3.27" N, 98^{o}56'19.86" E) is situated in the northern part of Straits of Malacca about 120 km south-west of Pulau Langkawi and 140 km north-west of Pulau Pinang (**Figure 1.2**). It is approximately 550 m in length, 400 m wide and 125 m in height and rises almost vertically from a depth of 80 meters. Kirk (1994) stated that in optically clear waters of the tropics, the attenuation of solar radiation with increasing depth is a function of the optical properties of the water itself, since there is very little dissolved or particulate matter to absorb the light. This aptly describes the usually clear waters around Pulau Perak. It has a pristine and remarkable coral reef ecosystem (Affendi et al., 2008). The island is well known for its tukun (reef) which harbours big fishes. This tiny rocky island is sparsely littered with greenery as the island is covered in green shrubs **(Figure 1.3, Figure 1.4 and Figure 1.5)**. It also acts as a shelter for boats during stormy weather. There is a light house, jetty and helipad on the island **(Figure 1.3, Figure 1.4 and Figure 1.5)** with a small number of army personnel who guards the island as it is an island of contention between Malaysia and Indonesia. It sits at the very edge of the continental shelf and therefore experiences the upwelling phenomena periodically in December to March of each year (Tan et al., 2006). The effect of this has yet to be documented especially on corals in the Straits of Malacca. Witman & Smith (2003) who studied upwelling in the Galapagos strongly suggested that upwelling sites be given special consideration in the planning of marine reserves to ensure biodiversity conservation. This is in line with the suggestion that Pulau Perak be gazetted as a Marine Protected Area (Affendi et al., 2008).

The current issues and exploitation of Pulau Perak are mainly illegal long line fishing and unregulated sport fishing and SCUBA diving activities. In addition development of infrastructures (helipad, jetty, military base etc.) and potential aquarium trade collection could be a concern to the health of the reef. Nevertheless Pulau Perak has already been given protection in 1980 under the Fisheries (Maritime) Regulations (1967) which only allow fishing using traditional appliances in the waters of 5 nm around it. Any form of fishing using commercial gear such as trawls or purse seine nets is deemed illegal (Najib et al., 2002). This is seen as a step towards establishing the island as a Marine Park in the future by the Department of Fisheries Malaysia to protect and enhance fisheries activities in the surrounding areas.

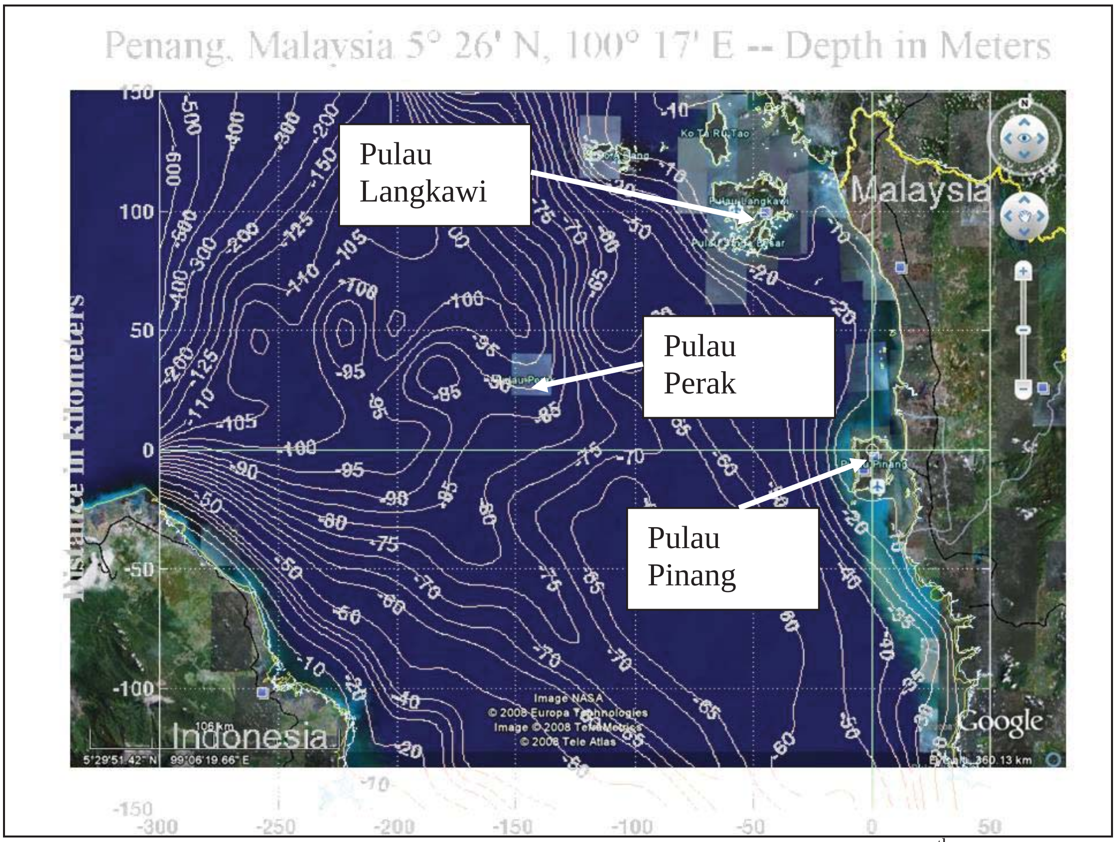

Figure 1.2: A combination of a satellite picture (taken from Google Earth on 20th October 2008) and a bathymetry map of the area (taken from Lipa et al., 2005) showing Pulau Perak in Straits of Malacca. Pulau Langkawi and Pulau Pinang are also shown. (Taken from Affendi et al., 2008)

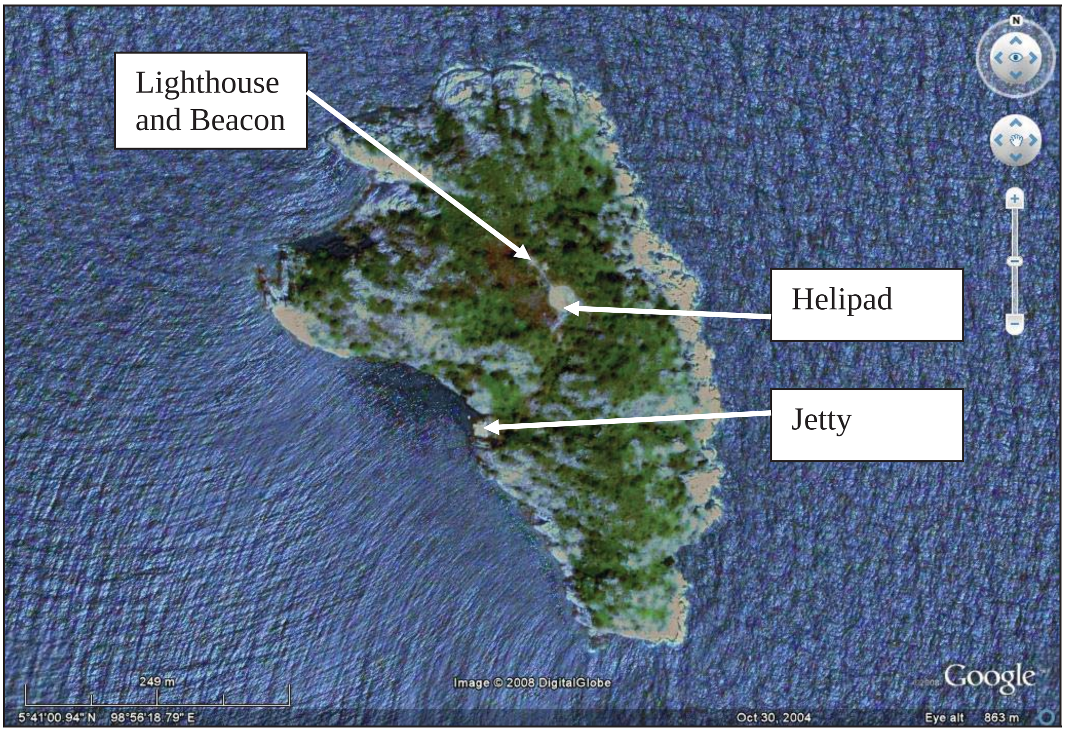

Figure 1.3: Picture taken by satellite of Pulau Perak. The helipad, jetty and lighthouse are also shown. Picture taken from Google Earth on 20th October 2008. (Taken from Affendi et al., 2008)

Figure 1.4: Undated picture from the air of Pulau Perak western side. The jetty and helipad can be seen as small white structures. Photo taken from www.benalec.group.com website in May 2004. (Taken from Affendi et al., 2008)

Figure 1.5: Picture of Pulau Perak from a boat from the south in 2006. The lighthouse can be seen at the top of the island. Note the green vegetation on the island. A bird is seen flying back to its nest on the island (Taken from Affendi et al., 2008)

As Pulau Perak is situated near the Andaman Sea the coral diversity is expected to be a unique mixture from the Straits of Malacca and the Andaman Sea. Gopinadha-Pillai & Scheer (1974) work was considered to be the first collection of corals made at Pulau Perak with a total coral diversity collected at only 14 species from 10 genera. Nevertheless a comprehensive coral species list of the island has yet to be documented.

From the POSTIARS surveys, Pulau Perak was found to be a unique reef system compared to other reef areas in Peninsular Malaysia. This was shown by the presence of indicator invertebrates such as the Banded Coral Shrimp (*Stenophus hispidus*) which is now rare in other parts of Peninsular Malaysia but abundant at Pulau Perak. They are intensively collected for the aquarium trade in other areas. Their strong presence in the island waters is very encouraging due to the fact that it is one of the positive indicator species for reef health (Hodgson & Liebeler, 2002; Hodgson et al., 2006). Even a rare nudibranch was recorded (*Phyllidiopsis phiphiensis)* where it was previously thought that this species was only to be found in Phi Phi Island, Thailand.

One other interesting finding by Affendi et al. (2008) was that there are a number of Crown-of-Thorns Sea Stars (COTS) *Acanthaster planci* at Pulau Perak. Prior to this it was believed that they do not occur on the West Coast of Peninsular Malaysia. Furthermore, the COTS at Pulau Perak had a distinct colouration and pattern compared to the ones found on the East Coast of Peninsular Malaysia. They speculated that the COTS in Pulau Perak is a different clade from the ones on the East Coast as reported by (Gérard et al., 2008) which found two distinct clades of COTS between the West Indian Ocean and the Pacific Ocean.

During the POSTIARS surveys, a total of 86 species of coral reef fish were observed at Pulau Perak (Yusuf et al., 2007). The composition of species was different from other parts of Peninsular Malaysia. Fish life in this island is both high in abundance and diversity. A number of fishes with the right size and age for commercial harvesting were seen in schools which suggest that this island has not been degraded by commercial fisheries. More studies need to be conducted to complete the fish data of the island for its proper conservation and management.

‘Reef walls’ throughout tropical and sub-tropical regions are understudied compared to normal reef types such as ‘fringing reefs’ (Witman & Smith, 2003). This may be due to the fact that reef walls are much less to be found compared to fringing reefs around the world. Some reef wall studies such as Winston & Jackson (1984) at Rio Bueno, Jamaica, investigated the distribution of crytobiota (Cheilostome bryozoans) under corals on a vertical reef wall. They reported that the vertical reef wall had a dense population of corals and other sessile animals and that the foliaceous coral growth-form was dominant. Other studies that have been done include the diverse multi-phyletic communities of epifaunal invertebrates that commonly encrust the reef walls (Ayling, 1981; Baynes, 1999; Gili & Coma, 1998; Witman, 1992) which included sponges, anemones, octocorals, gorgonians, bryozoans, molluscs, polychaetes, ascidians and corals. Witman & Smith (2003) studied a vertical reef wall at Rocas Gordon in the Galapagos Marine Reserve where the reef had a vertical inclination from the surface to greater than 70 m depth. They focused only at 12 m depth using permanent quadrats to document how fast invertebrate species richness and abundance change at reef wall sites, and to identify the major biological or physical correlates of community change. The only scleractinian corals they found on the reef wall was the branching *Pocillopor*a sp.. Lastly Garpe & Öhman (2003) documented the only reef wall site found out of 11 sites surveyed at Mafia Island Marine Park, Tanzania. They used Wiens & Rotenberry (1981) point-base method modified by Bergman et al. (2000). The vertical reef wall of 2-25 m depth was at a site called ‘Mchangani’ and it was of 2-25 m depth only. They surveyed Mchangani at 7-10 m which was exposed to strong waves to document fish and coral distribution patterns. They found that Mchangani differed from the other ten sites in that it naturally contained little coral, was highly dominated by algae and that it had the lowest proportion of branching substrates and substrate diversity. Before this study nothing near what has been documented on other reef walls had been done for Pulau Perak.

In addition to Pulau Perak being a ‘reef wall’ it is also categorised as a reef in the ‘mesophotic zone’ (30-150 m depth). Reefs in the mesophotic zone are also understudied compared to shallow reef (< 30 m) systems and this has slowed the understanding of ecology, biodiversity and connectivity of shallow and deep coral reef communities (Menza et al., 2008). There are only a handful of publications that exist on the deep forereefs and even then they are mostly descriptive (Fricke & Knauer, 1986; Fricke & Meischner, 1985; Goreau & Wells, 1967; Grigg, 2006; Jarrett et al., 2005; Kühlmann, 1983; Lehnert & Fischer, 1999). However there are five comprehensive studies on the mesophitic reefs, the first is by Liddell et al. (1997) which reported on the percent cover and species diversity of reef communities down to a depth of 250 m where they showed a distinct bathymetric zonation pattern with coral cover of 3–23% at depths shallower than 50 m and subsequent decreases in coral cover with increasing depths. In contrast, the percent cover of sponges increased with increasing depth in the same study. The second is on the photophysiology of mesophotic corals (Mass et al., 2007), the third is on the ecological distributions of mesophotic corals (Kahng & Kelley, 2007) and the fourth is on the biophysical coupling of coral growth in mesophotic environments with internal waves or upwelling events (Leichter & Genovese, 2006). The fifth and latest study is by (Lesser et al., 2010) who studied on the photoacclimatization of the coral *Montastrea cavernosa* in the mesophotic zone. However, one interesting finding that has sparked interest of coral reef ecologists and managers alike is from a long-term study that spanned 30 years which showed that reefs more than 30 m depth change very little in percent cover or diversity (Bak et al., 2005). They suggested this because the factors that cause deterioration and destruction in shallow reefs are not as effective at deep reefs and that the deeper ocean has a more resilient environment. In addition it has been suggested that these reefs could be used as refugia for critical taxa (e.g. coral and fish), as well as sources/sinks for shallow coral populations (Riegl & Piller, 2003). There has been no work done on mesophotic zone coral reefs in Southeast Asia and this makes Pulau Perak a very unique area for this kind of scientific study.

1.1 Research Objectives

1) To document the benthic community substrate cover at West and East facing walls with regards to their depth profiles from 0 m to 45 m *(using vertical transects)*

2) To determine the substrate cover differences (if any) between Shallow (10 m) and Deep (20 m) depths at six distinct facing reef walls around Pulau Perak with emphasis on 'Hard Coral' cover and their relation to fish and invertebrate indicators of reef health *(using horizontal transects)*

2.0 MATERIALS AND METHODS

The usual reef surveys for other studies are on reef flats, reef crests and reef slopes unlike for this study in Pulau Perak where it is a reef wall and therefore normal methods of reef survey were modified to suit the objectives of the study. Field work was done from 25 June to 9 July 2009.

2.1 To document the benthic community substrate cover at West and East facing walls with regards to their depth profiles from 0 m to 45 m *(using vertical transects)*

The substrate cover was assessed at the West and East Wall of the island **(Figure 2.1)** as they were logistically the easiest to do work to deep depths of 45 m. Three vertical transects at each West and East Wall of Pulau Perak from 0 m - 45 m depth were surveyed by divers using SCUBA. Each transect was not less than 15 m apart from each other. Diver pairs descended to 45 m and slowly ascended while visually documenting the substrate cover at every 5 m x 5 m quadrats while writing down the data on water proof paper secured to dive slates. A belt-quadrat method was used along the vertical transect. The divers had to document each quadrat within five minutes especially at deeper depths due to the constraint of the no-decompression time for compressed air SCUBA diving. The substrate cover categories documented were taken from the Reef Check (Hodgson et al., 2006) and the Line Intercept Transect (English et al., 1997) methods **(Table 2.1)**. It is noted that the method used here is considered a non-conventional method as there was none found in the literature for surveying a coral reef wall as the ones found in Pulau Perak.

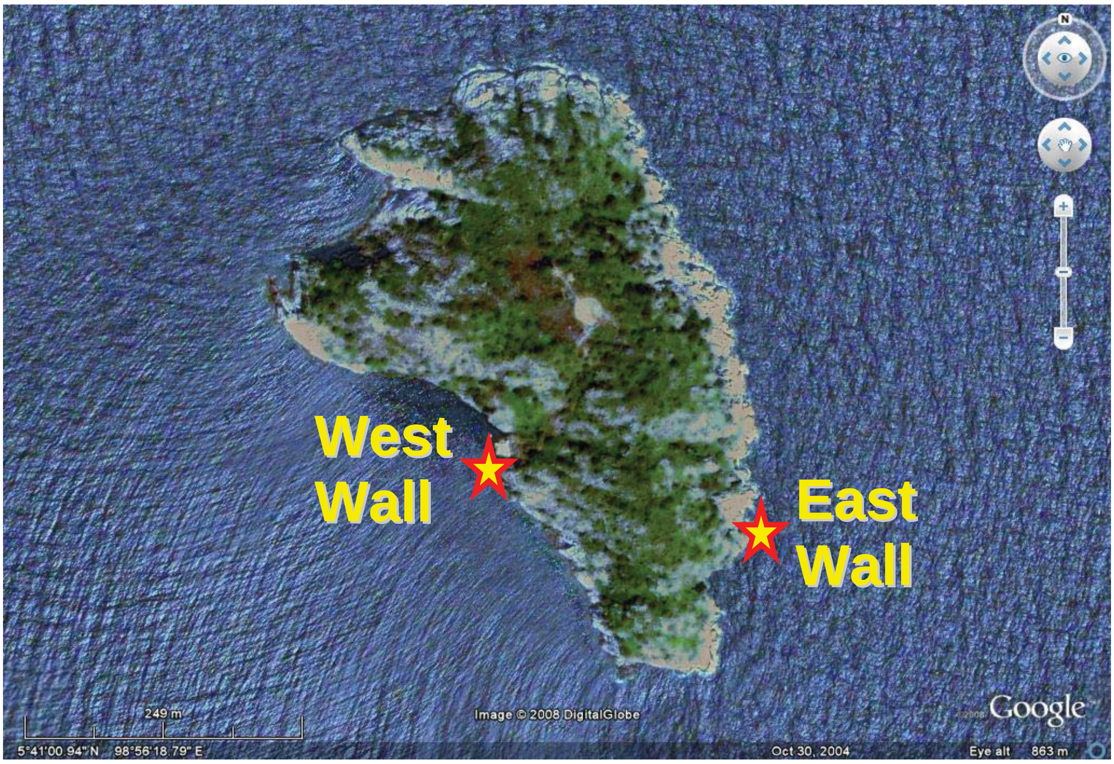

Figure 2.1: Map showing the West Wall and East Wall study sites at Pulau Perak (Map from Google Earth).

Table 2.1: Substrate cover categories used in the vertical transect belt-quadrat (5 m x 5 m) method for the East and West Wall of Pulau Perak. The substrate cover categories are modified from the Reef Check (Hodgson et al., 2006) and the Line Intercept Transect (English et al., 1997) methods.

No	Substrate cover category	Note
1	Live Coral (LC)	Scleractinian coral tentacles/tissue observed. Live coral included bleached live coral
2	Dead Coral (DC)	White scleractinian coral skeleton or overgrown by algae. The coral may be standing or broken into pieces. Appears fresh and white *or* with corallite structures still recognizable (i.e. their structure is still complete/not yet eroded). Recently dead, white to dirty white
3	Algae (AL)	All algae except coralline algae
4	Coralline Algae (CA)	Red algae of the family Corallinaceae which includes the articulated (erect), tree like with non-calcified branches attached to the substrate; and the non-articulated (encrusting), the slow growing crusty type on the rocks
5	Sponge (SP)	All sponges of the phylum Porifera
6	Gorgonian (GG)	Various corals of the order Gorgonacea except Sea Whip
7	Sea Whip (SW)	Order Gorgonacea corals forming flexible 'whip-like' colonies with few or no branches
8	Other (OT)	Any other living sessile organism including sea anemones, tunicates, gorgonians
9	Rock (RC)	Any non-living hard substrate whether it is covered in e.g. turf, algae, barnacles, oysters etc. Rock also includes dead coral that is more than about 1 year old, i.e. is worn down so that few corallite structures are visible, and covered with a thick layer of encrusting organisms and/or algae.

Data of the reef walls documented thus far were at a coarse level (e.g. 'Live Coral Cover', 'Dead Coral Cover'). Therefore the next step was to achieve a more detailed description for the 'Live Coral Cover' using coral growth-forms with regards to depth.

Therefore 'Live Coral Cover' were categorized further into coral growth-forms of 'Branching', 'Massive', 'Foliose', 'Plate', 'Encrusting' and 'Others' **(Figure 2.2)**. This is a detailed assessment of the live coral growth-forms for each quadrat using a modified coral growth-form categories from the Line Intercept Transect (LIT) method of English et al. (1997) **(Table 2.2)**. The abundance of each coral growth-form was documented as a percentage (%) of the total live coral found in each quadrat.

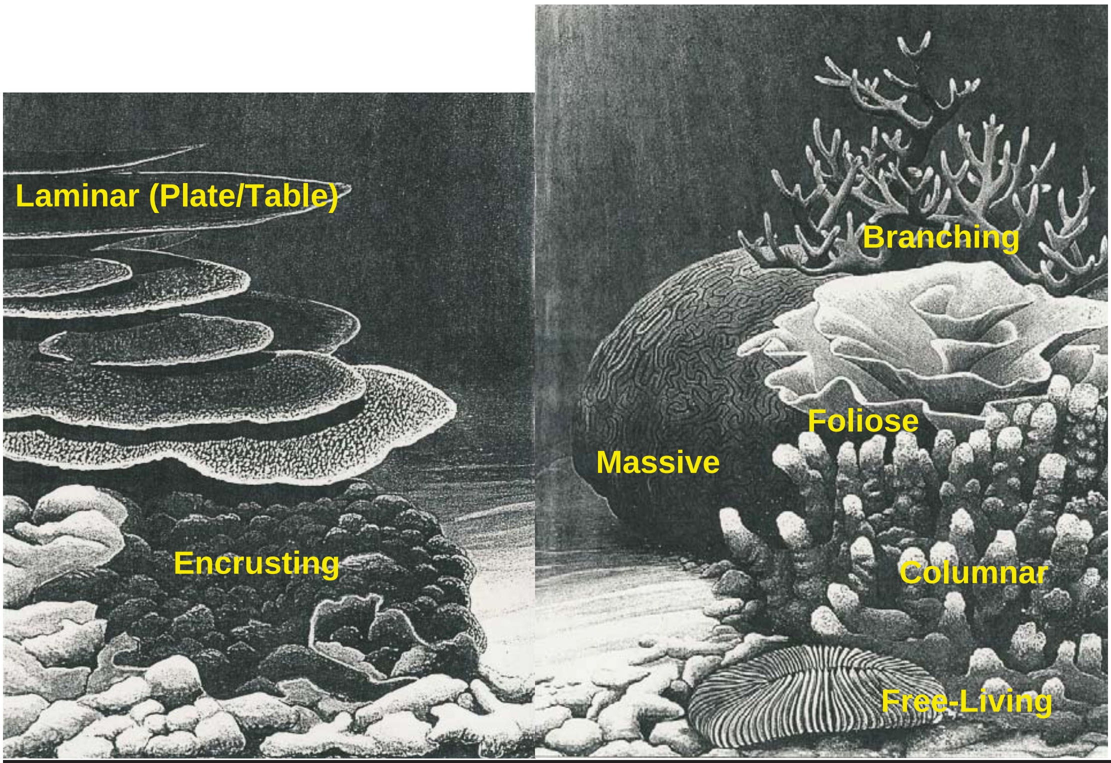

Figure 2.2: Common Hard Coral (Scleractinian) growth-forms (Taken from Veron, 1995)

Table 2.2: Scleractinian (Hard Coral) growth-forms in each quadrat surveyed using a modified LIT (English *et al*., 1997) coral growth-form categories

No	Hard Coral Growth Form	Note
1	Branching (BC)	At least 2^{o} branching
2	Massive (MC)	Solid boulder or mound AND Small columns, knobs or wedges
3	Foliose (FC)	Coral attached at one or more points, leaf-like
4	Plate (PC)	Attached to substratum as laminar plates
5	Encrusting (EC)	Base plate of immature acropora forms; Growing over rocks or boulders as thin layers
6	Others (OT)	Other forms not mentioned above such as tabular, mushroom, fire coral, blue coral and organ pipe coral

All statistical tests were done using the R statistical software (version 2.9.2). A One Way ANOVA with Tukey's Honest Significant Differences (HSD) test with 95% CI were used for comparing the distribution of each substrate category for each wall. An arcsine transformation was used for all percentage data and a Levene's test to check for homogeneity of variance was done prior to ANOVA tests. A Multi Way ANOVA using a Linear Model (R 2.9.2 Software) was used to compare the distribution of each substrate category between East and West Walls.

2.2 To determine the substrate cover differences (if any) between Shallow (10 m) and Deep (20 m) depths at six distinct facing reef walls around Pulau Perak with emphasis on 'Hard Coral' cover and their relation to fish and invertebrate indicators of reef health *(using horizontal transects)*

Six walls were chosen and surveyed **(Figure 2.3)**. They were:

1) East Wall
2) South-east Wall
3) South Wall
4) North-west Wall
5) West Wall
6) North Wall

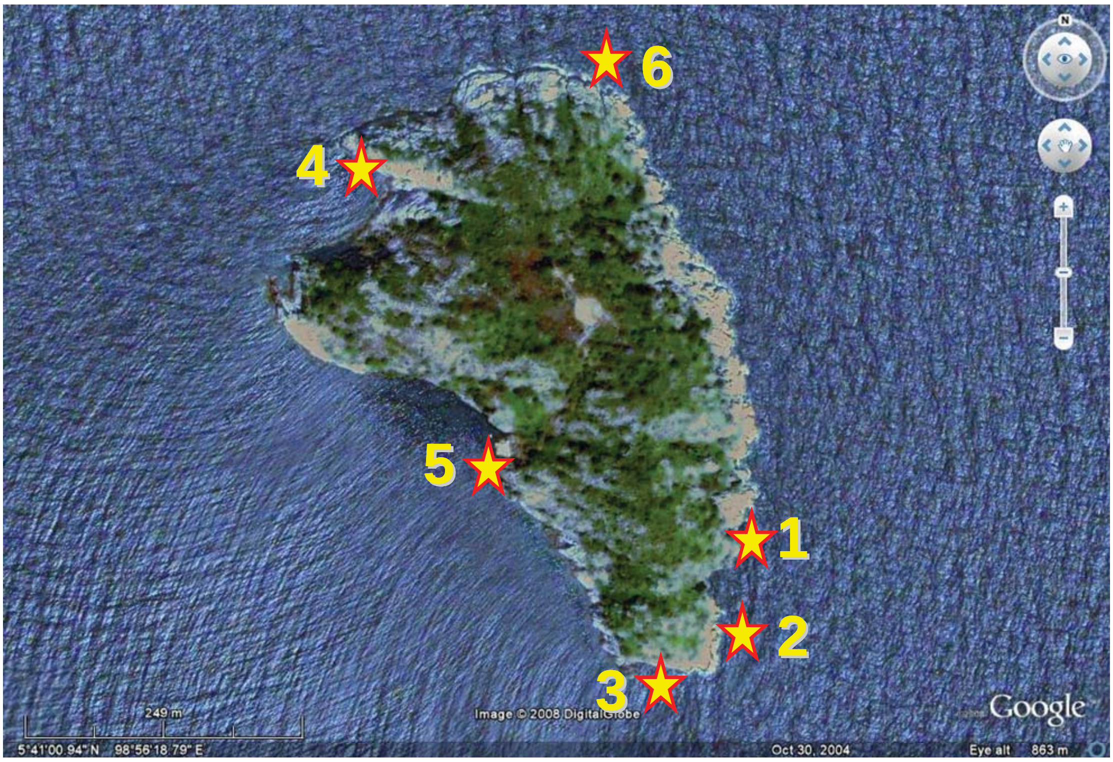

Figure 2.3: Map showing the six wall study sites where 1=East Wall, 2=South-East Wall, 3=South Wall, North-west Wall, 5=West Wall, 6=North Wall. (Map from Google Earth)

Two biologist SCUBA divers were deployed at each depth (Shallow 10 m and Deep 20 m) for one wall between 8-9 a.m.. This was done for six days to complete the survey of the six walls. At each depth the survey method used was a modified Reef Check (Hodgson et al., 2006). Substrate cover (%) and resources such as selected indicator reef fish and invertebrate densities were also documented **(Table 2.3).**

Table 2.3: a) Substrate cover, b) Indicator reef fish and c) Indicator Invertebrate categories documented using the modified Reef Check method (Hodgson et al., 2006)

Component	Category	Note	Biological Indicator for
a) Substrate	Hard Coral (HC)	Scleractinian corals and includes fire coral (Millepora), blue coral (Heliopora) and organ pipe coral (Tubipora) because these are reef builders.	Blast Fishing, Poison Fishing & Nutrient Pollution (if HC has low percentage cover)
	Soft Coral (SC)	Includes zoanthids	

Table 2.3, continued

	Recently Killed Coral (RKC)	Corals that has died within the past year	Blast Fishing, Poison Fishing & Nutrient Pollution (if RKC has high percentage cover)
	Nutrient Indicator Algae (NIA)	Blooms of fleshy algae that may be responding to high levels of nutrient input	Nutrient Pollution (if NIA has high percentage cover)
	Sponge (SP)	All sponges (but no tunicates)	Nutrient Pollution (if SP has high percentage cover)
	Rock (RC)	Any hard substratum larger than 15 cm whether it is covered in e.g. turf or encrusting coralline algae, barnacles, oysters etc.	
	Rubble (RB)	Rocks between 0.5 and 15 cm diameter	
	Sand (SD)	Smaller than 0.5 cm	
	Silt (SI)	Sediment that remains in suspension if disturbed	
	Others (OT)	Any other sessile organism including sea anemones, tunicates, gorgonians or non-living substrata	
	Gap (G)	Gully less than 1m deep	
b) Fish	Chaetodontidae	Butterfly Fish	Overfishing, Poison Fishing & Aquarium Fish Collection (if Butterfly Fish density is low)
	Haemulidae	Sweetlips/Grunts/ Margates	Overfishing, Blast Fishing, Poison Fishing & Aquarium Fish Collection (if Butterfly Fish density is low)
	Lutnajidae	Snapper	Overfishing & Blast Fishing (if Sweetlips density is low)

Table 2.3, continued

	Cromileptis altivelis	Barramundi Cod	Overfishing, Blast Fishing, Poison Fishing & Aquarium Fish Collection (if Barramundi Cod density is low)
	Serranidae	Grouper/Coral Trout	Overfishing, Blast Fishing & Poison Fishing (if Grouper density is low)
	Cheilinus undulatus	Humphead (Napolean) Wrasse	Overfishing, Blast Fishing, Poison Fishing & Aquarium Fish Collection (if Humphead Wrasse density is low)
	Bolbometopon muricatum	Bumphead Parrot Fish	Overfishing, Blast Fishing, Poison Fishing & Aquarium Fish Collection (if Bumphead Parrot Fish density is low)
	Scaridae	Other Parrot fish (> 20 cm)	Overfishing, Blast Fishing, Poison Fishing & Aquarium Fish Collection (if Parrot fish density is low)
	Muraenidae	Moray Eel	Overfishing & Aquarium Fish Collection (if Moray Eel density is low)
c) Invertebrate	*Stenopus hispidus*	Banded Coral Shrimp	Aquarium Fish Collection (if Banded Coral Shrimp density is low)
	Diadema spp. and *Echinothrix diadema*	Long spined Black Sea Urchin	Overfishing & Nutrient Pollution (if Long spined Black Sea Urchin density is high)
	Heterocentrotus mammilatus	Pencil Urchin	Curio Collection (if Pencil Urchin density is low)
	Thelenota ananas *Stichopus chloronotus* *Holothuria edulis*	Sea cucumbers (Edible) - Prickly redfish - Greenfish - Pinkfish	Overfishing (if Sea cucumbers density is low)
	Acanthaster planci	Crown of Thorns Sea Star	Overfishing (if Crown of Thorns Sea Star density is high)
	Tridacna spp.	Giant clam	Overfishing & Curio Collection (if Giant clam density is low)

Table 2.3, continued

	Charonia tritonis	Triton	Overfishing & Curio Collection (if Triton density is low)
	Tripneustes spp.	Sea Egg/Collector urchin	Curio Collection (if Collector urchin density is low)
	Malacostraca (Decapod)	Lobster (spiny and slipper/rock)	Overfishing (if Lobster density is low)

The methodology for using modified Reef Check (RC) is as follows. A pair of SCUBA divers deployed a 100 m transect line and one marker buoy each was fixed at the start and end point of the transect line. Two transect lines were deployed horizontally on the reef wall at 10 m and 20 m depths (chart datum). GPS reading (WGS84) was taken from the first (start) buoy of the transect. The divers then took a compass reading for the heading of the transect to the second (end) buoy before starting their survey of the transect. The line transect was then divided into four sections of 20 m with an interval of 5 m each. The first pair of SCUBA divers did the Fish survey by observing 2.5 m of the above and below of the transect line depth and 5 m perpendicular away from the wall for every 20 m section. This resulted in four replicates of 500 m^3 surveyed reef. The second pair of SCUBA divers then did the Invertebrate survey by observing 2.5 m of the above and below of the transect line depth for every 20 m of the transect. This resulted in four replicates of 100 m^2 surveyed reef. The final pair of SCUBA divers did the Substrate survey where the substrate was documented at every 0.5 m on the transect line for every 20 m section. This resulted in 40 points per 20 m section of the transect. Finally the transect lines and buoys were retrieved and the dive survey ended.

For the Substrate survey by using the 40 points in each section, a percentage of each substrate type was then calculated. Consequently the criteria set by the ASEAN-Australian Living Coastal Resources project (Chou et al., 1994) for ‘Live Coral’ (Hard Coral and Soft Coral) cover was used to ascertain the status of reef surveyed (>75% is excellent, 50-75% is good, 25-50% is fair and <25% is poor). In addition Harborne et al. (2000) had estimated that the mean percent cover for islands on the east coast of Peninsular Malaysia to be at 42.2%.

The R Software (Version 2.9.2) was used to analyse the data from the surveys above using a one way ANOVA with Tukey's Honest Significant Differences (HSD) test with 95% CI. An arcsine transformation was used for all percentage data and a Levene's test to check for homogeneity of variance was done prior to ANOVA tests. A Multi Way ANOVA using Linear Models were used prior to generating cluster Dendrograms using the Ward method with Euclidian distances for the comparison of the six walls with regards to the biota surveyed.

3.0 RESULTS

3.1 Objective 1: Benthic community substrate cover at West and East facing walls with regards to their depth profiles

3.1.1 Benthic community substrate cover with depth for East Wall

From the vertical transect survey using belt-quadrats (5 m x 5 m) a graph **(Figure 3.1)** is produced showing the distribution of the benthic substrate categories according to their depth for the East Wall.

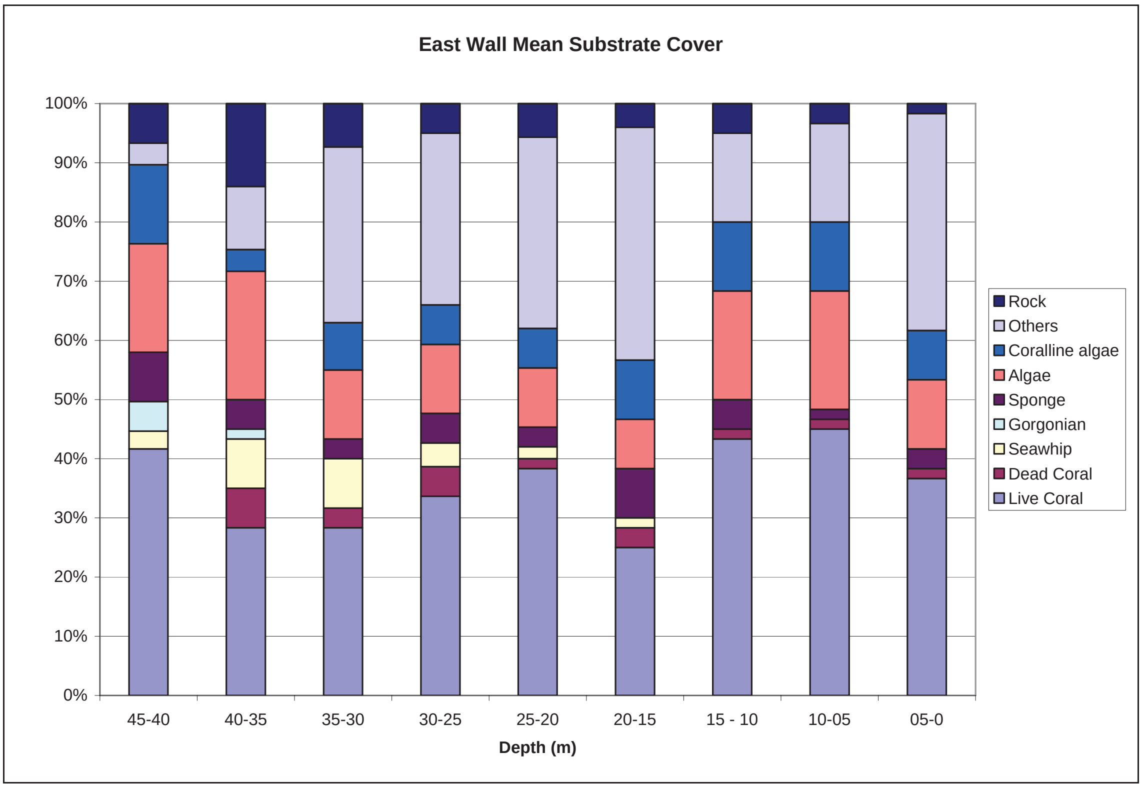

Figure 3.1: The benthic community substrate mean percentage cover for East Wall according to depth.

Using a One Way ANOVA with Tukey's Honest Significant Differences (HSD) test with 95% CI (R 2.9.2 Software) some significant differences were found in the benthic community substrate cover with depth for East Wall **(Table 3.1).**

Table 3.1: Significant differences found in benthic community substrate cover with depth for East Wall. Depths are categorized into 45-40m=D9, 40-35m=D8, 35-30m=D7, 30-25m=D6, 25-20m=D5, 20-15m=D4, 15-10m=D3, 10-5m=D2, 5-0m=D1.

Substrate/Organism	Statistical Results	Summary of Tukey's HSD results (p<0.05)
Sea Whip (SW)	p<0.01, F=4.70 (n=3)	D8=D7 > D3=D2=D1
Gorgonian (GG)	p<0.001, F=9.25 (n=3)	D9 > D8=D7=D6=D5=D4=D3=D2=D1
Coralline Algae (CA)	p<0.01, F=4.04 (n=3)	D9=D3=D2 > D8

From **Figure 3.1** and **Table 3.1**, even though there were some differences found on the 'Sea Whips', 'Coralline Algae' (p<0.01) and the 'Gorgonian' (p<0.001), the most important discovery was that there was no significant difference found for 'Live Coral' cover from 0-45m for the East Wall at 5 m intervals.

3.1.2 Benthic community substrate cover with depth for West Wall

From the vertical transect survey using belt-quadrats (5 m x 5 m) a graph **(Figure 3.2)** is produced showing the distribution of the benthic substrate categories according to their depth for the West Wall.

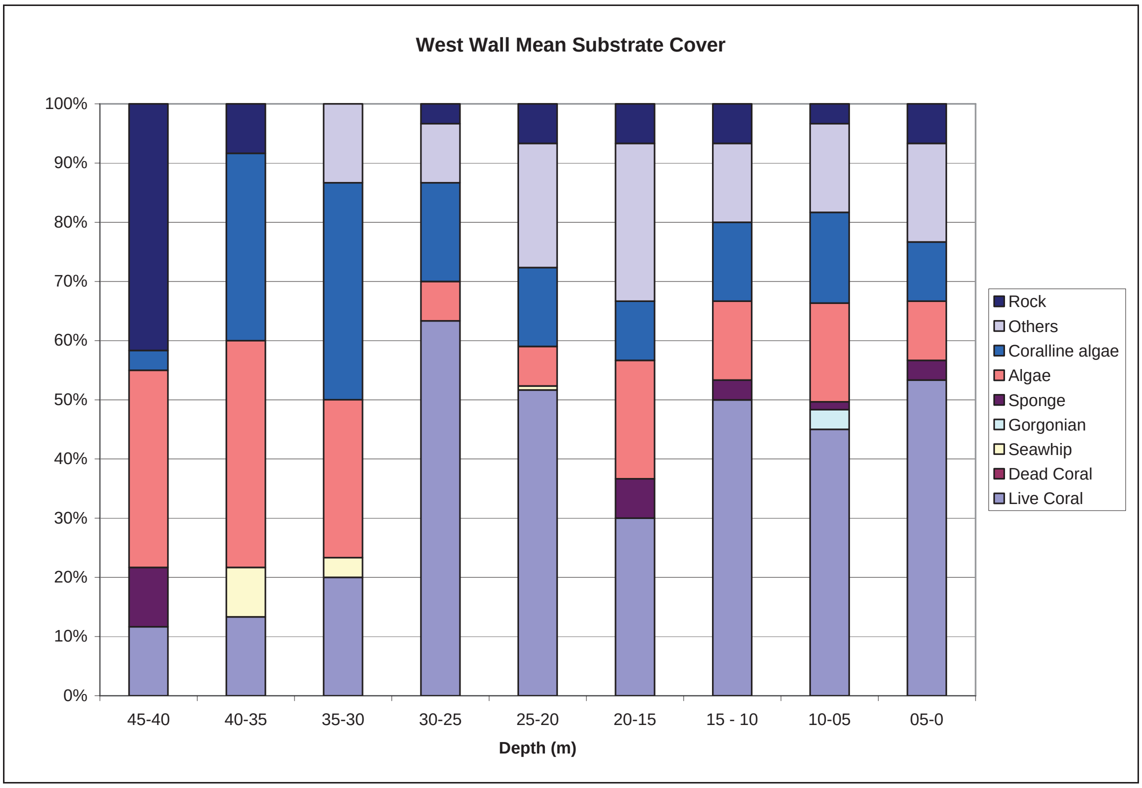

Figure 3.2: The benthic community substrate mean percentage cover for West Wall according to depth.

Using a One Way ANOVA with Tukey's Honest Significant Differences (HSD) test with 95% CI (R 2.9.2 Software) some significant differences were found in substrate cover with depth for West Wall **(Table 3.2).**

Table 3.2: Significant differences found in substrate cover with depth for West Wall. Depths are categorized into 45-40m=D9, 40-35m=D8, 35-30m=D7, 30-25m=D6, 25-20m=D5, 20-15m=D4, 15-10m=D3, 10-5m=D2, 5-0m=D1.

Substrate/Organism	Statistical Results	Summary of Tukey's HSD results (p<0.05)
Live Coral (LC)	p<0.001, F=14.91 (n=3)	D9=D8=D7 < D6=D5=D4=D3=D2=D1
Sea Whip (SW)	p<0.01, F=5.15 (n=3)	D8=D7 > D9=D6=D5=D4=D3=D2=D1
Gorgonian (GG)	p<0.01, F=4.00 (n=3)	D2 > D9=D8=D7=D6=D5=D4=D3=D1
Sponge (SP)	p<0.001, F=6.63 (n=3)	D9 > D8=D7=D6=D5=D2
Algae (AL)	p<0.05, F=2.69 (n=3)	D9=D8=D7=D6=D5=D4=D3=D2=D1
Coralline Algae (CA)	p<0.05, F=3.65 (n=3)	D9 < D8=D7

From **Figure 3.2** and **Table 3.2**, six groups of organisms were found to be significantly different with depth. They were the 'Sea Whip' (p<0.01) which was only to be found at the deeper depths of 30-40m, 'Gorgonian' (p<0.01) which was only to be found at the shallow depth of 5-10m, 'Sponge' (p<0.001) which was found more at three depths of 40-45m, 15-20m and 0-5m, 'Algae' (p<0.05) but had no significant difference between depths, 'Coralline algae' (p<0.05) which was less to be found at 40-45 m depth. The most important finding was that there was a difference in 'Live Coral' cover (p<0.001) which was found to be less in deeper depths of 30-45m.

3.1.3 Difference in benthic community substrate cover with depth between the East and West Walls

Data for the East and West Wall benthic community substrate cover are shown in **Figure 3.3** for comparison.

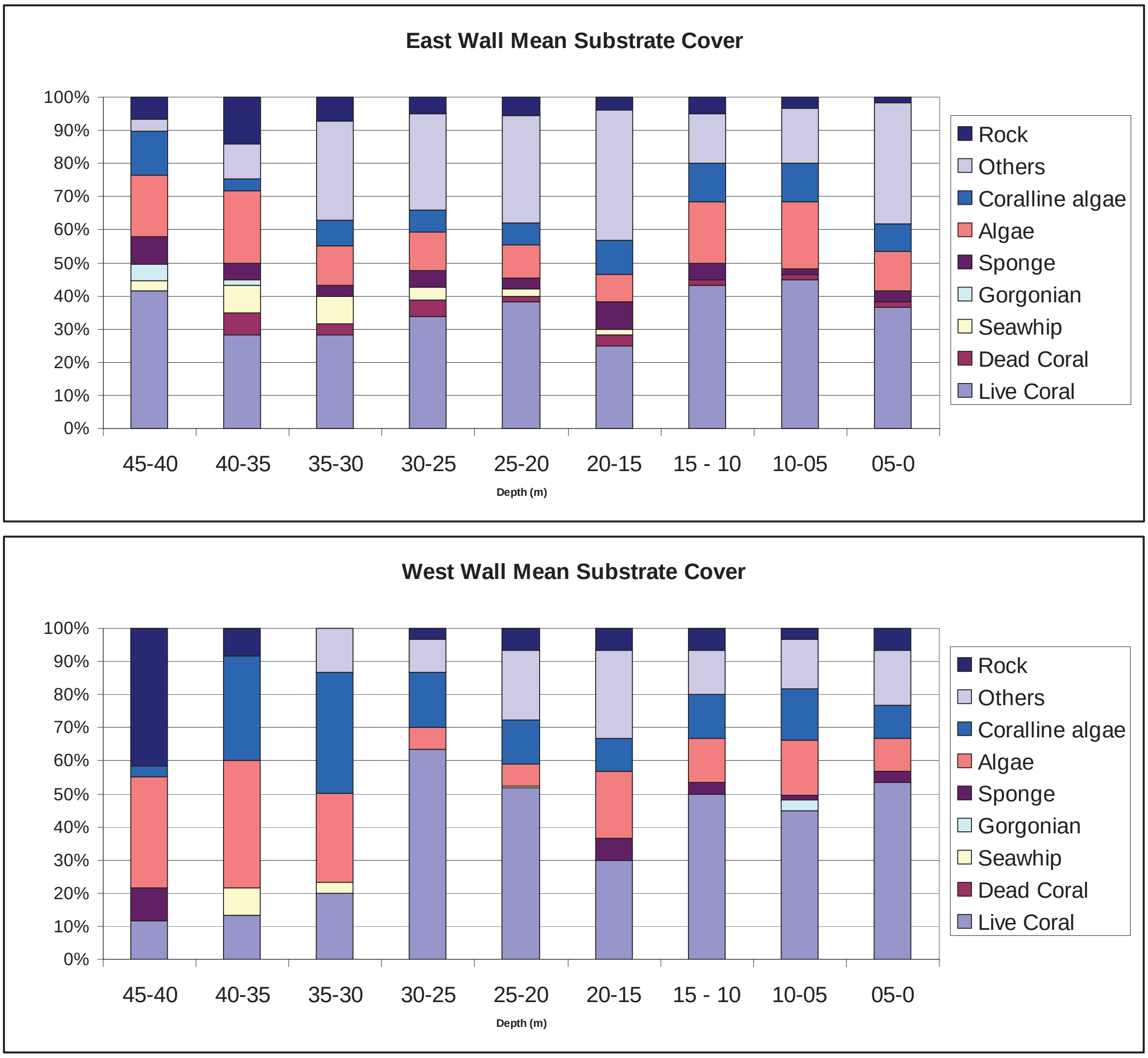

Figure 3.3: Combined data of benthic community substrate cover for East and West Walls according to depth (m).

A comparison of data for both Walls was done by performing a Multi Way ANOVA using a Linear Model (R 2.9.2 Software). Some significant differences were found between the two factors tested ('Wall' and 'Depth') and are shown in **Table 3.3**.

Table 3.3: Statistical results of the benthic community substrate cover with depth between the East and West Wall. Depths are categorized into 45-40m=D9, 40-35m=D8, 35-30m=D7, 30-25m=D6, 25-20m=D5, 20-15m=D4, 15-10m=D3, 10-5m=D2, 5-0m=D1.

Substrate/Organism	Statistical Results	Summary of Tukey's HSD results (p<0.05)
Live Coral (LC)	Depth: p<0.001, F=4.64 Wall: n/s Depth*Wall: p<0.05, F=2.86	LC % cover is different with depth for both walls n/s LC % cover is different between walls at D9 and D6
Dead Coral (DC)	Depth: n/s Wall: p<0.01, F=9.00 Depth*Wall: n/s	n/s DC % cover is different between walls n/s
Sea Whip (SW)	Depth: p<0.001, F=8.81 Wall: p<0.05, F=6.43 Depth*Wall: n/s	SW % cover is different at both walls where D8=D7=D6 > D9=D5=D4=D3=D2=D1 SW % cover is different between walls n/s
Gorgonian (GG)	Depth: p<0.001, F=5.625 Wall: n/s Depth*Wall: p<0.001, F=7.63	GG % cover is different at both walls where D9=D8 >D7=D6=D5=D4=DD3=D2=D1 n/s GG % cover is different between walls at all depths
Algae (AL)	Depth: p<0.05, F=2.30 Wall: n/s Depth*Wall: n/s	AL % cover is different with depth for both walls n/s n/s
Coralline Algae (CA)	Depth: p<0.05, F=2.46 Wall: p<0.001, F=16.33 Depth*Wall: p<0.001, F=4.90	CA % cover is different with depth for both walls CA% cover is different between walls CA % cover is different between walls at D8 and D7

Seven groups of substrate were found to have significant difference in their distribution between walls. They were 'Dead Coral' which was different between walls (p<0.01) but not for any depth, 'Sea Whip' which was different at 25-40 m depths (p<0.001) and between walls (p<0.05), 'Gorgonian' which was different between the depths of 35-45m and at all depths between walls (p<0.001), 'Algae' was generally different with depth (p<0.05), 'Coralline Algae' which had a difference with depth (p<0.05), between walls (p<0.001) and depths between walls (p<0.001) at 30-40m where West Wall had more 'Coralline Algae'. The most important was the 'Live Coral' cover which differed between depths for both walls (p<0.001) where there was more 'Live Coral' on the West Wall at 25-30m compared to the East Wall (p<0.05) and inversely more on the East Wall at 40-45m depth (p<0.05).

3.1.4 Coral growth-forms with depth for East Wall

The graph below **(Figure 3.4)** shows the coral growth-form with depth data for the East Wall.

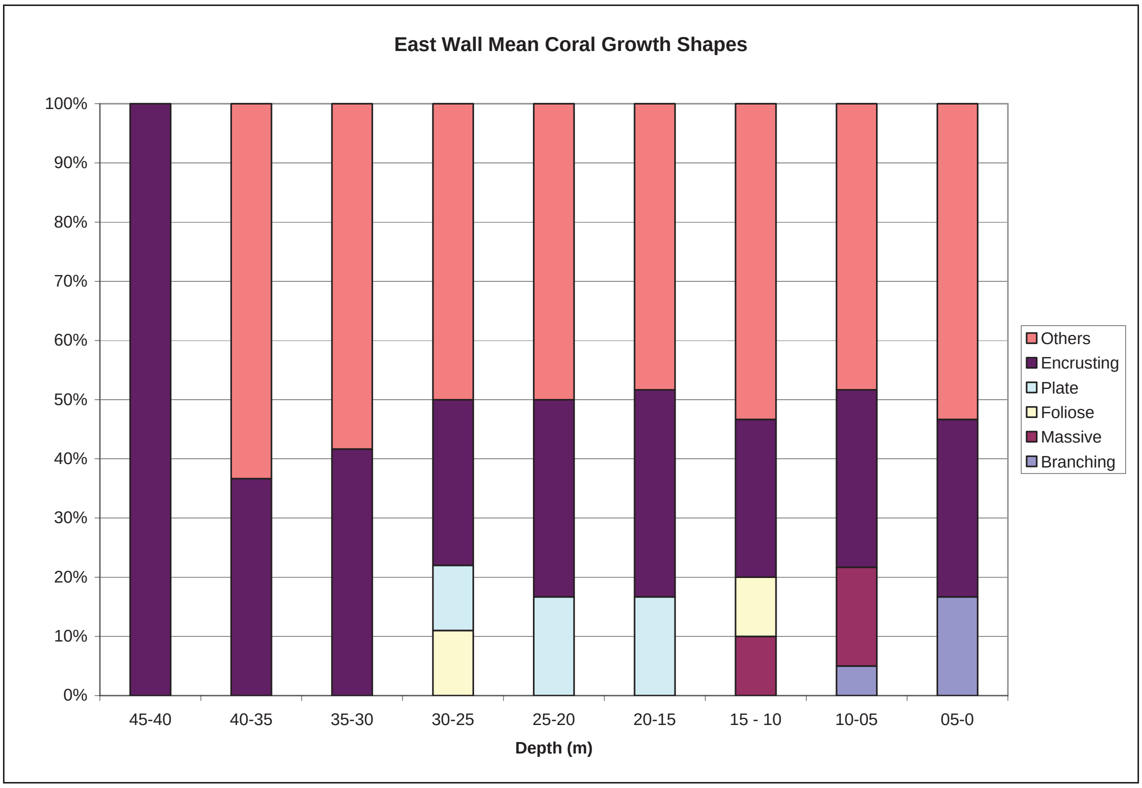

Figure 3.4: Graph shows the coral growth-forms with depth for the East Wall.

Using the One Way ANOVA with Tukey's Honest Significant Differences (HSD) test with 95% CI (R 2.9.2 Software) there was no significant difference found.

3.1.5 Coral growth-forms with depth for West Wall

The graph below **(Figure 3.5)** shows the coral growth-form with depth data for the West Wall.

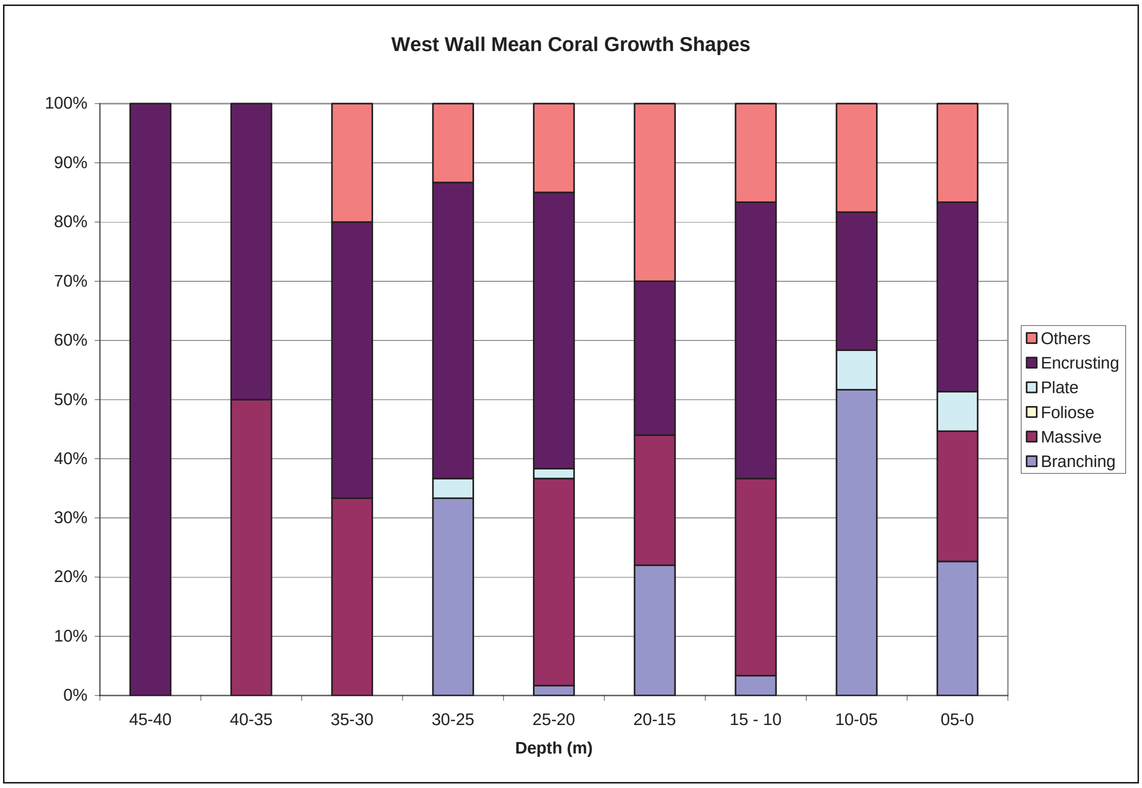

Figure 3.5: Graph shows the coral growth-forms with depth for the West Wall

Using the One Way ANOVA with Tukey's Honest Significant Differences (HSD) test with 95% CI (R 2.9.2 Software) some significant differences were found as shown in **Table 3.4** below.

Table 3.4: Significant differences found in coral growth-forms with depth for West Wall. Depths are categorized into 45-40m=D9, 40-35m=D8, 35-30m=D7, 30-25m=D6, 25-20m=D5, 20-15m=D4, 15-10m=D3, 10-5m=D2, 5-0m=D1.

Coral growth-shape	Statistical Results	Summary of Tukey's HSD results (p<0.05)
Branching (BC)	p<0.05, F=2.88 (n=3)	D2 > D7=D8=D9
Massive (MC)	p<0.05, F=2.93 (n=3)	D8 > D9=D6=D2
Encrusting (EC)	p<0.001, F=45.097 (n=3)	D9 > D8=D7=D6=D5=D3 > D4=D2=D1

Three coral growth-forms were found to be significantly different with depth. They were the 'Branching' ($p<0.05$) which was the most dominant at the shallow depth of 5-

10 m and was not present deeper than 30 m, ‘Massive’ ($p<0.05$) was found to be dominant at 35-40 m and present at all depths but absent at deeper depths of 40-45 m, ‘Encrusting’ ($p<0.001$) was dominant at 40-45m and present at all depths. ‘Plate’ and ‘Foliose’ growth-form distribution were not significantly different with depth. However ‘Plate’ coral was not present deeper than 30 m depth.

3.1.6 Difference in coral growth-forms with depth between Walls

Data for the East and West Wall coral growth-forms were compared in a bar graph **(Figure 3.6).**

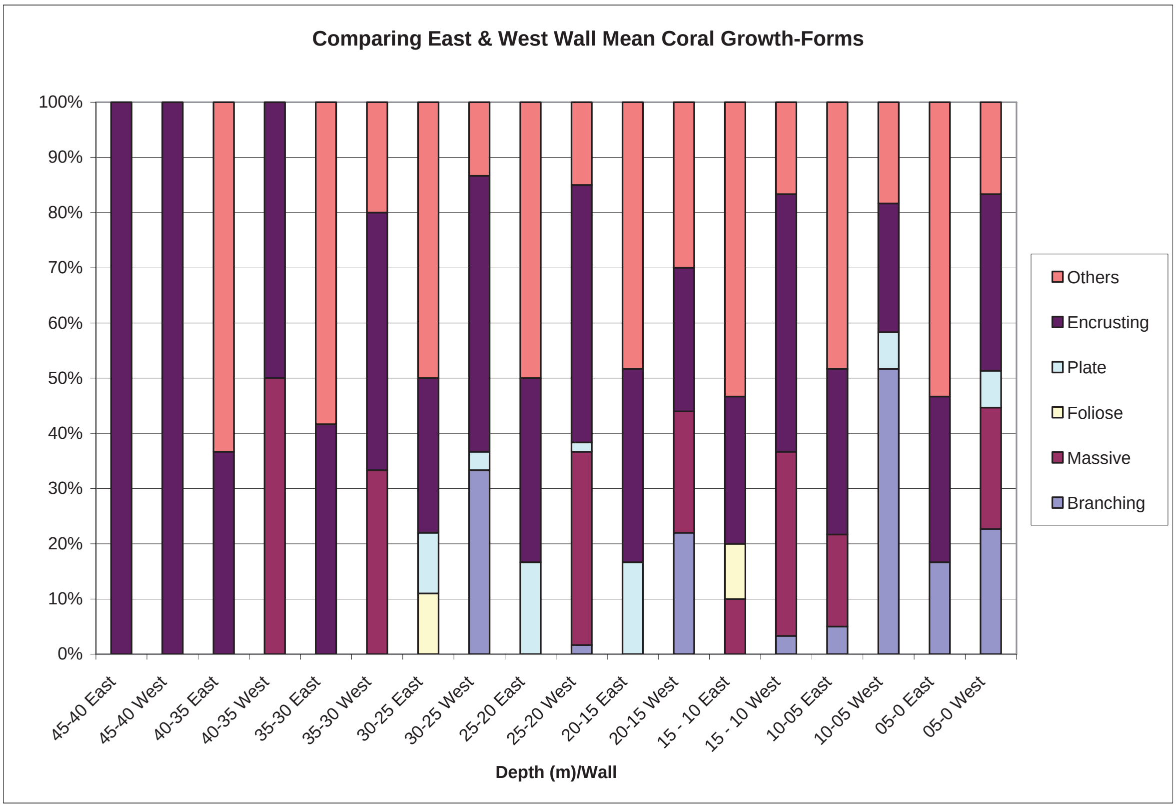

Figure 3.6: Combined data of coral growth-forms for East and West Walls according to depth.

A comparison of data for both Walls was done by performing a Multi Way ANOVA using a Linear Model (R 2.9.2 Software). Some significant differences were found between the two factors tested (‘Wall’ and ‘Depth’) and are shown in **Table 3.5.**

Table 3.5: Multi Way ANOVA results for comparing the data of coral growth-forms with depth from East and West Walls. Depths are categorized into 45-40m=D9, 40-35m=D8, 35-30m=D7, 30-25m=D6, 25-20m=D5, 20-15m=D4, 15-10m=D3, 10-5m=D2, 5-0m=D1.

Coral growth-shape	Statistical Results	Summary of Tukey's HSD results (p<0.05)
Branching (BC)	Depth: p<0.05, F=3.00 Wall: p<0.01, F=9.31 Depth*Site: n/s	BC% is different with depth for both walls BC% is different between walls n/s
Massive (MC)	Depth: n/s Wall: p<0.001, F=20.40 Depth*Site: p<0.05, F=2.77	n/s MC% is different between walls MC% is different between walls at D8, D7,D5,D4,D3 and D1
Foliose (FC)	Depth: n/s Wall: n/s Depth*Site: n/s	n/s n/s n/s
Encrusting (EC)	Depth: p<0.001, F=6.75 Wall: n/s Depth*Site: n/s	Intercept, different at D9 n/s n/s
Others (OT)	Depth: n/s Wall: p<0.01, F=10.13 Depth*Site: n/s	n/s OT% is different between walls n/s

Four coral growth-forms were found to have significant difference in their distribution with depth between walls. They were 'Branching' which had a difference with depth (p<0.05) and between walls (p<0.01) but had no difference with depth between walls, 'Massive' which had a difference between walls (p<0.001) and a difference with depth between walls (p<0.05) except for the depths of 5-10 m, 25-30 m and 40-45 m, 'Encrusting' which had a difference with depth at both walls (p<0.001) and 'Others' which only had a difference between sites (p<0.01). Even though 'Foliose' had no significant difference it could only be found on the East Wall and at only 10-15 m and 25-30 m. 'Plate' coral had no significant difference and grew on both walls at similar depths.

<u>3.2 Objective Two: Substrate cover differences (if any) between Shallow (10m) and Deep (20m) depths at six distinct facing reef walls around Pulau Perak with emphasis on 'Hard Coral' cover and their relation to fish and invertebrate indicators of reef health</u>

3.2.1 Difference in substrate cover between depths at the six walls

The graph below **Figure 3.7** summarises the data collected at the six walls.

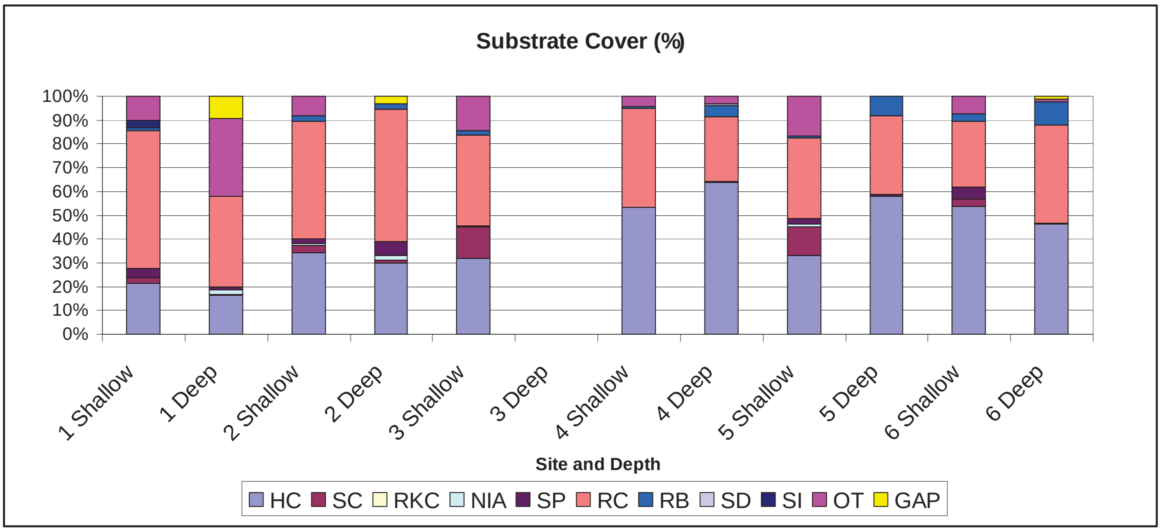

Figure 3.7: The difference in substrate cover between the six walls (Shallow vs. Deep) at Pulau Perak. Site 3 Deep data is unavailable due to datasheet loss during survey. 1= East Wall, 2= South-east Wall, 3= South Wall, 4= North-west Wall, 5= West Wall, 6= North Wall.

By using the criteria set by the ASEAN-Australian Living Coastal Resources project (Chou et al., 1994) the status 'Live Coral' cover of the reef areas surveyed are shown in **Table 3.6** where for the Shallow areas they ranged from 'poor'(23.8%) to 'good' (56.9%) and for the Deep areas they ranged from 'poor' (16.9%) to 'good' (64.4%). Seven reef areas (South Wall Shallow, North-west Wall Shallow & Deep, West Wall Shallow & Deep and North Wall Shallow & Deep) had a higher 'Live Coral' cover than the mean percent cover of 42.2% for islands on the east coast of Peninsular Malaysia as reported by Harborne et al. (2000).

Table 3.6: Status for the 'Live Coral' cover of the reef areas surveyed using criteria set by Chou et al. (1994). n/a= not applicable as data were lost during survey. 1= East Wall, 2= South-east Wall, 3= South Wall, 4= North-west Wall, 5= West Wall, 6= North Wall.

Reef area	Live Coral Cover (%)	Status
1 Shallow	23.8	poor
2 Shallow	37.5	fair
3 Shallow	45.0	fair
4 Shallow	53.1	good
5 Shallow	45.0	fair
6 Shallow	56.9	good
1 Deep	16.9	poor
2 Deep	31.3	fair
3 Deep	n/a	n/a
4 Deep	64.4	good
5 Deep	58.1	good
6 Deep	46.3	fair

Using a One Way ANOVA (R 2.9.2 Software) to compare substrate cover between shallow and deep depths at each wall, some significant differences were found **(Table 3.7).**

Table 3.7: Statistical results in comparing substrate cover between Shallow depth 10 m and Deep depth 20 m for the six walls. n/s= not significant, N/A= not available.

Substrate	East Wall	South-east Wall	South Wall	North-west Wall	West Wall	North Wall
Hard Coral (HC)	n/s	n/s	N/A	n/s	**p<0.01, F=21.62**	n/s
Soft Coral (SC)	n/s	n/s	N/A	n/s	p=0.06784, F=4.95	**p<0.05, F=6.82**
Recently Killed Coral (RKC)	n/s	n/s	N/A	n/s	n/s	n/s
Nutrient Indicator Algae (NIA)	n/s	n/s	N/A	n/s	n/s	n/s
Sponge (SP)	n/s	n/s	N/A	n/s	**p<0.05, F=9.00**	n/s
Rock (RC)	n/s	n/s	N/A	n/s	n/s	n/s
Rubble (RB)	n/s	n/s	N/A	p=0.08631, F=4.20	p=0.06623, F=5.02	n/s
Sand (SD)	n/s	n/s	N/A	n/s	n/s	n/s
Silt (SI)	n/s	n/s	N/A	n/s	n/s	n/s
Others (OT)	**p<0.05, F=7.25**	n/s	N/A	n/s	**p<0.001, F=62.49**	**p<0.05, F=6.82**
GAP	**p<0.05, F=8.13**	n/s	N/A	n/s	n/s	n/s

Three walls had differences in their substrate cover between depths surveyed. They were East Wall which had more OT (p<0.05) and GAP (p<0.05) in Deep area, West

Wall which had more SP ($p<0.05$) and OT ($p<0.001$) in Shallow area, HC ($p<0.01$) was more in Deep area and North Wall which had more SC ($p<0.05$) and OT ($p<0.05$) in Shallow area.

3.2.2 Shallow depths (10 m) ‘Hard Coral’ cover at the six walls

To show whether wall orientation could result in similar ‘Hard Coral’ cover in Shallow depths, statistical tests were done to check which walls had similar ‘Hard Coral’ cover for Shallow study areas.

A One way ANOVA was performed comparing all Shallow sites with Tukey HSD 95% CI graphs **(Figure 3.8)** using R 2.9.2 software.

From the one way ANOVA (n=4) comparing all six Shallow sites for ‘Hard Coral’ (HC) it was found that there were significant differences ($p<0.01$, $F=5.17$) between walls at Shallow depth for ‘Hard Coral’ cover. In addition it was found that the biggest differences were between the East Wall and North-west Wall and between East Wall and North Wall **(Figure 3.8)**.

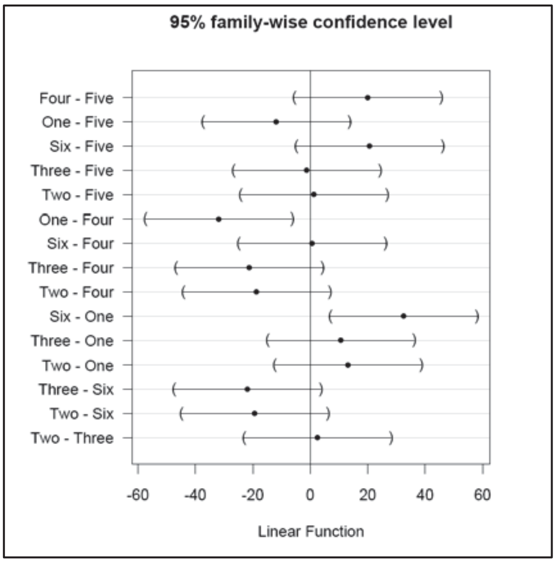

Figure 3.8: HC Tukey HSD with 95% CI for all six Shallow Sites using ‘Hard Coral’ (HC). One= East Wall, Two= South-east Wall, Three= South Wall, Four= North-west Wall, Five= West Wall, Six= North Wall.

Subsequently a cluster dendrogram **(Figure 3.9)** was generated using the Ward method with Euclidean distances (R 2.9.2 software) using the Shallow Sites Hard Coral % cover for each wall. It is to show how similar or different the walls are to each other based on the % Hard Coral cover.

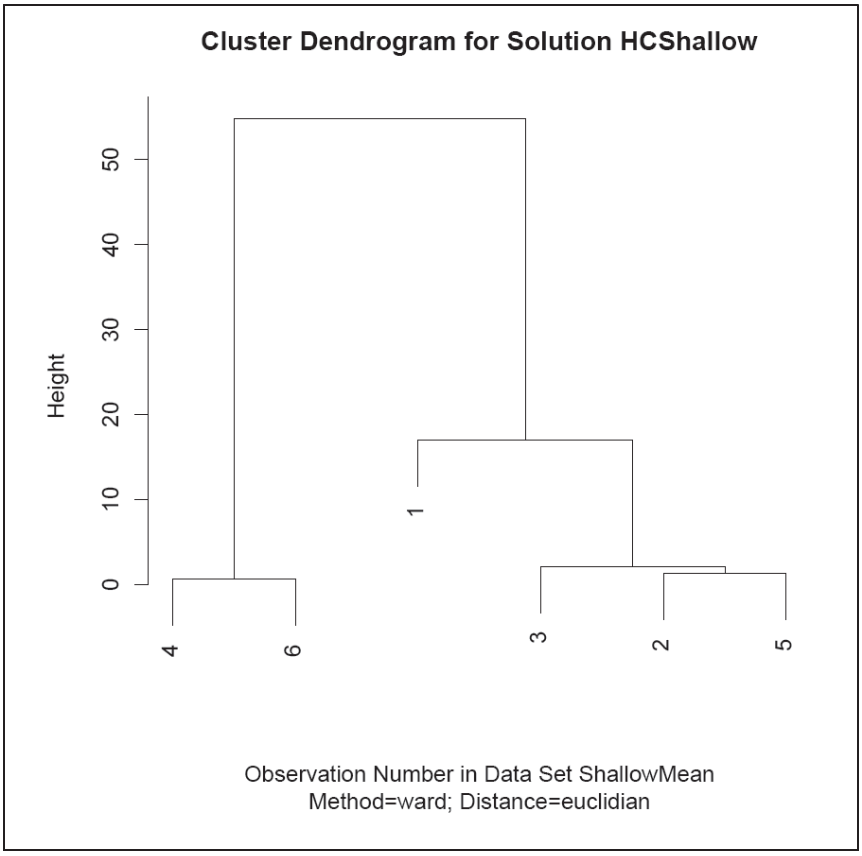

Figure 3.9: Cluster dendrogram using the Ward method with Euclidean distances (R 2.9.2 software) to show which Shallow sites were similar or different. 1= East Wall, 2= South-east Wall, 3= South Wall, 4= North-west Wall, 5= West Wall, 6= North Wall.

Figure 3.9 shows that there are three groups of walls at Shallow depth with similar 'Hard Coral' cover which were:

i) Wall 4 (North-west Wall) and Wall 6 (North Wall)

ii) Wall 1 (East Wall)

iii) Wall 2 (South-east Wall), Wall 3 (South Wall) and Wall 5 (West Wall)

3.2.3 Deep depths (20 m) 'Hard Coral' cover at the six walls

To show if wall orientation could result in similar 'Hard Coral' cover at Deep depths, statistical tests were done to check which walls had similar 'Hard Coral' cover in the Deep study areas.

A One way ANOVA comparing ALL Deep sites with Tukey HSD 95% CI graphs **(Figure 3.10)** using R 2.9.2 software was done.

From the one way ANOVA (n=4) comparing all five Deep sites (Site 3 data was lost during survey) for 'Hard Coral' (HC) it was found that there was a significant difference ($p<0.001$, $F=11.52$) between walls at Deep depth for 'Hard Coral' cover. In addition **Figure 3.10** shows that the differences were between Site One (East Wall) and Site Five (West Wall), Site Two (South-east Wall) and Site Five (West Wall), Site One (East Wall) and Site Four (North-west Wall), Site Two (South-east Wall) and Site Four (North-west Wall) and between Site One (East Wall) and Site Six (North Wall).

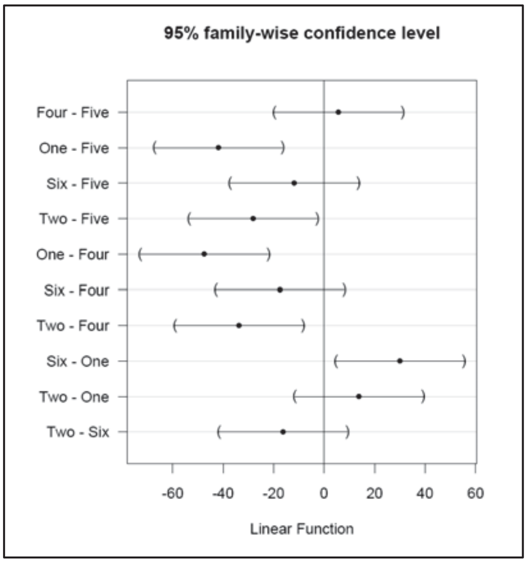

Figure 3.10: HC Tukey HSD with 95% CI for all five Deep Sites (Site Three data was lost during survey) using 'Hard Coral' (HC). One= East Wall, Two= South-east Wall, Three= South Wall (data lost) Four= North-west Wall, Five= West Wall, Six= North Wall.

Subsequently a cluster dendrogram (**Figure 3.11)** was generated using the Ward method with Euclidian distances (R 2.9.2 software) using the Deep Sites Hard Coral % cover for each wall. It is to show how similar or different the walls are to each other based on the % Hard Coral cover.

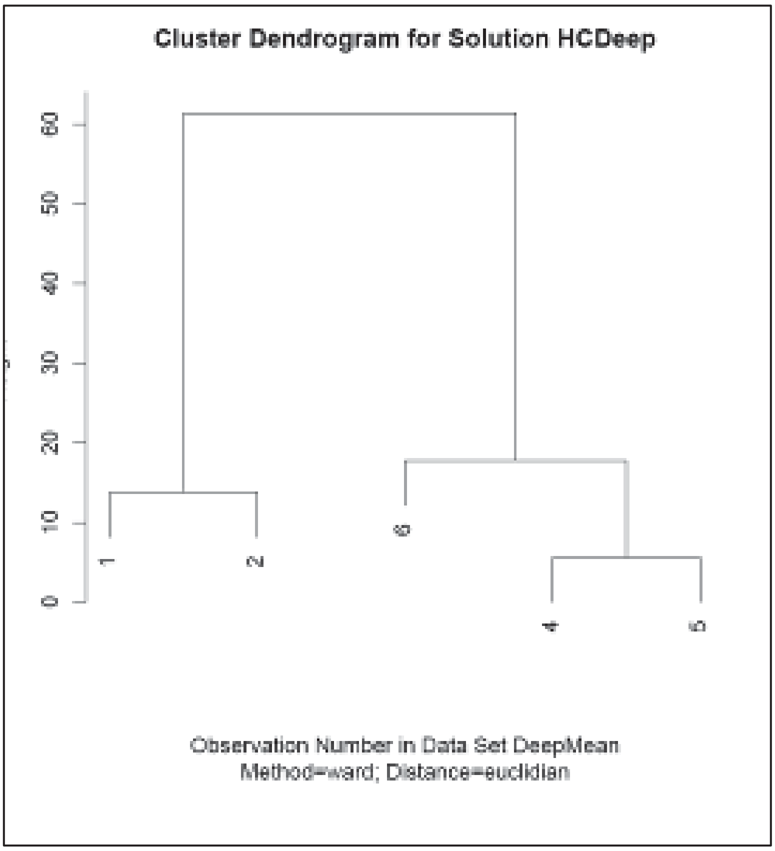

Figure 3.11: Cluster dendrogram using the Ward method with Euclidian distances (R 2.9.2 software) to show which Deep sites were similar or different. 1= East Wall, 2= South-east Wall, 3= South Wall (data lost), 4= North-west Wall, 5= West Wall, 6= North Wall.

Figure 3.11 shows that there are three groups of walls at Deep depth with similar 'Hard Coral' cover which were

i) Wall 1 (East Wall) and Wall 2 (South-east Wall)

ii) Wall 6 (North Wall)

iii) Wall 4 (North-west Wall) and Wall 5 (West Wall)

3.2.4 Abundance of indicator fishes with depth at the six walls

From the surveys done on the six walls, the indicator fish density is as shown in **Figure 3.12** and the wall comparison statistical results are shown in **Table 3.8**.

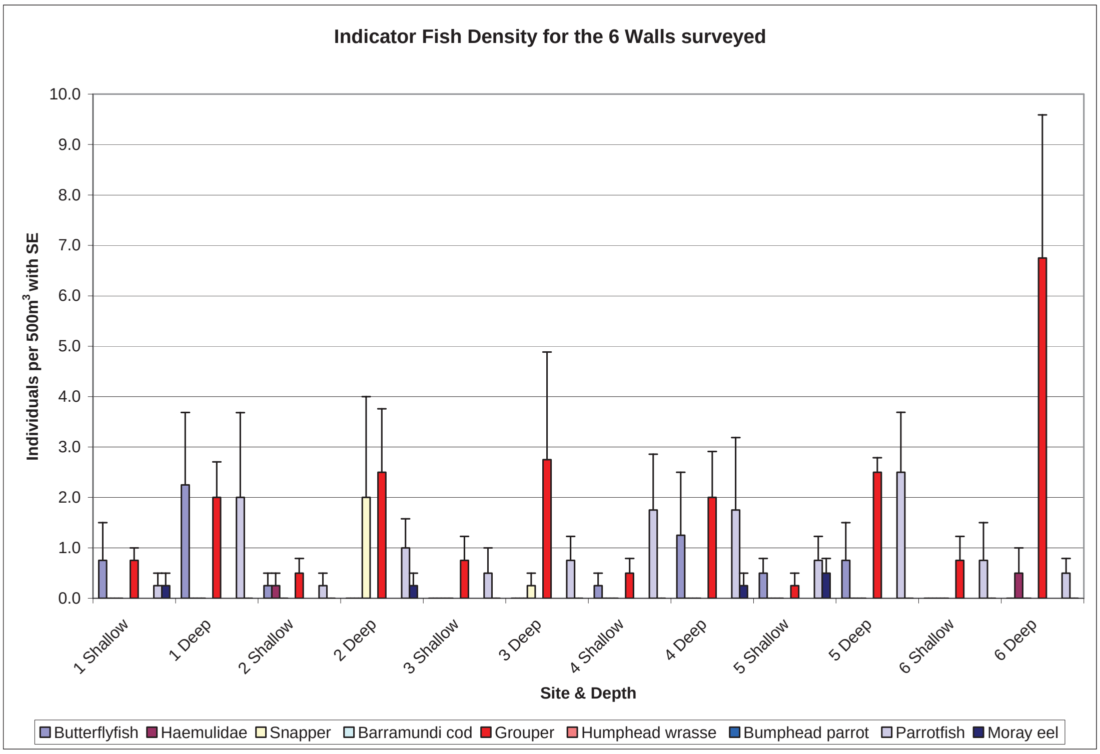

Figure 3.12: The difference in indicator fish densities (individuals per 500m^3) between the six walls (Shallow vs. Deep) at Pulau Perak. 1= East Wall, 2= South-east Wall, 3= South Wall, 4= North-west Wall, 5= West Wall, 6= North Wall. Error bars denotes Standard Errors.

Table 3.8: Indicator Fish densities one way anova (n=4) for Shallow vs Deep depths for each wall. n/s= not significant, N/A= not available.

Fish	East Wall	South-east Wall	South Wall	North-west Wall	West Wall	North Wall
Chaetodontidae (Butterflyfish)	n/s	n/s	n/s	n/s	n/s	n/s
Haemulidae (Sweetlips)	n/s	n/s	n/s	n/s	n/s	n/s
Lutnajidae (Snapper)	n/s	n/s	n/s	n/s	n/s	n/s
Cromileptis altivelis (Barramundi cod)	n/s	n/s	n/s	n/s	n/s	n/s
Serranidae (Grouper)	n/s	n/s	n/s	n/s	**p<0.01, F=34.72**	p=0.08232, F=4.34

Table 3.8, continued

Cheilinus undulatus (Humphead wrasse)	n/s	n/s	n/s	n/s	n/s	n/s
Bolbometopon muricatum (Bumphead parrot)	n/s	n/s	n/s	n/s	n/s	n/s
Scaridae (Parrotfish)	n/s	n/s	n/s	n/s	n/s	n/s
Muraenidae (Moray eel)	n/s	n/s	n/s	n/s	n/s	n/s

From **Figure 3.12** and **Table 3.8** it is shown that only the Grouper had a significant difference in abundance between depths and at only the West Wall ($p<0.01$) where the Deep area had more than the Shallow area. This shows that at the Shallow area there was a higher disturbance compared to the Deep area.

3.2.5 Abundance of Indicator Invertebrates with depth at the six walls

From the surveys done on the six walls, the indicator invertebrate density is as shown in **Figure 3.13** and the wall comparison statistical results are shown in **Table 3.9**.

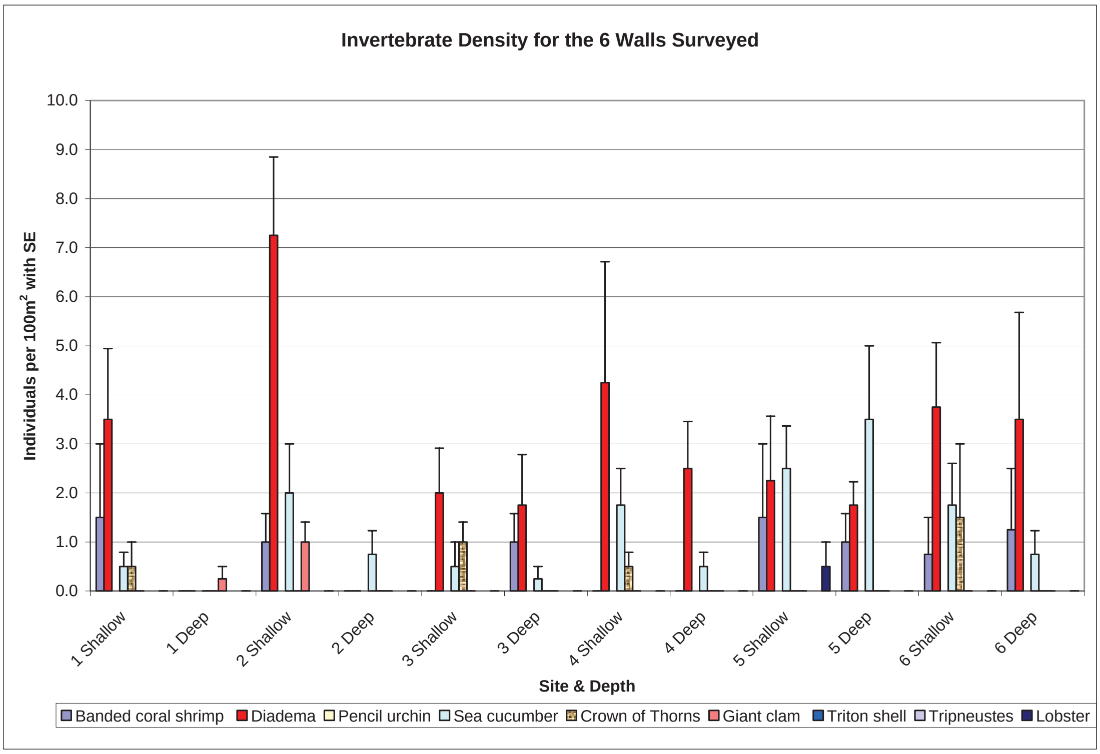

Figure 3.13: The difference in indicator invertebrate densities (individuals per 100m^2) between the six walls (Shallow vs. Deep) at Pulau Perak. 1= East Wall, 2= South-east Wall, 3= South Wall, 4= North-west Wall, 5= West Wall, 6= North Wall. Error bars denotes standard errors.

Table 3.9: Indicator Invertebrate densities one way anova (n=4) for Shallow vs Deep depths for each wall. n/s= not significant, N/A= not available.

Invert	East Wall	South-east Wall	South Wall	North-west Wall	West Wall	North Wall
Stenopus hispidus (Banded coral shrimp)	n/s	n/s	n/s	n/s	n/s	n/s
Diadema spp. (Long spined Black Sea Urchin)	p=0.05152, F=5.88	**p<0.01, F=20.51**	n/s	n/s	n/s	n/s
*Heterocentrotus mammilatus (*Pencil urchin)	n/s	n/s	n/s	n/s	n/s	n/s
Thelenota ananas Stichopus chloronotus Holothuria edulis (Sea cucumber)	n/s	n/s	n/s	n/s	n/s	n/s
Acanthaster planci (Crown of Thorns)	n/s	n/s	**p<0.05, F=6.00**	n/s	n/s	n/s
Tridacna spp. (Giant clam)	n/s	**p<0.05, F=6.00**	n/s	n/s	n/s	n/s
Charonia tritonis (Triton shell)	n/s	n/s	n/s	n/s	n/s	n/s
Tripneustes spp. (Collector urchin)	n/s	n/s	n/s	n/s	n/s	n/s
Malacostraca (Lobster)	n/s	n/s	n/s	n/s	n/s	n/s

From **Figure 3.13** and **Table 3.9** it is shown that Diadema spp. abundance was significantly more in abundance in the Deep area only at South-east Wall where this shows that there was a higher disturbance in the Deep area. Nevertheless Giant Clam abundance was lower in the Shallow area only at South-east Wall where it shows that disturbance is lower in the Shallow area. Crown of Thorns abundance was higher in the Shallow area only the South Wall where this shows that there was a higher disturbance in the Shallow area.

3.2.6 Combined Substrate Cover, Indicator Fishes and Invertebrates densities at Shallow depth at the six walls

The substrate cover, indicator fish and invertebrate density data from Shallow depth were combined to produce a Cluster dendrogram (**Figure 3.14)** using the Ward method with Euclidian distances (R 2.9.2 software). This was done so as to compare with the cluster dendrogram with only the substrate cover data (see **Figure 3.9)**.

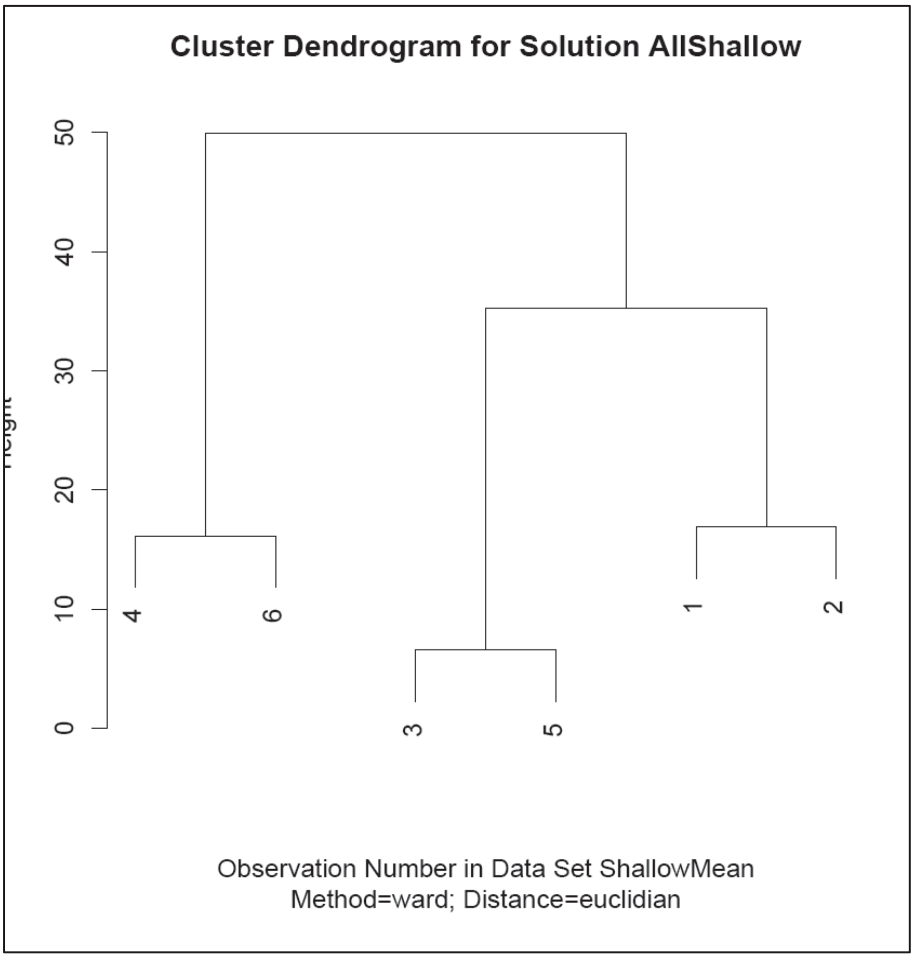

Figure 3.14: Cluster dendrogram using the Ward method with Euclidian distances (R 2.9.2 software) to show which Shallow sites were similar or different for a combination of substrate cover, indicator fish and invertebrate densities. 1= East Wall, 2= South-east Wall, 3= South Wall, 4= North-west Wall, 5= West Wall, 6= North Wall.

Figure 3.14 shows that there are three groups of walls at Shallow depth which had similar or closely similar combination of substrate cover, indicator fish and invertebrate densities which were:

i) Wall 4 (North-west Wall) and Wall 6 (North Wall)

ii) Wall 3 (South Wall) and Wall 5 (West Wall)

iii) Wall 1 (East Wall) and Wall 2 (South-east Wall)

3.2.7 Combined Substrate Cover, Indicator Fishes and Invertebrates densities at Deep depth at the six walls

The substrate cover, indicator fish and invertebrate density data from Deep depth was combined to produce a Cluster dendrogram (**Figure 3.15)** using the Ward method with Euclidian distances (R 2.9.2 software). This was done to compare with the cluster dendrogram with only the substrate cover data (see **Figure 3.11)**.

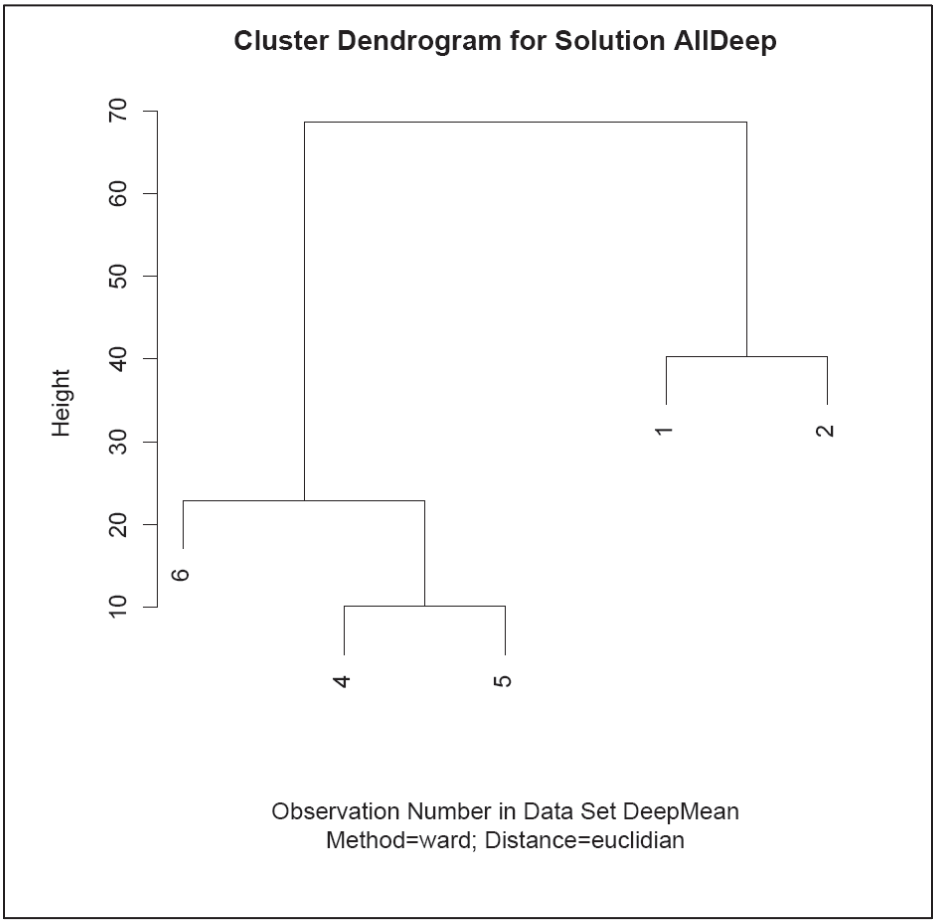

Figure 3.15: Cluster dendrogram using the Ward method with Euclidian distances (R 2.9.2 software) to show which Deep sites were similar or different for a combination of substrate cover, indicator fish and invertebrate densities. 1= East Wall, 2= South-east Wall, 3= South Wall, 4= North-west Wall, 5= West Wall, 6= North Wall. Site 3 data was lost during survey.

From **Figure 3.15** it clearly shows that there are 3 groups of Walls at Deep depth which had a similar combination of substrate cover, indicator fish and invertebrate densities which were

i) Wall 6 (North Wall)

ii) Wall 4 (North-west Wall) and Wall 5 (West Wall)

iii) Wall 1 (East Wall) and Wall 2 (South-east Wall)

4.0 DISCUSSION

From the benthic community substrate cover results **(Chapters 3.1.1, 3.1.2 & 3.1.3)** especially for the photosynthetic flora and fauna ('Algae', 'Coralline Algae', 'Live Coral') it seems that there are several factors which are affecting their distribution along the depth gradient. Nevertheless due to the priority of the objectives of this study, the focus is more on the 'Live Coral' as they are the primary reef builders. Meeting the objectives of this study would help elucidate the possible main factors that affect their distribution with regards to reef wall orientation and depth.

'Live Coral' cover in relation to wall orientation

An initial important discovery from the results of the benthic community substrate cover was that there was no significant difference found for 'Live Coral' cover from 0-45 m for the East Wall **(Figure 3.1 and Table 3.1)** and in contrast there was a lower 'Live Coral' cover on the West Wall at deeper depths from 30–45 m **(Figure 3.2 and Table 3.2)**. This indicated that the East Wall had an analogous environment for the growth of 'Live Coral' from the surface of the water until to the depths of 45 m and that the environment for 'Live Coral' growth was different between 0–30 m and 30–45 m for the West Wall.

When both Walls were compared **(Figure 3.3 and Table 3.3)**, 'Coralline Algae' was found to be more on the West Wall at 30–40 m ($p<0.001$). The 'Coralline Algae' had replaced the 'Live Coral' at 30–40 m depths on the West Wall as it had a better ability to photosynthesise at lower light levels compared to 'Live corals' (Sorokin, 1993).

It was again found that the ‘Live Coral’ cover was different at 25-30 m and 40-45 m depths between Wall sites ($p<0.05$) where there was more ‘Live Coral’ on the West wall at 25-30 m but more on the East Wall at 40-45 m depth **(Figure 3.3 and Table 3.3)**. This shows that the depth for optimum growth of ‘Live Coral’ differed between Walls and that for the West Wall it was at 25-30 m.

It is hypothesised that orientation of the wall to sunlight and its quality could be the main factor for the difference in ‘Live Coral’ distribution between the Walls. It is known that light quality can change due to many factors e.g. with deeper depth photosynthetic active radiation (PAR) light would be less (Bosscher & Schlager, 1992; Crabbe & D. J. Smith, 2002; Sorokin, 1993), higher turbidity also causes less light and especially for Pulau Perak the shadow effects of corals above another as it is a reef wall. From the works of Crabbe & Smith (2003) where they studied on Reef walls in Southeast Sulawesi and Bosscher & Schlager (1992) where they modelled an accurate simulation of reef growth of the fore reef walls in Belize, they found that light is one of the major controls on reef growth and carbonate production on reef walls. They found that the growth of reef builders such as ‘Hard Corals’ depend on the amount of light available for photosynthesis whereby as light gets less with increasing depth there will be less reef growth. This difference in light quality between walls has yet to be answered and would be the next step in future studies.

Coral morphology in relation to wall orientation

The results thus far were only at a coarse level (e.g. ‘Live Coral Cover’, ‘Dead Coral Cover’). The next step was to achieve more detail for the ‘Live Coral Cover’ using coral growth-forms with regards to depth because certain coral growth shapes are dominant according to their physical environment especially to light quality (Sorokin, 1993;

Veron, 1995; Veron & Stafford-Smith, 2000). In addition coral morphology surveys are important for predicting biodiversity value and fisheries potential for reefs (Edinger & Risk, 2000). They used reef classification by coral morphology to predict coral reef conservation value in Indonesia. By using LIT methods the coral morphology data was collected and classified to conservation classes by using triangular diagrams based on Grime (1977) r-K-S ternary diagrams (r=ruderals, K=competitors, S=stress tolerators). Consequently the conservation classes could then be used as a reliable predictor of coral species richness, habitat complexity, and occurrence of rare coral species. They concluded that the conservation value estimated was more reliable than by just using the reef condition index currently used in Southeast Asia which is live coral cover, or coral mortality. Using the conservation value would better define the reef status and therefore accurately predict biodiversity value and fisheries potential. Their coral morphology triangles and conservation class could also be used to help zone marine protected areas. For this study no triangle was able to be generated as a diversity index (Shannon Weiner) could not be calculated. Therefore it is suggested that future studies should include coral abundance and diversity to at least a genus level to be able to better estimate the reef conservation value of Pulau Perak reef walls.

For the East Wall it was found that there was no difference in their coral growth-form distribution with regards to depth **(Chapter 3.1.4)**. Therefore it is again hypothesized that the environment and light quality is similar enough along the depth gradient for the East Wall so that it has no significant effect on the coral growth-form distribution. Nevertheless **Figure 3.4** indicates that the deepest survey depths of 40-45 m had a dominance of ‘Encrusting’ corals which is a coral growth-form that thrives in low light level areas (Sorokin, 1993; Veron, 1995; Veron & Stafford-Smith, 2000).

For the West Wall there were differences found for the coral growth-forms with depth. It was found that the ‘Branching’ corals were more in the shallows at 5-10 m and was not present deeper than 30 m, the dominance at deeper depths were found to be for the ‘Massive’ and ‘Encrusting’ corals which was dominant at 35-40 m and 40-45 m respectively (**Figure 3.5 and Table 3.4)**. This situation has been regarded as ‘normal’ for coral growth-form distribution according to light quality. ‘Branching’ growth-forms thrives in high light areas (shallow) while ‘Massive’ and ‘Encrusting’ are growth-forms which thrives in low light levels (deep) (Sorokin, 1993; Veron, 1995; Veron & Stafford-Smith, 2000).

The distribution of Plate coral growth-forms for reef walls in Pulau Perak was compared to a normal coral reef such as in the Red Sea (Riegl & Piller, 1997) where they had reported that in clear waters (5-15 m depth) there would be more Massive *Porites* sp Hard Corals and that at low light (>25 m depth) there would be more Plate Hard Corals. Pulau Perak Plate corals were different as they were found at shallower depth of 15-30 m on the East Wall (**Figure 3.4)** and 0-10 m and 20-30 m for the West wall (**Figure 3.5)**. Studies on mesophotic zone coral reefs by Lesser et al. (2010) and Todd (2008) showed that many coral species grew as Plate growth-forms to maximise light capture which is a typical response of a phenotypically plastic nature of corals to decreasing irradiances (light) with depth. This implies that light decrease is slower with depth in Pulau Perak where the water having a lower extinction coefficient (k) of light (this will be discussed later in this section). The other explanation for less Plate corals at depth was to elude self shading that would be detrimental to photosynthesis for the corals (Lesser et al., 2000).

From the comparison of coral growth-forms with depth between Walls **(Figure 3.6 and Table 3.5)** it was shown that some coral growth-forms are different between depth and Walls. For example 'Branching' corals at East Wall was distributed only from 0-10m depth but for the West Wall it was from 0-30 m. This is similar to what was reported by Witman & Smith (2003) in Galapagos reef wall where they documented that the only scleractininan coral found at around 12 m were branching *Pocillopora* sp. but Garpe & Öhman (2003) in Tanzania reported that the reef wall had the lowest proportion of branching substrates at 7-10 m. Whereas for 'Massive' corals at Pulau Perak East Wall it was present down to 15 m but for the West Wall it was present down to 40 m. The 'Massive' corals were more dominant in deeper depths at West Walls and this could be due to their better ability to harness lower light if compared to the East Wall which had a higher light quality at similar depth. This differs from what was observed by Winston & Jackson (1984) in Jamaica where they found that their reef wall was dense with corals and dominated by the foliaceous growth-forms. The actual reason for the significant difference in coral growth shape dominance along Pulau Perak reef wall depth profiles has yet to be tested and therefore needs to be further studied in the future.

In conclusion, Objective 1 of this study has been met whereby it was proven that there is a significant difference between West and East reef wall benthic community substrate cover with regards to their depth profiles. East facing walls seem to be better than the West as it had a consistent live coral cover from 0-45 m depth. In addition this was also found to be true for the coral growth-form distribution.

Substrate cover differences between depths at six wall orientations

The next step in this study was to verify if there was any difference in the substrate cover especially its Hard Corals at two depths, Shallow (10 m) vs. Deep (20 m) on additional four walls. These depths were chosen following the Reef Check method as this time horizontal modified Reef Check transects were used **(Chapter 2.2)**. This is because at the beginning of the study it was presumed that the environment and its reef walls to be similar all around Pulau Perak as it is a small island. From the results in Objective 1 **(Chapter 3.1)** this was found to be untrue. Additional information on indicator fish and invertebrate presence and abundance were also done for the six walls for comparison.

The reef status for both Shallow and Deep depths on the six reef walls surveyed were found to be in the range of 'poor' to 'good' **(Table 3.6)** but interestingly 7 out of 12 reef areas surveyed (Shallow and Deep at 6 Walls) were above the mean percent cover of 42.2% for islands on the east coast of Peninsular Malaysia (Harborne et al., 2000). This demonstrates how relatively pristine Pulau Perak is especially when it is situated in the Straits of Malacca. Nevertheless it is noted that this direct comparison is not entirely correct as Pulau Perak reefs are reef walls compared to the fringing reefs of the east coast islands.

The comparison of the effect of depth (Shallow vs Deep) on substrate cover for the six walls showed that only three walls had differences **(Figure 3.7 and Table 3.7)**. The reason for the three wall reefs (East, West and North Walls) having significantly different substrate cover between Shallow and Deep areas is still unknown but the orientation of the walls to available sunlight is hypothesized to be an important factor. Only the West Wall had a 'Hard Coral' difference between Shallow and Deep where the Shallow area had a lower percentage cover. This could have been caused by physical damage and coral death by the jetty being built on the West Wall **(Figure 1.3 and Figure 2.3).**

The Hard Coral cover comparison between the Shallow depths of the six walls revealed that East Wall Shallow was different to two walls which was the North and North-west walls which had a higher cover of 56.9% and 53.1% respectively **(Figure 3.8)**. It is hypothesised that these were the result of the orientation of the walls to the upwelling phenomenon and is discussed in detail later in this section.

Similarity between the six wall orientations with regard to Hard Coral cover

The cluster dendrogram **(Figure 3.9)** for comparing Hard Coral cover at the six Shallow Walls resulted in dividing them into three groups which is shown in **Figure 4.1** below. Nevertheless the shallow reef wall areas seemed to be divided into a North and South groups. The grouping is speculated to be due to the similarities in their water current, temperature and/or light quality that has affected the Hard Coral cover distribution and is discussed later in this section.

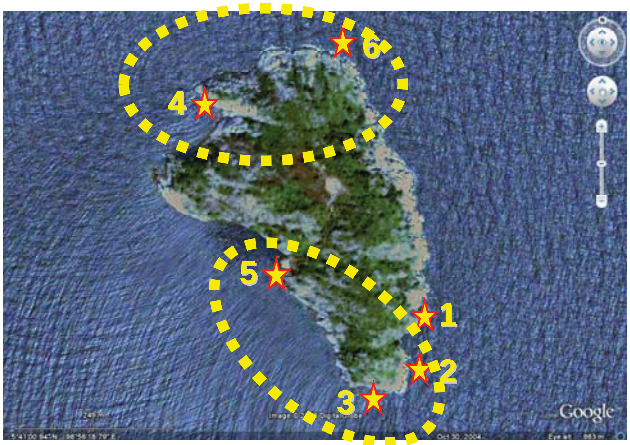

Figure 4.1: Map showing the three groups from the cluster dendrogram of Walls at Shallow depths that had similar Hard Coral cover. The groups were 4=North-west Wall & 6=North Wall, 1=East Wall and lastly 2=South-east Wall, 3=South Wall & 5=West Wall. Map taken from Google Earth.

The Hard Coral cover comparison between the Deep depths of the six walls revealed that East Wall Deep differs from three walls where it was higher than the West and North-west Walls and was lower than the North Wall **(Figure 3.10)**. This further proves that East Wall Deep might be receiving higher light quality of the morning sunlight compared to the West which only gets the afternoon sunlight. In addition the South-east wall also had a higher Hard Coral cover compared to the West and North-west walls.

The cluster dendrogram **(Figure 3.11)** for comparing Hard Coral cover at the five Deep Walls resulted in dividing them into three groups which is shown in **Figure 4.2** below. The grouping shows similar results from Objective 1 **(Chapter 3.1)** that there is a difference between East and West Walls and this could be to the differences in their light quality as they are at deeper depths of 20 m which would be more affected by the shadow of the island itself and cuts off the high quality light of the morning sunlight. This is discussed later in this section.

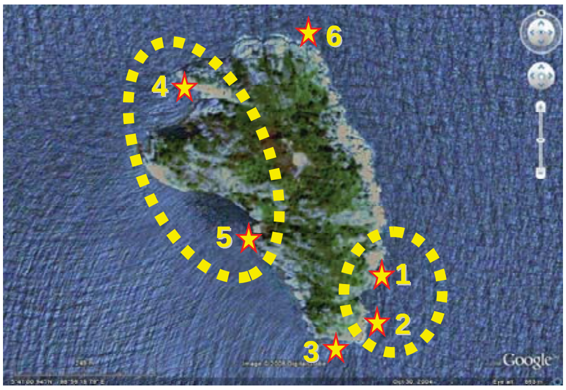

Figure 4.2: Map showing the three groups from the cluster dendrogram of Walls at Deep depths that had similar Hard Coral cover. The groups were 4=North-west Wall & 5=West Wall, , 1=East Wall & 2=South-east Wall and lastly 6=North Wall (3=South Wall data was lost). Map taken from Google Earth.

When comparing between Shallow and Deep Wall sites, it is surprising to know that the grouping of Wall sites is different where for example Wall 4 (North-west Wall) and Wall 5 (West Wall) is similar for Deep but was so different for Shallow areas. This could be due to them being less affected by the islands shadow in the morning and thus getting much better sunlight compared to the deep sites. Further study on the light quality of the six walls is needed to understand and prove this idea of differing light quality.

Similarity between the six wall orientations with regard to Hard Coral cover combined with abundance of indicator fish and invertebrates

The abundance of indicator fish and invertebrates was also done to examine if there would be any difference in the grouping of walls with regards to depth if these two sets of data were to be combined with the Substrate cover data to produce the cluster dendrograms. It is well documented that the fish and invertebrates abundance is correlated to the quality of the reef especially to the Hard Corals (Bergman et al., 2000; Dorenbosch et al., 2007; Edgar, 1999; Garpe & Öhman, 2003; Hodgson et al., 2006; Jackson & Winston, 1982; Kee Alfian et al., 2005).

Indicator fish abundance comparison between Shallow and Deep depths for the six walls showed that only Grouper had significant differences **(Figure 3.12 and Table 3.8)**. Nevertheless it was only for the West Wall where the deeper site had more Groupers. This could be due to the deep area of 20 m had one of the highest Hard Coral cover **Figure 3.7** and also has a very high Live Coral cover **Figure 3.2** with a good mixture of coral growth-forms **Figure 3.5** that the Groupers could use as their habitat.

Indicator invertebrate abundance comparison between Shallow and Deep depths for the six walls (**Figure 3.13 and Table 3.9)** revealed that the South-east wall had differences for Diadema sea urchins and Giant clams where the Shallow area had more of the two organisms. The South Wall was the only other wall that had a difference but this was only for Crown of Thorns (COT) where the Deep area had a higher abundance of the COT. These differences could be due to the fact that for both areas of Shallow South-east and Deep South wall there are ledges at those specific depths and therefore the organism would have a bigger flat area to settle and grow if compared to the reef wall.

The data from the Hard Coral cover, indicator fish and invertebrate abundance for the Shallow Walls were combined, a cluster dendrogram was produced **(Figure 3.15)** and consequently a map showing the three groups is shown below **(Figure 4.3)**. When compared to the cluster dendrogram of just Hard Corals **(Figure 3.9)** there was a difference where 2=South-east Wall is no longer grouped with 3= South Wall & 5=West Wall. This was due to fish and invertebrate density of 2=South-east Wall is more similar to 1=East Wall **(Figure 3.12 and Figure 3.13)**. This shows that combining fish and invertebrate data would change the groupings when compared to just having the Hard Coral cover data alone. It is suggested that the interaction between the substrate, fish and invertebrates needs to be further studied in the future.

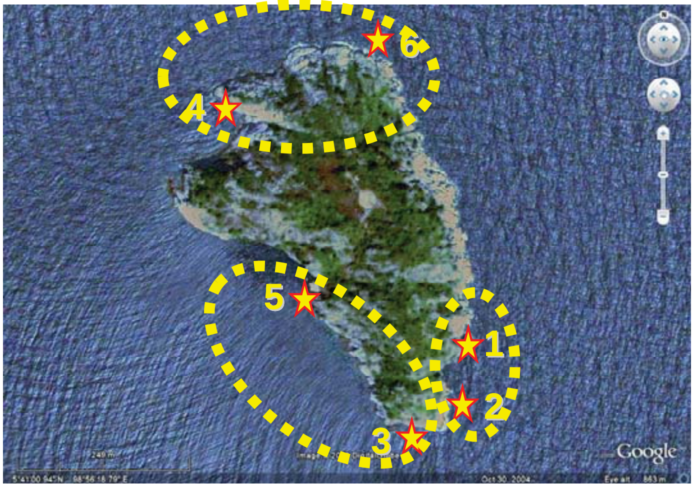

Figure 4.3: Map showing the three groups from the cluster dendrogram of Walls at Shallow depths that had similar Substrate cover and abundance of Fish and Invertebrates. The groups were 4=North-west Wall & 6=North Wall, 5=West Wall & 3=South Wall and lastly 1=East Wall & 2=South-east Wall. Map taken from Google Earth.

The data from the Hard Coral cover, indicator fish and invertebrate abundance for the Deep Walls were combined, a cluster dendrogram produced **(Figure 3.14)** and consequently a map showing the three groups is shown below **(Figure 4.4)**. When compared to the cluster dendrogram of just Hard Corals **(Figure 3.11)** there was no difference in the groupings. Therefore Deep areas were more similar if compared to the Shallow areas **(Figure 4.2 and Figure 4.3)** when Hard Coral cover, fish and invertebrate data were combined compared to when only Hard Coral cover data was used. The reason for this needs to be further studied in the future.

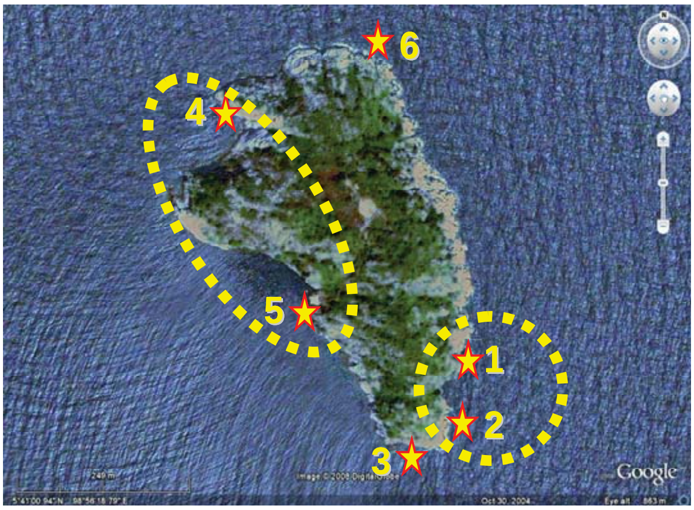

Figure 4.4: Map showing the three groups from the cluster dendrogram of Walls at Deep depths that had similar Substrate cover and abundance of Fish and Invertebrates. The groups were 4=North-west Wall & 5=West Wall, 1=East Wall & 2=South-east Wall and lastly 6=North Wall (3=South Wall data was lost). Map taken from Google Earth.

In conclusion, Objective 2 of this study has been met whereby it was proven that there are significant differences between the six walls around the island with regards to their orientation to sunlight and also with regards to the depths. In addition this was also found to be true when indicator fish and invertebrate densities were included especially for the Deep reef walls.

Possible effects of sea water temperature

The effect of sea water temperature at Pulau Perak to the distribution of Hard Corals, fish and invertebrates between depths and reef walls is yet unknown. It is speculated that sea water temperature between reef walls has only slight differences and not have a significant effect especially on the Hard Coral distribution as the island is small.

Edmunds et al. (2010) coral recruitment study in Moorea, French Polynesia supports this, as even though they documented their sites having variation in mean daily sea water temperature, it did not relate to coral recruitment. Nevertheless their study sites recorded a variability of only <0.9^{o} C compared to Pulau Perak which could have a greater temperature range during upwelling periods. They hypothesised that coral recruitment is more likely to be influenced by the interaction of factors especially seasonal variation in wave and current exposure. Therefore we need to understand Pulau Perak currents throughout the year and compare between monsoon seasons and also during upwelling and non-upwelling periods.

Sea water temperatures between shallow and deep depths have also been found to be relatively insignificant (Lesser et al., 2010). They reported that even though temperature differences between depths could have an affect on productivity rates, the changes in temperature with depth are relatively insignificant. They recorded only ~4^{o} C change from 0-90 m depth. This study in Pulau Perak only had a maximum depth of 45 m and therefore temperature is assumed to not have a significant effect on the biota. An exception might happen during upwelling periods where the temperature change could be significant (Witman & Smith, 2003).

Possible effects of hydrodynamics

The hydrodynamics of Pulau Perak has yet to be studied but it is speculated that due to the bathymetry **(Figure 1.2)** and the existence of upwelling in the area, the Northern part of the island would be more exposed to repeated strong currents by the upwelling compared to the South part. Therefore from **Figure 3.9 and Figure 4.1** they showed that by using Hard Coral Cover data the Shallow six sites were basically grouped into North & South groups. It is speculated that the difference of Hard Coral cover between

North and South reef walls could be due to the different hydrodynamics between the sites due to wave action, water current and upwelling currents. The Hard Coral cover could also be different due to the North reef wall corals are less tolerant of rare temperature anomalies due to them being acclimated to less background stress through long term exposure to the high water flow (McClanahan et al., 2005).

An interesting study by Rojas (2010) in Bunaken Island, North Sulawesi found six different sites that could be identified, according to their geographic location and coral diversity pattern. His study was similar to this Pulau Perak study where the most remarkable differences were found between the areas facing the east and west, with higher diversity to the east. Nevertheless he explained this could be due to the anthropogenic effects especially more tourism activities on the west facing reef wall. However he further explained that it could also be due to the ocean current that flows from west to east whereby the west reef wall being more exposed to stronger water currents.

It is suggested that for Pulau Perak future studies on hydrodynamics not only look at the horizontal currents but also the vertical currents especially due to the upwelling from deep depths. We suggest that temperature loggers and water current profilers are deployed at various depths around Pulau Perak as strong upwelling can be documented such as by Witman & Smith (2003) where they observed a rapid temperature decrease of 3-9^{o} C and water currents showing variable durations of 2-111 minutes and maximum velocities of 32.3 cms^{-1} on their reef wall study sites in Galapagos.

Possible effects of upwelling

Studying upwelling at Pulau Perak is a rare chance as Peninsular Malaysia has no records of other coral areas experiencing upwelling even on its east coast.

The upwelling in the area of Pulau Perak is due to the unique topology of the straits where the mountain ranges of Peninsular Malaysia and Sumatra Island acts as a monsoon windshield during the northeast monsoon (Tan et al., 2006). They studied the influences of Asian monsoon on chlorophyll a (chl a) in the Straits of Malacca using Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data. They found that during the northeast monsoon (NEM) of November until March each year, the monsoon wind will strongly influence the spatial distribution and seasonal variation of the chl a at the northern Straits of Malacca where Pulau Perak is situated. A phytoplankton bloom will form and moves towards the Andaman Sea. The NEM wind creates positive wind stress curl which causes a positive Ekman pumping resulting in an upwelling in the area of Pulau Perak. This upwelling brings nutrients to the surface water and maintains the bloom over the continental shelf. The SeaWiFS chl a increases as much as twice during this time and would engulf Pulau Perak during December to March of each year **(Figure 4.5)**.

Upwelling during the four months from December to March at Pulau Perak plus its interaction with the islands shape and hydrodynamics around the island is speculated to create different environments on different walls and depths. This would also affect how the corals are distributed and grow on them. Could this yearly phenomenon of about four months have affected the coral distribution and growth on the walls of Pulau Perak?

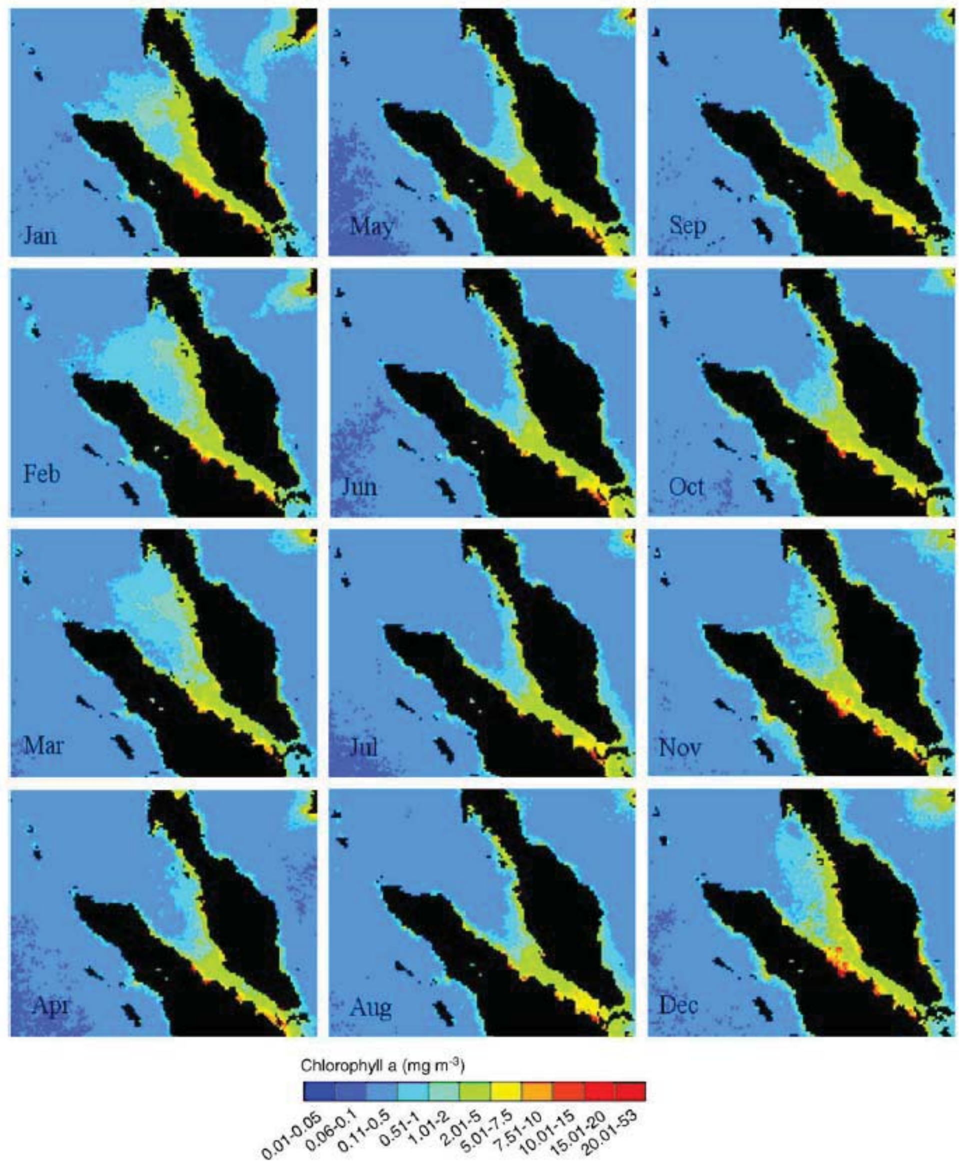

Fig. 2. Monthly composite of SeaWiFS chl *a* ($mg\,m^{-3}$), 1998–2002.

Figure 4.5: Monthly composite of SeaWiFS chl a (mg/ml^3), 1998–2002 where it can be seen that the upwelling phenomena at Pulau Perak is from Dec- Mar. (Taken from Tan et al., 2006)

The higher plankton abundance and would have an effect on the turbidity and therefore light quality to the corals on the reef walls of Pulau Perak. The waters around Pulau Perak will turn green (personal observation) and it is presumed that the underwater PAR light would decrease. This would affect the corals either by changing their zooxanthellae density or chlorophyll content and ultimately their growth and distribution along the depth gradient. Upwelling events can also carry nutrient rich (e.g. nitrate) cold water with high concentrations of zooplankton (Leichter et al., 2006; Lesser et al., 2010). Upwelling is an important mechanism of bottom-up forcing and can affect the composition and dynamics of benthic communities (Gili & Coma, 1998), as well as the growth of corals at mesophotic depths (Leichter & Genovese, 2006). However Lesser et al. (2010) did not observe any related growth of the Hard Coral *Montastrea cavernosa* with upwellling and the intrusion of deep cold water to mesophotic depths. Nevertheless it is hypothesised that the effect on corals would be different at each wall site as currents will bring the plankton and extra nutrients to different walls differently. This could explain the differences of substrate and Hard Coral cover between reef walls at Pulau Perak.

From **Figure 3.8 and Figure 4.1**, the Hard Coral cover comparison at Shallow depths revealed that the North and North-west walls had a higher cover of 56.9% and 53.1% respectively. This could be explained by the upwelling phenomenon that may have more impact on the northern reef walls of Pulau Perak. This is supported by work done by Leichter et al. (1998) off the Florida Keys, which found that growth of the Hard Coral *Madracis* sp was higher at the depth where upwelling from internal tidal bores was most frequent. Also since upwelling areas are usually characterized by high primary productivity, there is a potential effect of upwelled productivity on species diversity (Rosenzweig, 1995). This is further supported by the study at Rocas Gordon in the Galapagos Marine Reserve (Witman & Smith, 2003) where they found that at tropical upwelling sites the turnover of diversity and biomass may be unusually rapid. They even documented a rapid doubling of species richness within a year (1999-2000) in the subtidal sessile invertebrate community of a reef wall exposed to strong upwelling. Their reef wall diversity change was accompanied by an increase in percent cover, density and/or biomass of sponges, barnacles, ascidians and a non-reef building (ahermatypic) coral *Tubastrea coccinea*. The species richness of bryozoans, ascidians and corals increased by a factor of two or more. They suggested that species richness increased primarily by the recruitment of larvae or asexual propagules over only one year. Any acute effect on the growth rate and distribution of corals by the upwelling remains to be studied in Pulau Perak.

In contrast to the previous rapid rates reported above (Witman & Smith, 2003), a six year study of tropical reef walls had showed no change in species density in St. John, US Virgin Islands (Witman, 1992). Furthermore Glynn (1977) had reported the opposite where he compared the Hard Coral *Pocillopora* sp growth in upwelling versus non-upwelling regions off the west coast of Panama. Their growth rates were significantly lower in the upwelling region. However on normal coral reefs in North Pacific (Colgan, 1987) and Red Sea (Loya, 1990), species richness and diversity are able to return to pre-disturbance levels in 5-6 years.

The differences in rates of diversity increase and recovery between reef walls and normal coral reefs reflects the fundamental differences in rates of recruitment of the taxa dominating tropical reef walls such as in Pulau Perak versus normal coral reefs. For example, Jackson (1983) had suggested that sponges, ahermatypic corals, hydroids, bryozoans, polychaetes, molluscs, and ascidians recruits faster to natural hard substrate found on reef walls compared to Hard Corals. Therefore for future studies it is recommended that any upwelling studies on Pulau Perak reef walls should have a comparison study site on a nearby normal coral reef such as in Pulau Payar or Pulau Langkawi to further understand their differences in ecology.

Possible effects of light

It is hypothesised that the differences in all the biotic fauna between the reef walls at Pulau Perak is due more to their orientation to sunlight rather than other environmental factors such as temperature, hydrodynamics and upwelling.

There have been many studies on the environmental factors that can influence the ecology, physiology and morphology of scleractinian Hard Corals. These factors include temperature (Coles, 1988; Meesters & Bak, 1993), water motion (Dennison & Barnes, 1988; Jokiel, 1978), salinity (S. L. Coles & P. L. Jokiel, 1978), dissolved oxygen concentration (Coles & Jokiel, 1978), and also light quality (Falkowski et al., 1990) and quantity (Barnes & Chalker, 1990; Falkowski et al., 1990). Although Hard Corals respond to the factors mentioned above, light plays a key role in coral ecology (Veron, 1995). Light can affect coral settlement, movement (Maida et al., 1994; Mundy & Babcock, 1998; Yamashiro & Nishihira, 1995) and competition with other organisms (Baynes, 1999). The most important is that light enables photosynthesis and calcification of the symbiotic Hard Coral- zooxanthellate complex (Chalker et al., 1983; Falkowski et al., 1990; Ferrier-Pagès et al., 1985; Hidaka, 1988; Igleasias-Prieto & Trench, 1997; Ilan & Beer, 1999; P L Jokiel, 1986; Romaine et al., 1997). Light also plays an important part of coral productivity, physiology and ecology (Falkowski et al., 1990) and usually limits coral distribution to 60m depth.

In theory, light decreases exponentially with depth, which results in equal amounts of light received at any point within the same depth facing the same direction. Gattuso et al. (2006) reported that changes in solar radiation with increasing depth which is basically a change in both irradiance and spectral quality, is the primary abiotic factor which affects the productivity and distribution of benthic photosynthetic organisms.

This is also true for zooxanthellate corals in particular (Dustan, 1982; Falkowski et al., 1990; Frade et al., 2008; Wyman et al., 1987) . Present reef builders such as Hard Corals growth largely depends on the quality of light available for photosynthesis. Reef growth decreases with depth as light decreases (Bosscher & Schlager, 1992; James & Ginsburg, 1979; Schlager, 1981).

Even though reef corals can grow down to water depths that has 1% of surface irradiance (Chalker et al., 1988), this is the lower limit of the euphotic zone and is the depth where photosynthesis (primary production) equals respiration also known as the 'compensation depth' (Jerlov, 1976). The amount of light penetrating the water column depends on extinction coefficient (k) of PAR (Photosynthetically Active Radiation) in the water (Bosscher & Schlager, 1992). This means that different reefs would have different 'compensation depths' using this parameter. It was reported that for Belize reef it was 90-100 m with the k=0.05 m^{-1} and that mixed reef growth was <40 m (Done, 1983; James & Ginsburg, 1979) whereas k=0.035 m^{-1} for the Pacific atolls and thus the lowest limit for coral growth there was 140 m and the best reef growth was 70m (Bosscher & Schlager, 1992). Lesser et al. (2010) found that for the reefs at Lee Stocking Island, Bahamas it had downwelling irradiance of PAR (K_{dPAR}) for the water column similar to as Belize Reef of 0.05 m^{-1}. Nevertheless it had the midpoint of the euphotic zone at 40m and the compensation depth of 81m. From this study in Pulau Perak it is speculated that the 'compensation depth' seems to be much deeper than the maximum study depth of 45 m as Hard Corals are still found in abundance at 45m and the best reef growth were at < 30 m **(Figure 3.1 and Figure 3.2)**.

The availability of light limits the depth distribution of corals, where turbidity and sedimentation, which are both proxies for light, can have marked effects on their growth

(Crabbe & Smith, 2002; Meesters et al., 1998; Sorokin, 1993) and morphology (Crabbe & Smith, 2002; Kaandorp, 1999; Meesters et al., 1998; Sorokin, 1993). A coral colony would have physiological consequences and require morphological adaptations to maximize light capture if there any change in the amount of light received by the colony (Graus & Macintyre, 1982).

In addition, lower growth rates and morphology change in Tabulate *Acropora* sp Hard Corals has been reported when it is exposed to lowered light levels and increased sedimentation/turbidity. The corals would grow vertical earlier whereas in better light condition they would be more tabulate with only their final growing points growing vertically (Crabbe & Smith, 2003). They even found that the Massive corals are affected by low light levels where radial growth rates of Massive corals (*Porites* sp., *Favites* sp. and *Favia* sp.) were significantly lower at lower light levels with high turbidity. Further studies on mesophotic zone coral reefs have found that the corals go through a photo acclimatization process where the photosynthetic machinery is reorganized to maximize light collection. This could involve the expression of fluorescent pigments, replacement of genetically distinct zooxanthellae along the light gradient and changes in coral morphology (Falkowski et al., 1990; Frade et al., 2008; Lesser et al., 2010; Sampayo et al., 2007; Schlichter et al., 1986; Todd, 2008; Wyman et al., 1987). Changes of this kind on Pulau Perak corals have yet to be studied.

Liddell et al. (1997) reported on the percent cover and species diversity of reef communities down to a depth of 250 m where they showed a distinct bathymetric zonation pattern with coral cover of 3–23% at depths shallower than 50 m and subsequent decreases in coral cover with increasing depths. In contrast, the percent cover of sponges increased with increasing depth. They deduced that the decrease in light (irradiance) with increasing depth was one of the most important factors affecting the community structure of the deep reef systems. This was similar to the findings of this study in Pulau Perak **(Figure 3.2 and Table 3.4)** where it was found the Sponge distribution was a significant different between the deeper areas (40-45 m) compared to (5-10 m and 20-40 m).

It was shown from the results of this study that photosynthesising organisms such as ‘Hard Coral’ would thrive on East facing walls compared to West facing walls. Vermeij & Bak (2002) showed that there is a difference in light quality depending on the angle of the sunlight **(Figure 4.6)** and for the reef walls of Pulau Perak the light quality is expected to be very different as they have different orientations to the sun. In addition it has been reported that the quality of light in the morning and in the afternoon are different with regards to PAR quality (Brown & Dunne, 2008; Sorokin, 1993) so that the East facing reef walls would be better for photosynthesising organisms compared to the West facing reef walls. This could help explain the difference in West and East reef walls from Objective 1 and 2 previously.

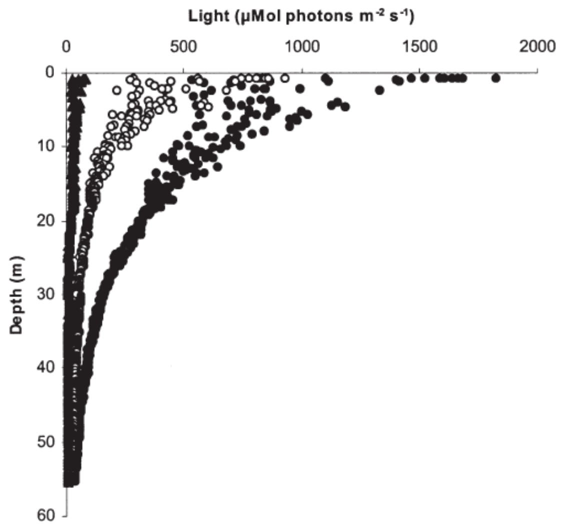

Fig. 2. Light gradient measured on May 6, 1998, at Buoy 1, Curaçao. Different markers indicate light coming from different directions. (●) The light coming in straight from above ($\alpha = 0°$). (O) The light coming from aside towards the reef in a 90° angle with the light coming from above ($\alpha \approx 90°$). (▲) The light coming from below, reflected by the reef ($\alpha = 180°$). All measurements in μmol photons m^{-2} s^{-1}

Figure 4.6: Graph showing the light gradient with depth when the light source is from different angles. (Taken from Vermeij & Bak, 2002)

The effect of orientation to sunlight by corals was studied by Lau et al. (2009) where they showed that Hard Coral physiology differed with regards to which jetty pillar they grew on **(Figure 4.7).** The pillars had different orientation to sunlight and therefore were exposed to different light quality. Jetty pillars are similar to reef walls as they do not have low gradient slopes as normal reefs do. Even though they did not find any coral cover difference when comparing pillar orientation as this study did for reef walls, they did find that the Hard Coral *Cyphastrea japonica* had a higher zooxanthella density at a higher light level pillar orientation. It is noted that they were only working in shallow waters of less than 15 m while Pulau Perak corals are present down to 45m. Therefore it can be implied that Pulau Perak Hard Corals would also have at least some different physiology between walls and depths which could then affect their distribution and abundance.

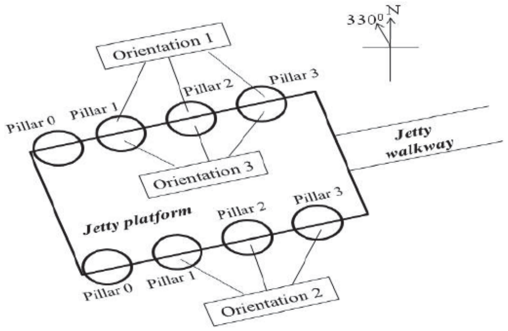

Figure 1: Schematic diagram showing the position of all three orientations Orientation 1 (OR1), Orientation 2 (OR2) and Orientation 3 (OR3) and their bearing. Only the Pillars 1, 2 and 3 were studied because the Pillars 0 were more exposed to sunlight compared to the other pillars which had smaller sunlit area.

Figure 4.7: Schematic diagram showing the jetty pillar orientation in the pillar jetty study. (Taken from Lau et al., 2009).

The most relevant study on orientation to sunlight for what was observed for Hard Coral distribution and abundance on Pulau Perak reef walls is the report by Brown & Dunne (2008) in Phuket, Thailand. They took cores from the East and West side from a shallow water Massive *Goniastrea aspera* Hard Coral and then exposed them to a combined elevated sea temperature and high solar radiation. They found that coral cores from both East and West had no significant difference in their response to elevated temperature but when they were experimented with additional light the East facing cores reacted differently. The East cores fared worse than the West cores in zooxanthellae loss and in photoinhibition. They speculated this was due to West side having a prior experience of being exposed to higher natural solar radiation PAR throughout the year (Afternoon Sun) compared to the East (Morning Sun), and therefore had a greater tolerance to the effects of elevated temperature and solar radiation. The protective influences of solar radiation on the west faces of hemispherical *Goniastrea aspera* colonies have also been described in earlier work by (Brown, Downs, Dunne, & Gibb, 2002; Brown, Dunne, Goodson, & Douglas, 2000, 2002; Brown, Dunne, Scoffin, & Le Tissier, 1994). This is the opposite to what was seen for Pulau Perak where the

East facing reef wall fared better than the West by having a better Hard Coral cover down to 45 m depth compared to the West that had less from 30-45 m **(Figure 3.1 and Figure 3.2)**. However it should be noted that their corals are taken from a shallow 5m coral reef compared to Pulau Perak which is significantly much deeper, a reef wall and has shadow effect from the island. A shallow reef flat has virtually no shadow effects. Furthermore their exposure experiment was done in a controlled lab environment and might not reflect what happens in the field when exposed to natural sunlight. However, Brown & Dunne (2008) found that the Fv/Fm (photosynthetic ratio) of the coral was consistently lower in West side cores compared to the East at the beginning of their experiments. They explained that this difference was due to natural field conditions. This means that in the field, the West side has a lower Fv/Fm compared to the East side. Consequently this showed that the East side is photosynthesising better compared to the West side and therefore growing rates should be higher for the East side in natural field conditions. This could mean that the Morning sun is better in the field and therefore could explain what was observed on the East reef wall of Pulau Perak. Nevertheless Brown & Dunne (2008) found that at high PAR doses, there was a greater reduction in Fv/Fm in the East compared to the West cores. They concluded that, zooxanthellae from West sides had a background tolerance and an improved photoacclimation ability compared to those from the East sides of coral colonies. This remains to be investigated for Pulau Perak corals.

The above finding is further supported by Vermeij & Bak (2002) study where they documented that the coral populations distribution are structured by light regimes. They studied six species of *Madracis* sp corals on a reef slope from 5-50 m and found that there were three strategies of response to light by the coral species:

Strategy 1 was where species strive for maximum light capture and colonies occur above a threshold light value. This limited their distribution to shallow waters (< 15 m). Strategy 2 was where species strive for maximum light capture but all colonies occured below a threshold light value. Species occurred only on the deeper parts (> 30 m) of the reef slope. For both 1 & 2 strategies their colony morphological variations were unrelated to variation in the amount of light the colonies received.

Strategy 3 was where species prefer low light habitats. Species were found on the entire reef slope and they showed a bimodal light preference. These species showed morphological variation in colony shape related to light availability.

Vermeij and Bak found that even small scale differences in the light environment along the deep fore reef could affect zooxanthellate coral distributions. They concluded that depth and light are only correlated as ecological factors for species that strive for maximum light capture (Strategy 1 or 2). It is not known what strategy the Hard Corals of Pulau Perak uses and this is what needs to be determined for future studies.

Nevertheless it is important to note that Vermeij and Bak did their study of corals on a reef slope and not a reef wall as at Pulau Perak and therefore the coral strategies could be different than the three that was given. Reef walls of Pulau Perak has more factors to be considered such as shading effects by corals above them, the angle of light as mentioned previously and also the shading by the entire island above the water. It is assumed that since the island has a near vertical cliff face it would cast a significant shadow on the reef wall below it **(Figure 1.2, Figure 1.3, Figure 1.4 and Figure 1.5)**. This would in turn affect the reef growth, its community structure and the response strategy of the corals towards light availability.

In conclusion, it is hypothesised that most of the significant differences in the study were due to the orientation of the reef walls to sunlight and therefore its light quality. It is recommended that this hypothesis be further tested in future studies.

Pulau Perak reef walls are considered unique as it is regarded a pristine reef for Peninsular Malaysia and more so for being in the Straits of Malacca. It is the only known ‘reef wall’ in Peninsular Malaysia and yet has scarce scientific data. To conserve this unique reef wall a comprehensive sustainable development plan has to be formulated. The plan can be achieved if:

i) Sufficient baseline studies are done
ii) Relevant scientific information are given to decision makers and politicians
iii) The uniqueness of the reef should be highlighted in the mass media
iv) The present military personnel stationed on the island are used to assist in its management
v) Sustainable sport fishing and SCUBA diving activities are regulated by the issuing of licenses etc.
vi) Sustainable commercial fisheries practices are promoted and illegal long line fishing is stopped
vii) Any new development is limited and managed using ‘Limits of Acceptable Change’ principles
viii) Ultimately to gazette Pulau Perak and its surrounding waters as a Marine Protected Area

It is hoped that this study would be able to assist in these above matters especially items (i) – (iii)

5.0 CONCLUSIONS AND RECOMMENDATIONS

Objective 1 of this study has been met whereby it was proven that there is a significant difference between West and East facing walls benthic community substrate cover with regards to their depth profiles. East facing walls seem to be better than the West as it had a consistent live coral cover from 0-45m depth. In addition this was also found to be true for the coral growth-form distribution.

Objective 2 of this study has been met whereby it was proven that there are significant differences between the six walls around the island with regards to their orientation to sunlight and also with regards to the depths. In addition this was also found to be true when indicator fish and invertebrate densities were included especially for the Deep reef walls.

It is hypothesised that most of the significant differences in the study were due to the orientation of the reef walls to sunlight and therefore its light quality. It is recommended that this hypothesis be further tested in future studies. All the hypotheses above can be tested in the future is by placing underwater PAR light loggers at various depths at each of the six walls studied to document any differences in their light regimes and consequently correlate with the biological data from Objective 1 and 2.