Patterns in the Distribution of Coral Communities in Inshore and Offshore Locations in the Southern Andaman Sea of Thailand

Aorn Sillapasathitwong

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Ecology (International Program)

Prince of Songkla University

2016

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I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

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ABSTRACT

Coastal waters in most parts of the world tend to have a higher nutrient concentration and amounts of suspended terrigenous sediment than waters further from the coast. Where terrestrial influences are less, reefs tend to experience lower amounts of resuspended sediment and thus are surrounded by clearer waters; assuming that terrigenous influences diminish with distance from the mainland. However, with few exceptions, reefs in Thailand are fringing reefs around continental islands, whether inshore or offshore. Here, this study aims to define spatial variations in coral communities and a diagnostic suite of community characteristics relevant to habitat type; coral community compositions may result from the different environmental and physical factors inshore and offshore habitats.

I found that coral assemblages in the southern Andaman Sea comprise two basic types: inshore and offshore reef types. The differences in coral assemblages were associated with water turbidity and distance from the mainland obviously. The inshore coral assemblages tended to be characterized by higher numbers of coral genera *Pectinia*, *Montipora* and *Podabacia* compared to reefs around offshore islands. Offshore reefs were characterized by a relatively high number of *Lobophyllia* and *Plerogyra* as well solitary Fungiid corals. The expected relationship between water quality and sensitive indicator groups like *Acropora* did not materialize, with *Acropora* being more common inshore. Coral replenishment in the southern Andaman is highly variable over space and time. The juvenile abundance tends to be higher in the turbid inshore reefs than the offshore reefs, but only one from two years study showed a significant difference. There was high variability in colony number and composition of juvenile corals across the reef stations. Total juvenile abundance was significantly different between the years, which suggests inconsistency in coral replenishment in this area. Adult and juvenile coral populations across the reef stations were decoupled; this indicates a disconnection between recruitment and community composition that suggests that coral population in the southern Andaman Sea probably relies on outside sources and have low levels of larval retention at the reefs. While there are strong inshore - offshore reef habitat differences in environmental conditions, reef communities and replenishment in southern Thailand, they are not consistent with expectations from the literature. These findings are important background information for management of marine protected areas based on the ecological knownledge and can be background information for predicting the reaction of a coral community to indicate terrestrial influences or monitor the environmental change of reef.

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CHAPTER 1

General Introduction and Review of Literature

1.1 Introduction

Coastal waters in most parts of the world tend to have a higher nutrient concentration and amounts of suspended terrigenous sediment than waters further from the coast. Where terrestrial influences are less, reefs tend to experience lower amounts of resuspended sediment and thus are surrounded by clearer waters (Boyer and Briceño, 2006; Cooper *et al.*, 2007; De'ath, 2007; Devlin and Brodie, 2005). Fundamental differences of inshore - offshore reef habitats have been examined by several studies in different regions, including the Great Barrier Reef, Caribbean Sea, and Florida reefs (Adjeroud *et al*., 2010; Done, 1982; Fabricius *et al*., 2012; Lirman and Fong, 2007; Smith *et al*., 2008). Differences in reef community composition and structure are often attributed to gradients in water quality (Cleary *et al.*, 2006; Done, 1982; Fabricius *et al.*, 2012; Smith *et al.*, 2008). As such, it is expected that the composition and nature of coral communities will change along a gradient of water quality associated with distance from mainland sources of sediment and nutrients.

These studies mostly examined lagoonal systems behind barrier reefs or atoll reef systems, but the reefs around Southeast Asia region are mostly unlike the reefs described in those studies, being continental island fringing reefs. This means the usual model of inshore/offshore systems, which assumes terrigenous influences diminish with distance from the mainland (Adjeroud *et al.*, 2010; Boyer and Briceño, 2006; Cleary *et al.*, 2008; Cooper *et al.*, 2007; Done, 1982; Fabricius, 2005), may be inappropriate for the Thai context. Reefs in Thailand are fringing reefs around continental islands (Department of Fisheries, 1999); whether inshore or offshore, reefs are still exposed to some level of terrestrial influence (Phongsuwan *et al.*, 2013). Therefore, studies of the literature of inshore and offshore reef systems in the other regions might create a false expectation of the nature of reef systems in Thailand.

The southern Andaman coast of Thailand consists of numerous tributaries and mangrove channels south of the Trang River, that drain to the coastal waters (Royal Thai Survey Department, 1997). They are sources of terrigenous sediments and nutrient that create siltation and nutrient enrichment in the coastal water; and decreased when further from the coast. The coral reef habitat in this region is fringing reefs around high continental islands, which are located some distance from the mainland. The reefs lie in the same latitude along an approximately 70 km east-west transect. Hypothetically, they are influenced by a gradient of terrigenous and nutrient concentration, decreasing from east to west as distance from the mainland increases.

That the reefs both near the mainland and further away are fringing reefs around high islands in a monsoon climate (and that the terrestrial areas of the islands consist of evergreen forests, waterfalls and streams that flow to the island coastal waters) suggests that the strong gradients found in overseas studies might be somewhat muted in the Thai system. There are many general assumptions or truisms about the characteristics of the inshore and offshore systems that may not, in fact, be valid; for instance, we hear that “offshore reefs have more *Acropora*”, “inshore reefs are mainly *Porites*”. According to these truisms most of the reef communities in Thailand which are dominated by *Porites* will tend to be inshore reef. Therefore, a large part of this study targets these broad assumptions, and tests them against observable data.

This study aims to define spatial variations in coral communities and a diagnostic suite of community characteristics relevant to habitat type; coral community compositions may result from the different environmental and physical factors inshore and offshore habitats. This partly redressed the current lack of ecological knowledge about the key characters of reef habitats in the southern Andaman Sea of Thailand, and suggested potential relationships between reef environments and coral communities that will provide key insights for protected area management planning in this area.

1.2 Literature review

1.2.1 How to categorize the inshore and offshore locations?

In general, inshore means "near or towards the coast" and offshore means "away from or at a distance from the coast". Therefore, discussions concerning inshore and offshore reef habitats typically are about a distance from the coast or mainland that alters level of terrestrial influence. Proximity to terrestrial influences can substantially alter the environment of a coral reef across the distance from the mainland (Done, 1982; Fabricius, 2005; Cooper *et al*., 2007; Lirman and Fong, 2007; Fabricius *et al*., 2012; Schaffelke *et al*., 2012). A large amount of terrestrial runoff from the adjacent catchments leads coastal waters to elevated nutrient concentrations, terrigenous sediment, suspended sediment, dissolved matter, and particulate matter into coastal waters (Fabricius, 2005; Schaffelke *et al*., 2012). Also, the high nutrient levels are reflected by increased phytoplankton biomass, which reduces light transmission through the water column (Fabricius, 2005). All these parameters are decreasing further offshore; nutrient and sediment levels tend to be lower and light transmission parameter are inversely related with nutrient and sediment level (Fabricius, 2005; McCook, 2001; Cooper *et al*., 2007; Lirman and Fong, 2007; Fabricius *et al*., 2012; Schaffelke *et al*., 2012). Further from the mainland, the water column tends towards lower nutrient concentration and lower suspended matter counts that reduce turbidity in the water column, so that it is clearer than the coastal waters (Schaffelke *et al*., 2012). These broad trends in water quality descriptors have been used often to characterize inshore and offshore environments.

1.2.2 Effects of terrestrial influences on ecological processes of corals

Terrestrial influences reflect a variety of inputs of dissolved inorganic nutrients, particulate matter and terrigenous sediment. These inputs also increase water turbidity which are known to affect the nature and composition of coral communities (Fabricius, 2005). Dissolved inorganic nutrients can affect the viability of individual corals in several ways, such as decreasing calcification (Marubini and Davies, 1996; Kinsey and Davies, 1979), reducing fertilization (Harrison and Ward, 2001; Lam *et al.*, 2015), and larval settlement (Ward and Harrison, 1997). These are causes of increased mortality and reduced reproduction of corals. Fabricius (2005) suggested these results are long term exposure to high nutrient concentration, but the dissolved inorganic nutrients in the nature can be disappeared quickly. Therefore, dissolved inorganic nutrients are probably not stay in the reefs for long in natural situation, except some location which exposed to chronic disturbance from an effluent. Terrigenous sediment consists of many types of sediment that can be considered as stressor as well as a food for corals (Anthony, 1999). The sedimentation imposes multiple stresses on coral by shading or smothering and also inhibit recruitment processes (Hubbard, 1997). Sediment smothering disrupts coral energy budgets by requiring expenditure on such processes as mucus production, sediment clearance and can impair feeding (Erftemeijer *et al*., 2012); also, the high sedimentation in reefs has been shown to decrease coral larval settlement success and survival (Babcock and Smith, 2000; Birrell *et al.*, 2005; Erftemeijer *et al.*, 2012). Suspended sediments can reduce available light and decrease quality of light spectrum for photosynthesis (Richmond, 1993), while it can be a food source in particle feeding of corals, especially corals in turbid waters (Anthony, 1999). Light is primary energy source for photosynthesis of the symbiotic zooxanthellae in coral tissue. Light irradiance importantly controls the reef development (Hubbard, 1997), and several water quality factors associated with light irradiance were related with the maximal reef depth (Cooper *et al.*, 2007).

1.2.3 Association of community composition with water quality

Associations between coral community characteristics and a gradient of terrestrial influence emphasizes the notion that spatial variability in certain characteristics of coral communities can be attributed to reef locations associated with different environmental conditions. Typically, it is reported that a coral community shows variation in coral reef characteristics between the inshore - offshore reefs assuming that terrigenous influences diminish with distance from the mainland, so these revealed a response of coral assemblages to terrestrial influence. The richness of coral species tends to be lower in coral communities adjacent to the terrestrial influence compared to the farther reefs; a trend that was consistent in the Great Barrier Reef (Fabricius *et al.*, 2012; Done, 1982) and Indonesia (Cleary *et al.*, 2005). The hard coral cover was less consistent, however; there is generally a lower amount of live coral cover in the inshore reefs in places such as the Great Barrier Reef (Done, 1982; Fabricius *et al.*, 2012), Indonesia (Cleary *et al.*,

2008) and the US Virgin Islands (Smith *et al.*, 2008). Interestingly, the Florida key reefs showed the reverse trend - with the highest coral cover in the inshore reefs, decreasing significantly in the farther reefs (Lirman and Fong, 2007).

On the Great Barrier Reef (GBR), community composition of reefs adjacent to the mainland was dominated by species of *Goniopora*, *Montipora*, *Galaxea*, *Porites* (Done, 1982) and *Turbinaria*. (Fabricius *et al.*, 2012), whereas the communities distant from the mainland tended to be dominated by *Acropora* spp. (Done, 1982; Fabricius *et al.*, 2012). These workers also reported that *Lobophyllia*. cover was related to good water quality in the reefs distant from the mainland (Fabricius *et al.*, 2012).

Hard coral replenishment is something that is difficult to reconcile with distance from shore, even though Koop *et al*. (2001) report that nutrient enrichment predicates poor recruitment and Birrell *et al*., (2005) report that sediment reduces coral settlement. In the GBR, hard coral juveniles were recruited at relatively low richness and density in the reefs located closer to the mainland, with a non-linear trend of increase in the reefs further from the mainland (Fabricius *et al.*, 2012). However, studies in the New Caledonia reported no spatial variation in juvenile coral abundance which corresponded to distance from terrigenous inputs (Adjeroud *et al.*, 2010). In the Florida Key reefs Lirman and Fong (2007) reported a contrasting pattern in coral recruitment between 2 years, and that coral recruits were higher on the offshore reefs in the first year and higher on the inshore reefs in the second year.

1.2.4 Reef habitats in the Andaman Sea of Thailand

Coral reefs in the Andaman Sea of Thailand are on the continental shelf extended from the western coast of Thailand. They are scattered along 700 km of coast in five provinces: Ranong, Phang - Nga, Phuket, Trang, and Satun. There are numerous river mouths and mangrove forests along the coast (Department of Marine and Coastal Resources, 2016a; Royal Thai Survey Department, 1997), which are sources of terrestrial runoff that increase nutrients levels and siltation in coastal waters. All reefs in this region are fringing reefs. Reef development varies between locations and probably reflect environmental conditions; reefs close to the mainland tend to be highly influenced by sediments and freshwater discharges that may inhibit proper reef formation (Department of Fisheries, 1999). Reefs further from the mainland are reported to be better developed because they are less influenced by freshwater, sediments, and effluent from the mainland (Department of Fisheries, 1999).

Coral reefs in the Andaman Sea are well developed on the east of islands which are sheltered from the south - west monsoon, whereas the west coast of islands are covered by a few of encrusting corals except in sheltered bays that reefs can well developed (Department of Fisheries, 1999). Moreover, reefs which are close to the edge of the continental shelf, surrounded by deep water region and high light transparent environments, such as may be found at the Surin and Similan Islands, can occur at up to 20 - 30 meters depth whereas, reefs in shallow waters which are turbid environments can be developed till to 3 - 10 meters depth (Department of Fisheries, 1999).

Published water quality parameter indicated coral reefs in the Southern region of Andaman Sea: south of Phuket to Satun province might be influenced from terrestrial influences more than the northern part. Salinity of the coastal waters in the Northern region: Ranong - Phuket province is around 32 - 33 ppt. Water salinity in the Southern region is around 29 - 32 ppt (Limpsaichol *et al.*, 1991).

In the southern Andaman Sea, reefs occur far out on the continental shelf, and are the basis of Mu Ko Phetra National Park and Tarutao National Park, Satun province. Across the very wide continental shelf, Department of Fisheries (1999) described reef habitat in this area into two groups, that is: nearshore islands group, and offshore islands group. The “nearshore islands” group is located between 2 - 15 km from the mainland, in a shallow water region, and includes Bulon, Khao Yai, and Tarutao island groups. The sea bed is composed mostly of fine sand or sandy mud, and water transparency is around 5 - 8 meters. The “offshore islands” group is located 50 km further from the shore, and consists of the Adang - Rawi Islands. They are in moderately deep water; the depth of the sea floor within 3 km of the islands ranges between 25 - 70 meters. This islands group is located far from the mainland, so environmental conditions are clear water all year (Department of Fisheries, 1999). Water transparency ranges between 8 - 15 meters. However, the Adang - Rawi island group is probably influenced by some siltation due to a large tourist community on one of the islands in the group (Lipe Island) (Phongsuwan *et al.*, 2013).

Around Tarutao Island, coral reefs are well developed along the east coast except in Ta Lo Wow Bay that is mangrove forest (Figure 1.1). Reef zonation shows a clear disjunction between flat and slope zone (Department of Fisheries, 1999). The west cost of Tarutao Island exposed to the force of the southwest monsoon. A few coral reefs have developed in sheltered bays (Department of Fisheries, 1999). In the neighboring islands to the east of Tarutao Island such as Leak Island, Ta Kieng Island, Klua Lo Island are equal, the reefs are also well developed similar to the east coast of Tarutao Island; they have a narrow reef flat and the reef slope is extended to around 7 m deep. At the north of Lean Island, reefs widely form and compose of high richness and abundance of corals (CBiPT, 2010).

Bulon Islands consist of Bulon Don Island, Bulon Mai Pai Island, and Bulon Le Island (Figure 1.1). Generally, reefs of these three islands are well formed around the coast of islands except at the west and east coasts of Bulon Le Island; the west coast is rocky reef and the east coast is sand patch (Department of Fisheries, 1999). Their maximum depth does not exceed 5 meters (Department of Fisheries, 1999).

Reefs of Adang - Rawi Islands are developed along coast of each island except the west coast of island and south coast of some island that exposed to open sea (Figure 1.1). Maximum depths of reef are formed in larger depth range between 7 - 12 meters (Department of Fisheries, 1999). Mostly, reef zonation can be divided into 3 reef zones: reef flat, reef crest, and reef slope. At high wave exposure coast such as northwest of Rawi Island, west of Rawi Island, southwest of Butang Island, and west of Butang Island, reefs are formed on rocky shore extended less than 20 - 30 meter (Phongsuwan *et al.*, 2001).

1.3 Project rationale

Much evidence from other geographical region suggest inshore - offshore reefs exposed to differing environmental conditions have fundamentally different community characteristics, and their usual model of inshore/offshore systems assumes terrigenous influences diminish with distance from the mainland. Reefs in Thailand fringe continental islands; however, reefs both near the mainland and further away are still exposed to some level of terrestrial influences, so that one might expect that some of the characteristics in other regions might be somewhat subdued in the Thai water reef system. To develop an understanding about a nature of inshore - offshore fringing reef systems, this study therefore aims to define spatial variations in coral communities and coral replenishment of the southern Andaman Sea reefs, to establish whether reefs of the southern Andaman Sea conform to the “standard model” of inshore/offshore systems.

1.4 Objectives

1.4.1 To examine differences in coral community composition in the inshore and offshore reef environments in the southern Andaman Sea of Thailand

1.4.2 To determine whether coral assemblages are correlated to environmental differences in inshore or offshore reefs

1.4.3 To examine differences in coral replenishment in the inshore and offshore reef environments in the southern Andaman Sea of Thailand

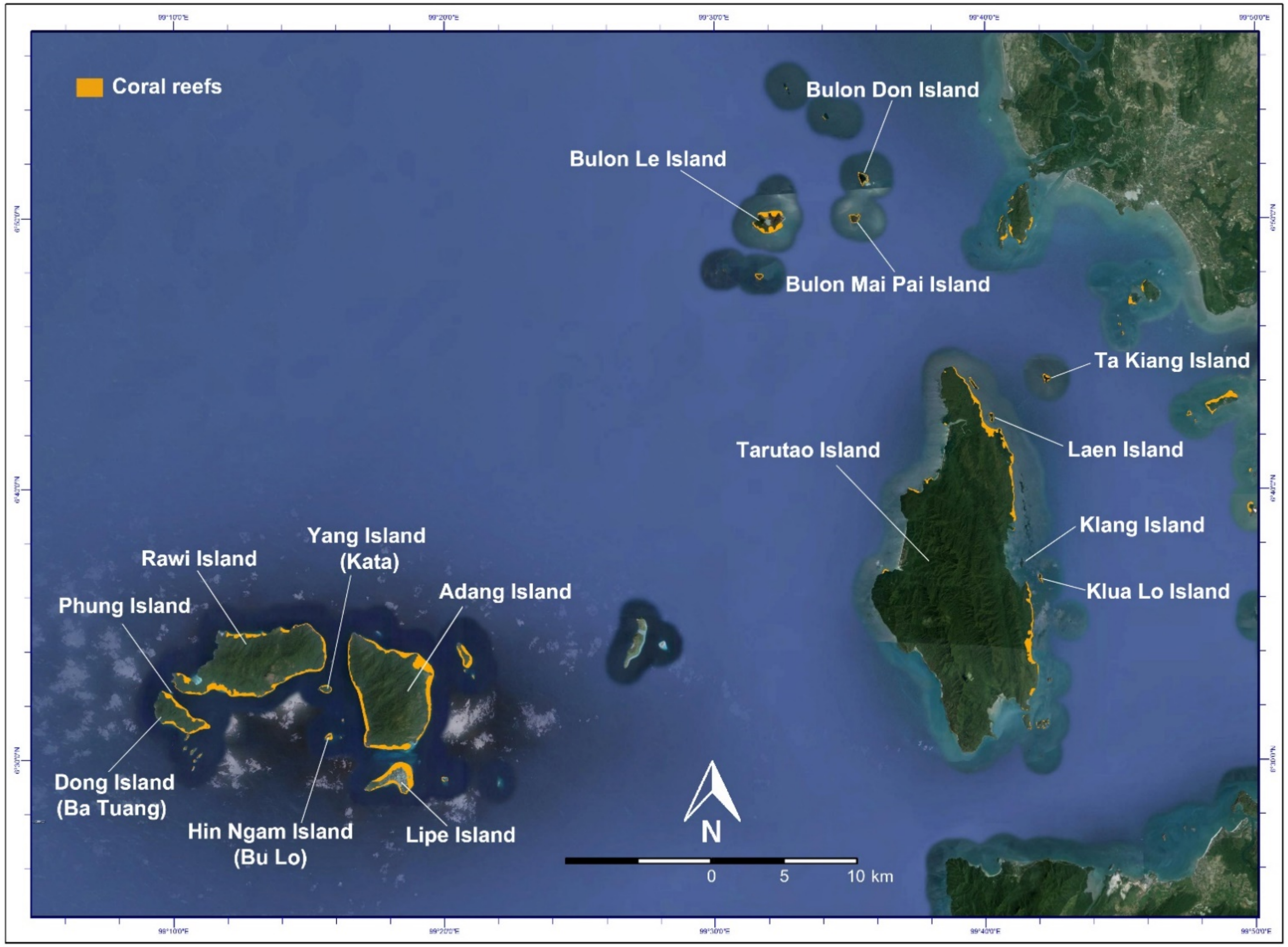


Figure 1.1 Distribution of coral reefs in the southern Andaman Sea of Thailand (Department of National Parks, Wildlife and Plant Conservation [DNP], 2011).

CHAPTER 2

Overviews of Methodology

2.1 Study area

The study area was located in Satun province at the southern end of the Andaman Sea of Thailand, which is the easternmost part of the Indian Ocean. The coast of southern Andaman Thailand is edged by estuaries and mangrove forests (Figure 2.1). The coral reefs in this area are fringing reefs formed around continental islands (Figure 2.1). The site for the current study form parts of Tarutao National Park and Mu Ko Phetra National Park. The area of interest consists of 3 island groups (Tarutao, Bulon, and Adang - Rawi archipelagos) that form an east - west line out from the mainland. They are existing in the same latitude (6°28'N - 6°51'N) along approximately 70 km transect from the mainland (measured from Google Earth); these island groups are hypothetically influenced by the gradient of terrestrial influence and terrigenous sediments. According the idea, this study proposed the Tarutao Island group and Bulon Island group which are located in a range of 10 - 20 km from the mainland as “inshore” group, and Adang - Rawi archipelago which is 70 km distant from the mainland as “offshore” group (Figure 2.2).

A hierarchical sampling design used to measure spatial variation in the coral assemblages in the southern Andaman Sea region. Within the region, there were two reef habitats: inshore and offshore reefs. The inshore reef had two island group and the offshore reef had one island group. Within island group, reef sites were selected scatter over the island group. Each site, three or seven replicate belt-transects were haphazardly chosen. A total of 22 reef sites from amongst the inshore and offshore reef habitats were investigated. The ten reef sites in the inshore group consisted of four sites at the Bulon Islands, and six sites at the Tarutao islands; the twelve reef sites in the offshore group were scattered throughout the Adang-Rawi islands, as shown in Table 2.1 and Figure 2.3.

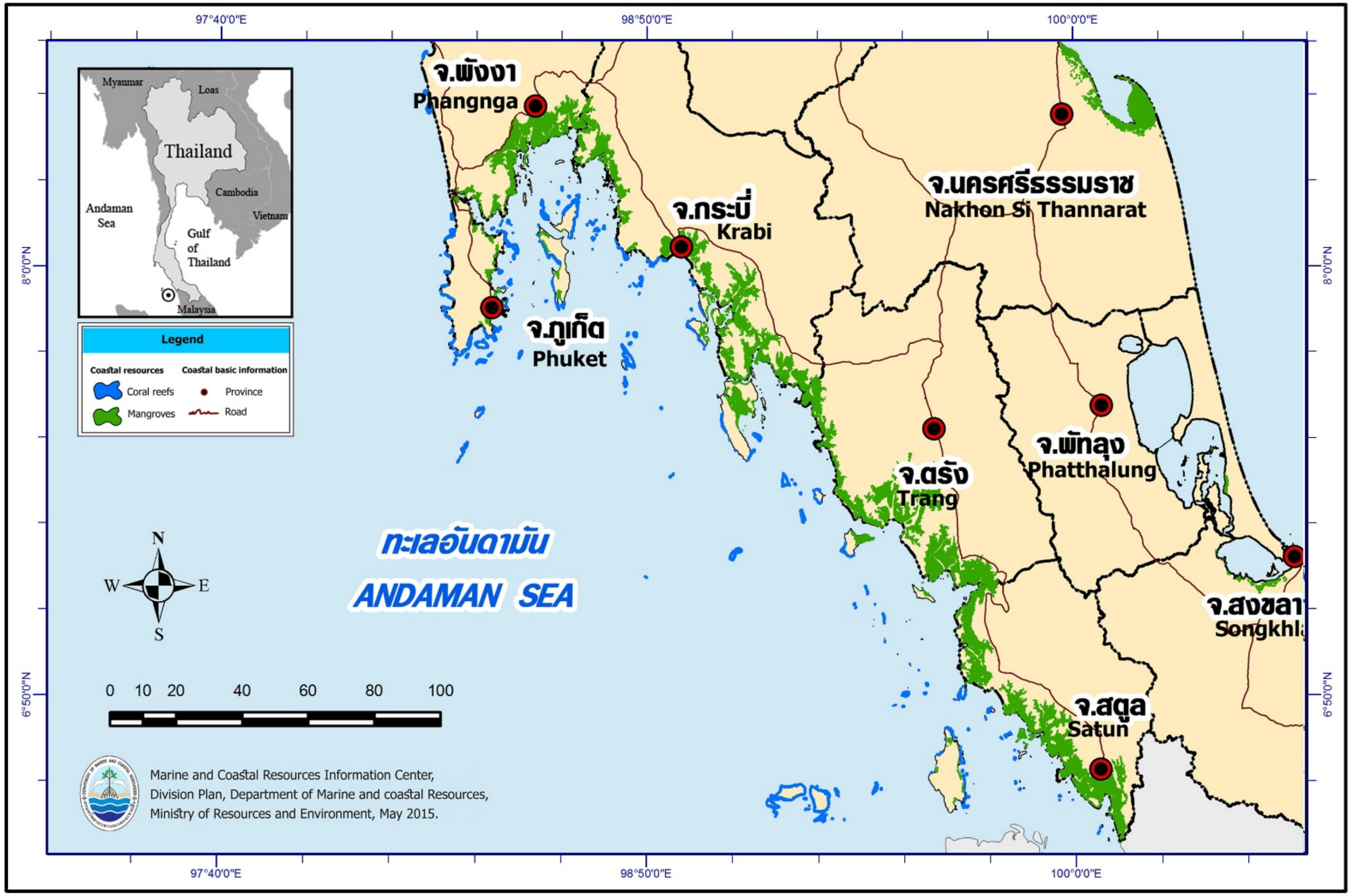


Figure 2.1 Distribution of mangrove forests and coral reefs in the southern Andaman Sea of Thailand (Modified from Department of Marine and Coastal Resources, 2016a, 2016b).

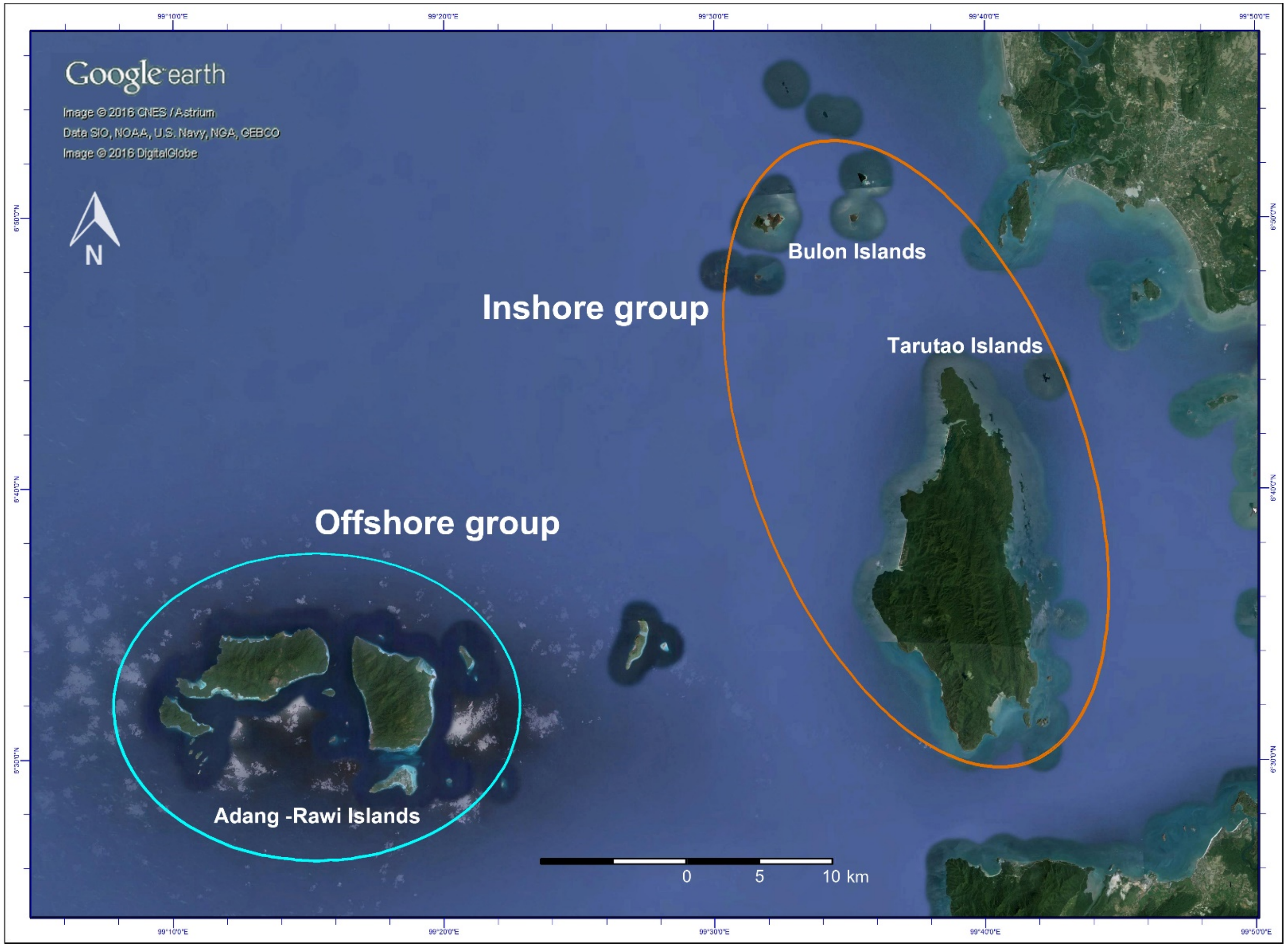


Figure 2.2 The proposition of inshore (orange circle) and offshore (light blue circle) island groups in the southern Andaman Sea of this study.

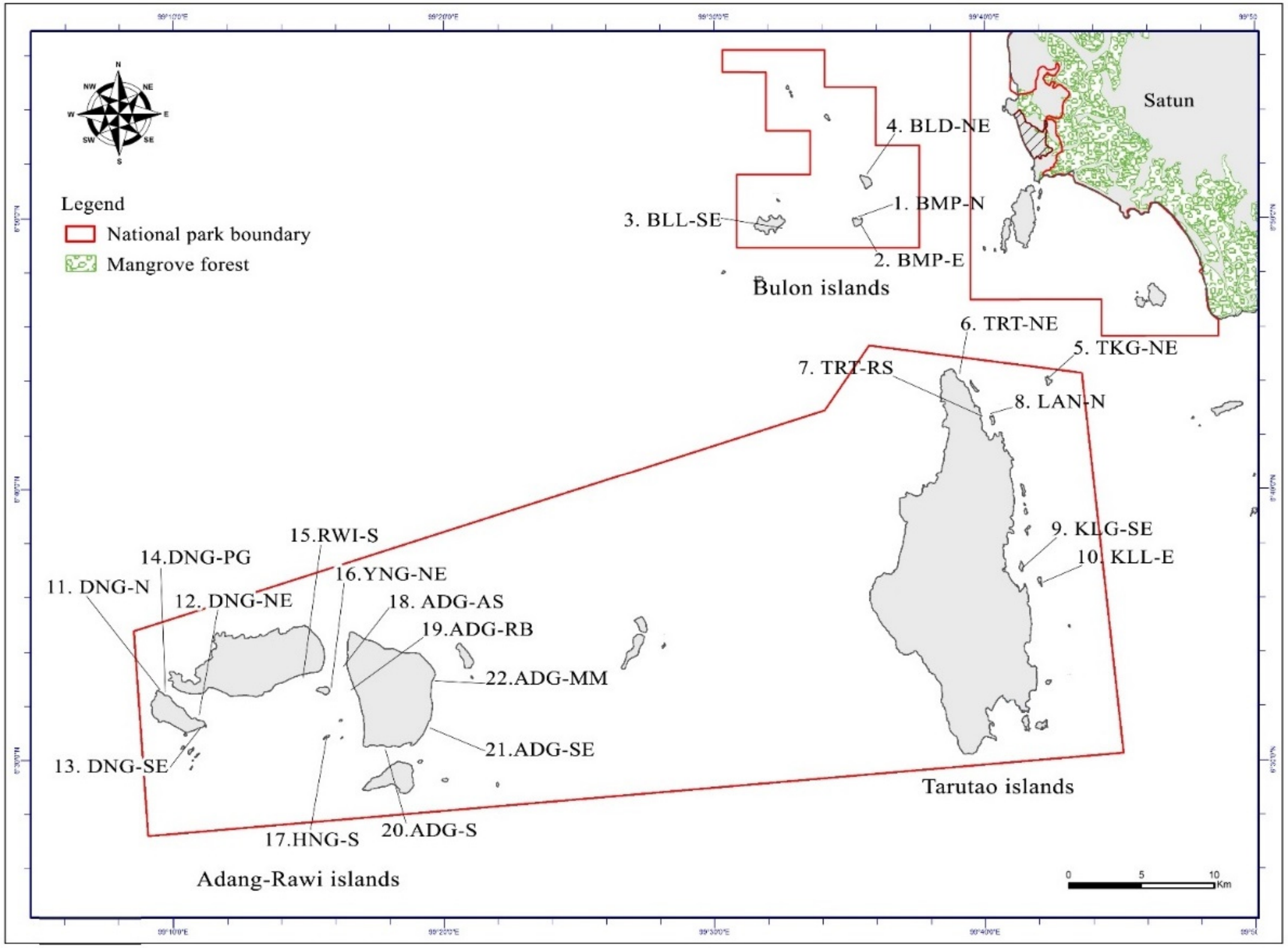


Figure 2.3 The study sites in Satun province, comprising 22 stations in Bulon islands, Tarutao islands and Adang - Rawi islands.

Table 2.1 The list of twenty - two study reef sites in the inshore and offshore habitat of the southern Andaman Sea of Thailand (Figure 2.3). Shaded entries represent stations that were also in the replenishment study.

Habitat	Site number	Reef site code	Archipelago	Site name
Inshore	01	BMP-N	Bulon	North of Bulon Mai Pai Island
	02	BMP-E	Bulon	East of Bulon Mai Pai Island
	03	BLL-SE	Bulon	South-East of Bulon Le Island
	04	BLD-NE	Bulon	North-East of Bulon Don Island
	05	TKG-NE	Tarutao	North-East of Ta Kiang Island
	06	TRT-NE	Tarutao	North-East of Tarutao Island
	07	TRT-RS	Tarutao	Rue Si Bay, Tarutao Island
	08	LAN-N	Tarutao	North of Laen Island
	09	KLG-SE	Tarutao	South-East of Klang Island
	10	KLL-E	Tarutao	East of Klua Lo Island
Offshore	11	DNG-N	Adang-Rawi	North of Dong Island
	12	DNG-NE	Adang-Rawi	North-East of Dong Island
	13	DNG-SE	Adang-Rawi	South-East of Dong Island
	14	DNG-PG	Adang-Rawi	Dong-Phung Island
	15	RWI-S	Adang-Rawi	South of Rawi Island
	16	YNG-NE	Adang-Rawi	North-East of Yang Island
	17	HNG-S	Adang-Rawi	South of Hin Ngam Island
	18	ADG-AS	Adang-Rawi	Song Bay, Adang Island
	19	ADG-RB	Adang-Rawi	Ruea Bai Bay, Adang Island
	20	ADG-S	Adang-Rawi	South of Adang Island
	21	ADG-SE	Adang-Rawi	South East of Adang Island
	22	ADG-MM	Adang-Rawi	Mae Mai Bay, Adang Island

2.1.1 The inshore habitat

The inshore reefs in the southern Andaman Sea are located further from the mainland in a range of 10 - 30 km. The Tarutao and Bulon Islands are in shallow water region; the seafloor within 3 km from the islands generally ranged 7 – 15 m deep. Reefs morphology formed extent width 30 - 80 meters and maximum depth of reef was formed in narrow depth range between 6 - 8 meters (Figure 2.4) (Department of Fisheries, 1999). The sea bottom is fine gain sand or muddy sand at a location which is close to mangrove forests. Water transparency is 5 - 8 m according to secchi-disc (Department of Fisheries, 1999). The Tarutao and Bulon reef environments are quite turbid - waters and high suspended particulate matter (Personal observation).

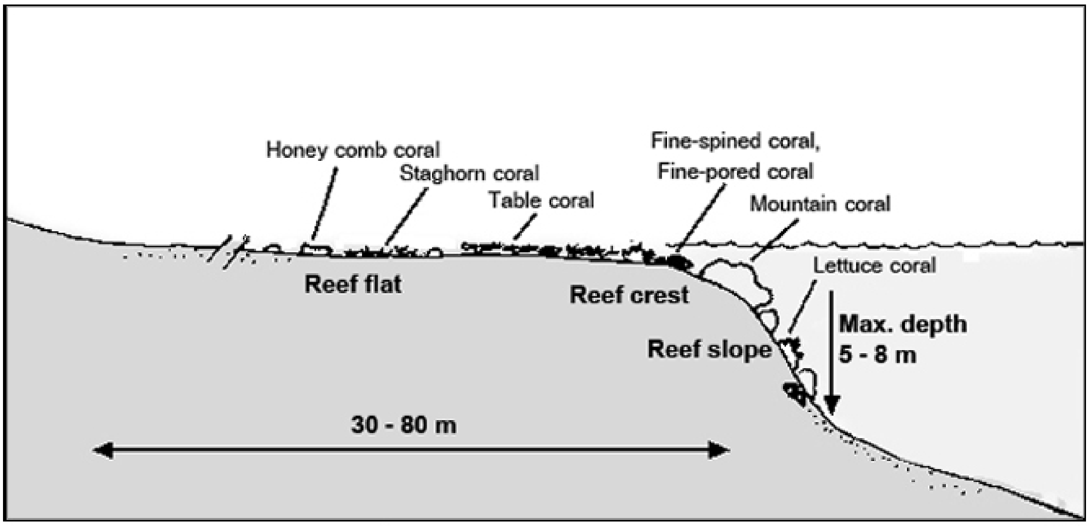


Figure 2.4 Diagram of general reef profile of reef in the eastern of Tarutao Island and neighboring islands (translated from Department of Fisheries, 1999).

The Bulon Archipelago study sites consist of Bulon Le Island, Bulon Don Island, and Bulon Mai Pai Island (Figure 2.5). The group lies between 10 - 20 km from the mainland. The Bulon group comprises low - lying, rocky islands composed of mudstone and sandstone; rocky shores alternate with sandy beaches and sandstone cliffs topped with evergreen forest and beach vegetation (Figure 2.6 and 2.8) (DNP, 2011). The Bulon reefs form to 5.5 - 7.5 m deep; the reef environments are moderate underwater visibility, quite clear waters with abundant particulate matter suspends in the water column (Figure 2.7 and 2.9). The reef bottom substrate is muddy - sand.

The Tarutao Archipelago is located 15 - 30 km from the mainland. The Tarutao study sites consist of the very large Tarutao Island and several very small islands along the eastern side of Tarutao Island, including TaKieng, Laen, Klang and KuaLo Islands (Figure 2.10 and 2.11). Tarutao Island is the largest island of this group. The large island covers approximately 152 km^2, and includes several types of terrestrial forests and large areas of mangrove forests. The western coast (facing the Andaman Sea) consists of many bays which are subject to fresh water influx from terrestrial streams and mangrove channels. This exposed coast supports few reefs, with sparse corals. All Tarutao reefs in this study were therefore located on the eastern side of the island. The eastern coast consists of limestone cliffs, bays, mangrove forests and sand - mud beaches (Figure 2.12). Furthermore, most of the small islands on the eastern side of Tarutao Island are limestone islands (Department of Mineral Resources, 2006a; DNP, 2007) as shown in Figure 2.14. The Tarutao reefs form to 5 - 7 m deep; the reef environments exhibit poor - low underwater visibility, turbid waters with abundant particulate matter suspends in the water column (Figure 2.13 and 2.15). The reef bottom substrate is muddy sand.

Figure 2.5 The study reef sites in the Bulon Island group located 10 - 20 km from the Satun coast. BMP-N, North of Bulon Mai Pai Island; BMP-E, East of Bulon Mai Pai Island; BLL-SE, South-East of Bulon Le Island; BLD-NE, North-East of Bulon Don Island.

Figure 2.6 The terrestrial landscape and vegetation of Bulon Mai Pai Island.

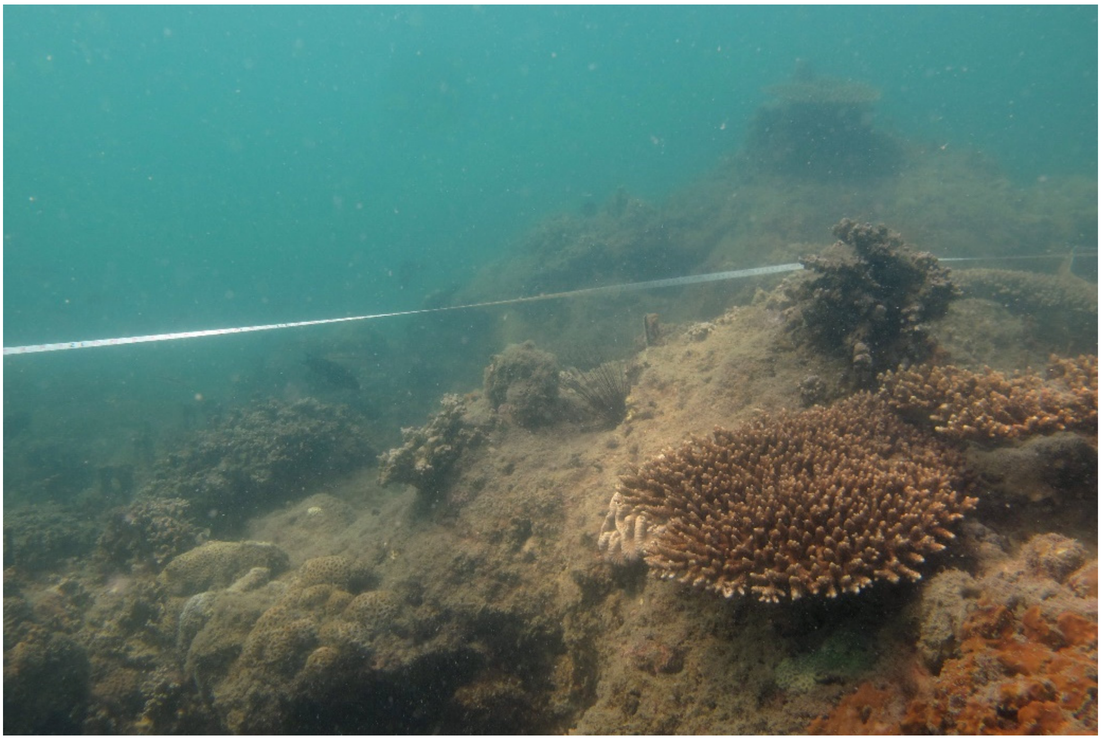


Figure 2.7 The inshore reef environments at Bulon Mai Pai Island.

Figure 2.8 The terrestrial landscape and vegetation of Bulon Don Island.

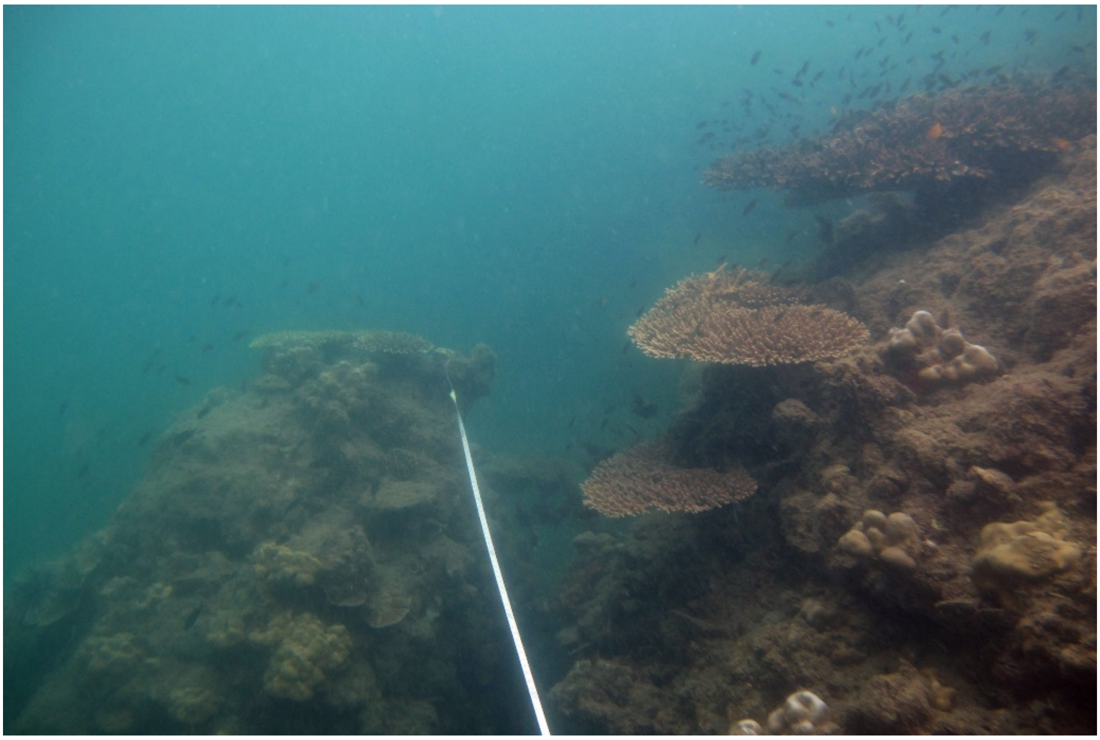


Figure 2.9 The inshore reef environments at Bulon Don Island.

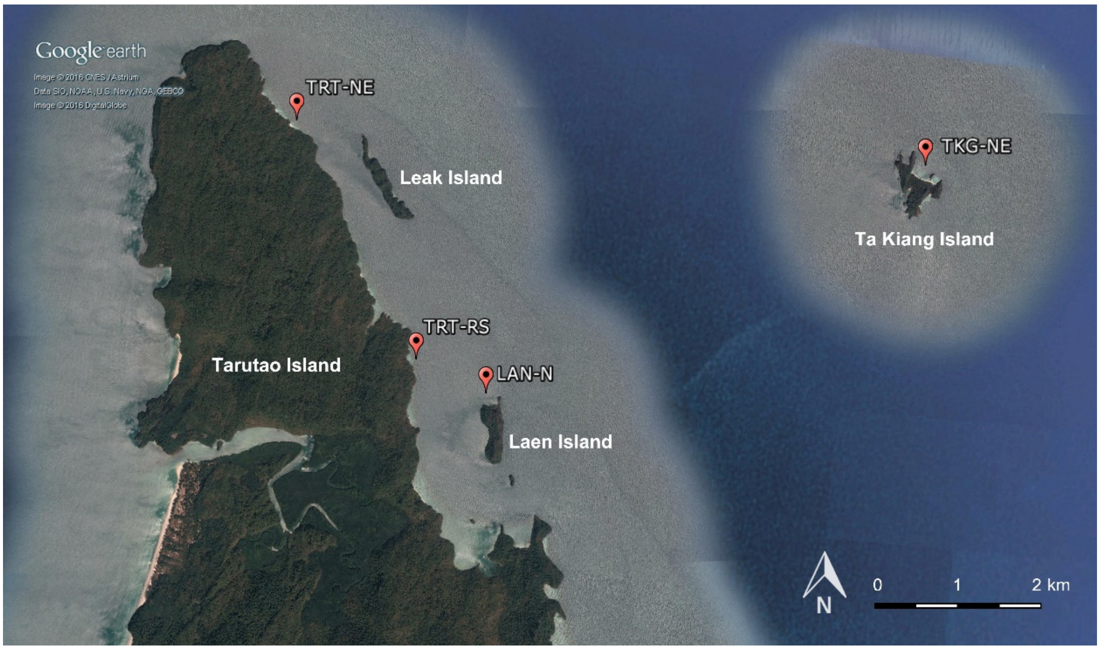


Figure 2.10 The study reef sites at the north - eastern Tarutao Island group. TKG-NE, North-East of Ta Kiang Island; TRT-NE, North-East of Tarutao Island; TRT-RS, Rue Si Bay, Tarutao Island; LAN-N, North of Laen Island.

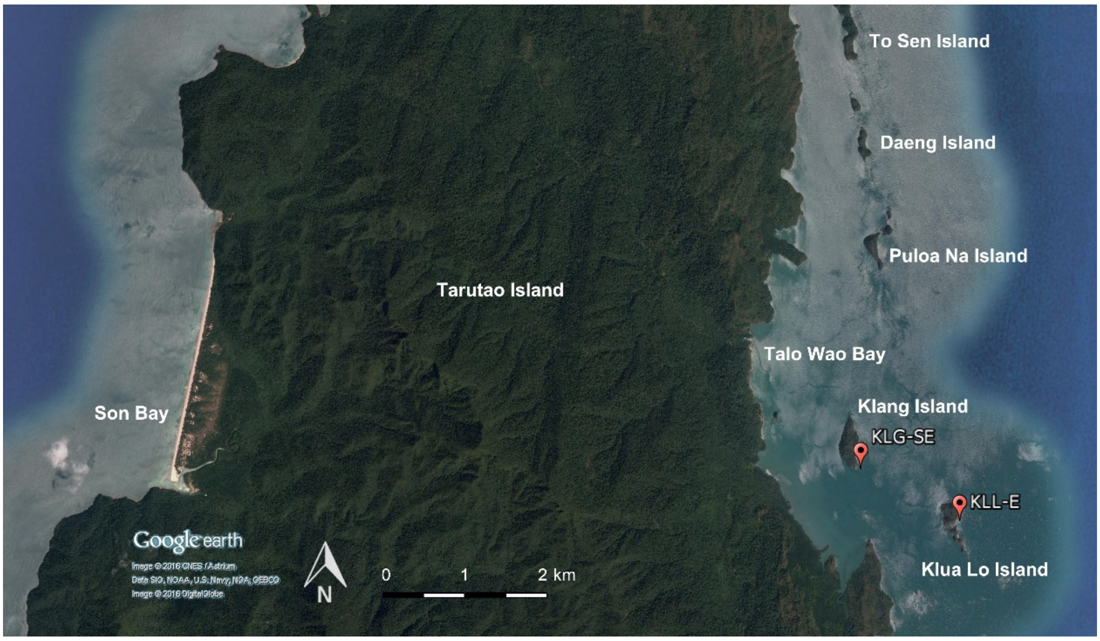


Figure 2.11 The study reef sites at the eastern Tarutao Island group. KLG-SE, South-East of Klang Island; KLL-E, East of Klua Lo Island.

Figure 2.12 The terrestrial landscape and vegetation of Tarutao Island.

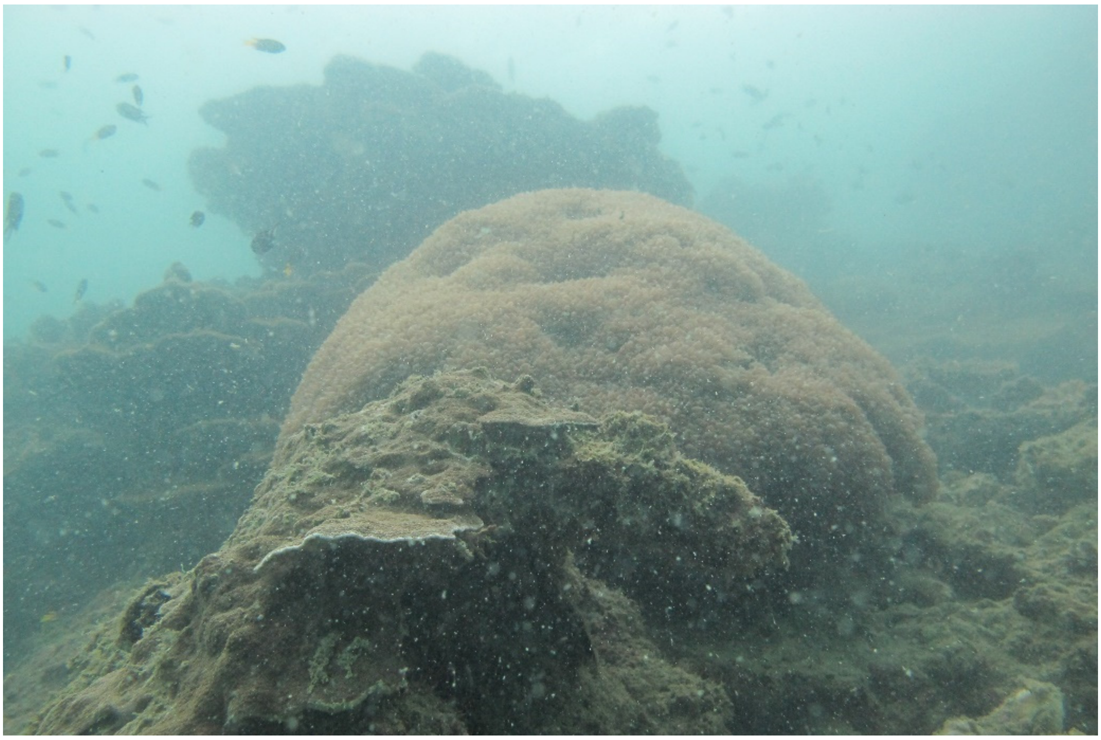


Figure 2.13 The inshore reef environments at Tarutao Island.

Figure 2.14 The terrestrial landscape and vegetation of Klang Island.

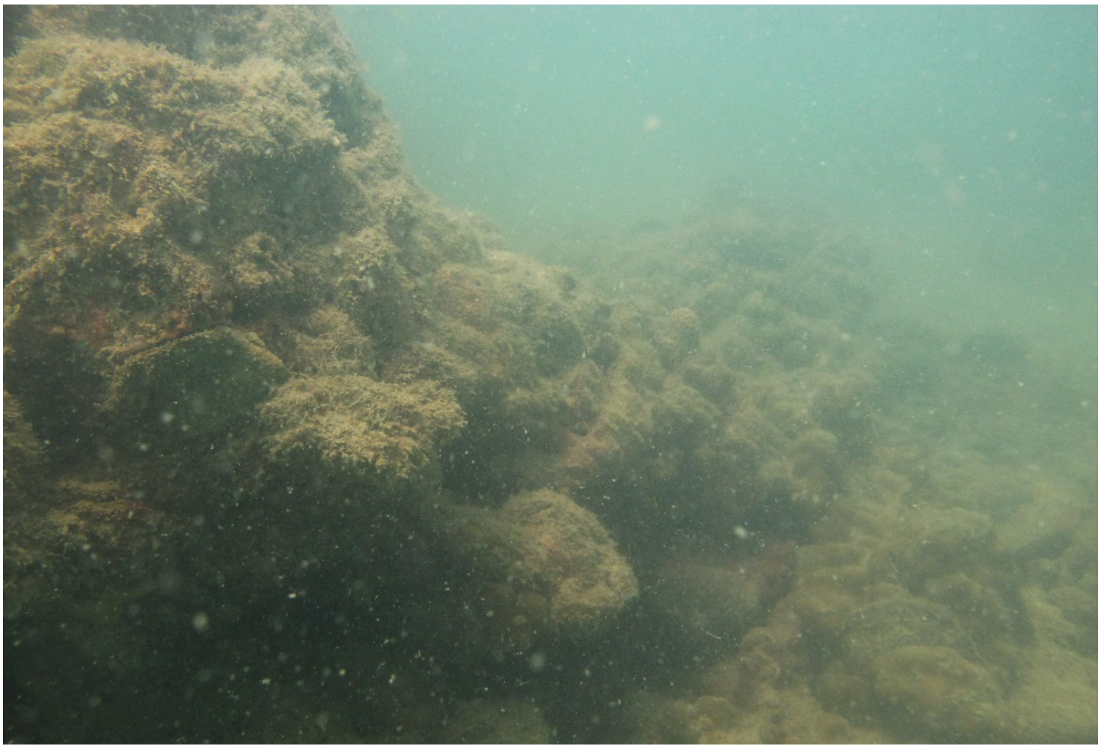


Figure 2.15 The inshore reef environments at Klang Island.

2.1.2 The offshore habitat

The offshore habitat is located in a range of 50 - 70 km from the Satun coast. It is located in moderately deep water region; the seafloor within 3 km from the islands generally ranged 25 - 70 m deep. Department of Fisheries (1999) reported that the Adang - Rawi reefs form broad reef flats, often 50 - 300 m wide and maximum depth of reef ranges between 7 - 12 m (Figure 2.16); they were generally deeper than the inshore reefs.

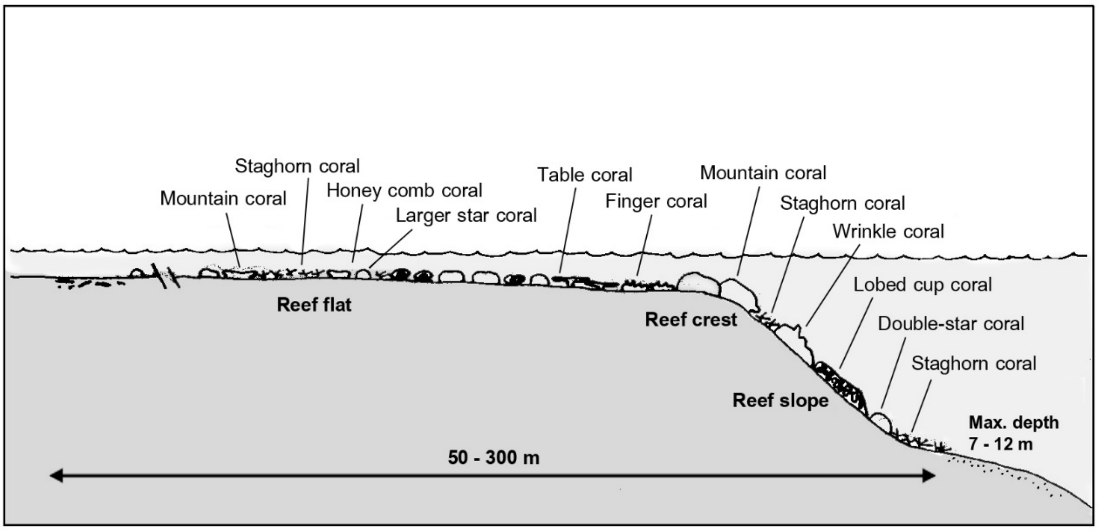


Figure 2.16 Diagram of general reef profile of reef in the Adang - Rawi Islands (Department of Fisheries, 1999).

Adang - Rawi Archipelago includes two large islands: Adang Island and Rawi Island and several small islands such as Dong Island, Phung Island, Hin Ngam Island, Yang Island (Figure 2.17). Most of the islands in this group are granite islands (Department of Mineral Resources, 2006b). Some mudstone interbedded with sandstone and siltstone presents at the north of Rawi Island, north east of Adang Island, Bu Lo Island, Burat Island, Cha Bang Islands and the small islands on the eastern side of archipelago (Department of Mineral Resources, 2006b). The terrestrial areas of the islands are generally topped with evergreen forest and beach vegetation, and the coasts are cliffs, bays and sandy beaches (Figure 2.18, 2.20, 2.22 and 2.24) (DNP, 2011). On the Lipe Island, there is a large tourist community and village.

The offshore reef environments experience relatively clearer waters which are moderate - high level underwater visibility and lower suspended particulate matter compared to the inshore reefs (Personal observation) (Figure 2.19, 2.21, 2.23 and 2.25). Water transparency is 8 - 15 m according to secchi-disc (Department of Fisheries, 1999). The reef bottom substrate is muddy - sand.

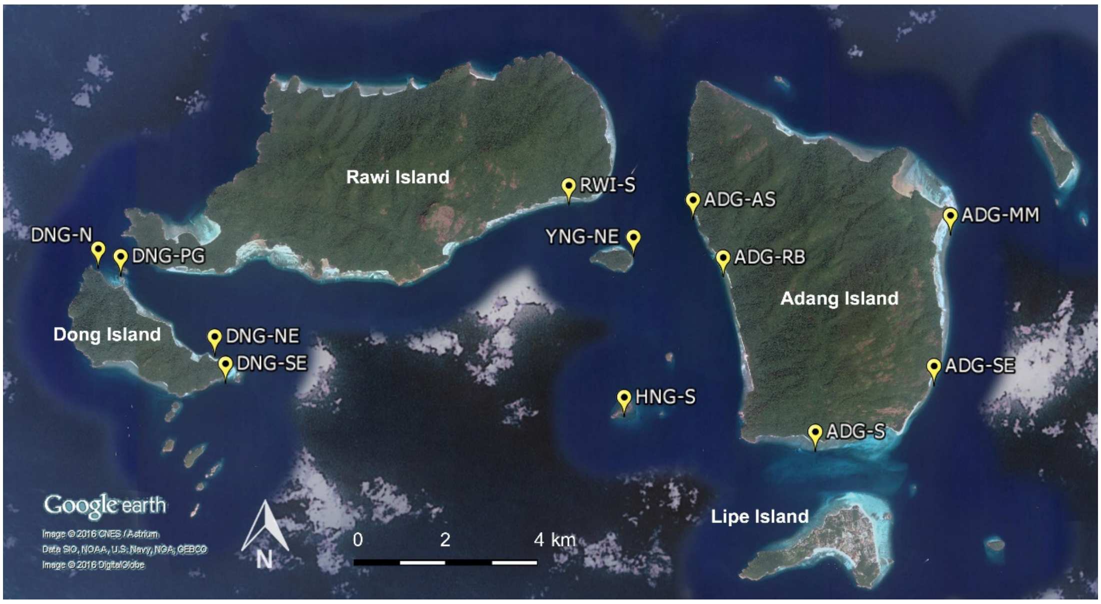


Figure 2.17 The study reef sites in the Adang - Rawi Island group located 55 - 70 km from the Satun coast. DNG-N, North of Dong Island; DNG-NE, North-East of Dong Island; DNG-SE, South-East of Dong Island; DNG-PG, Dong-Phung Island; RWI-S, South of Rawi Island; YNG-NE, North-East of Yang Island; HNG-S, South of Hin Ngam Island; ADG-AS, Song Bay, Adang Island; ADG-RB, Ruea Bai Bay, Adang Island; ADG-S, South of Adang Island; ADG-SE, South East of Adang Island; ADG-MM, Mae Mai Bay, Adang Island.

Figure 2.18 The terrestrial landscape and vegetation of the north of Dong Island.

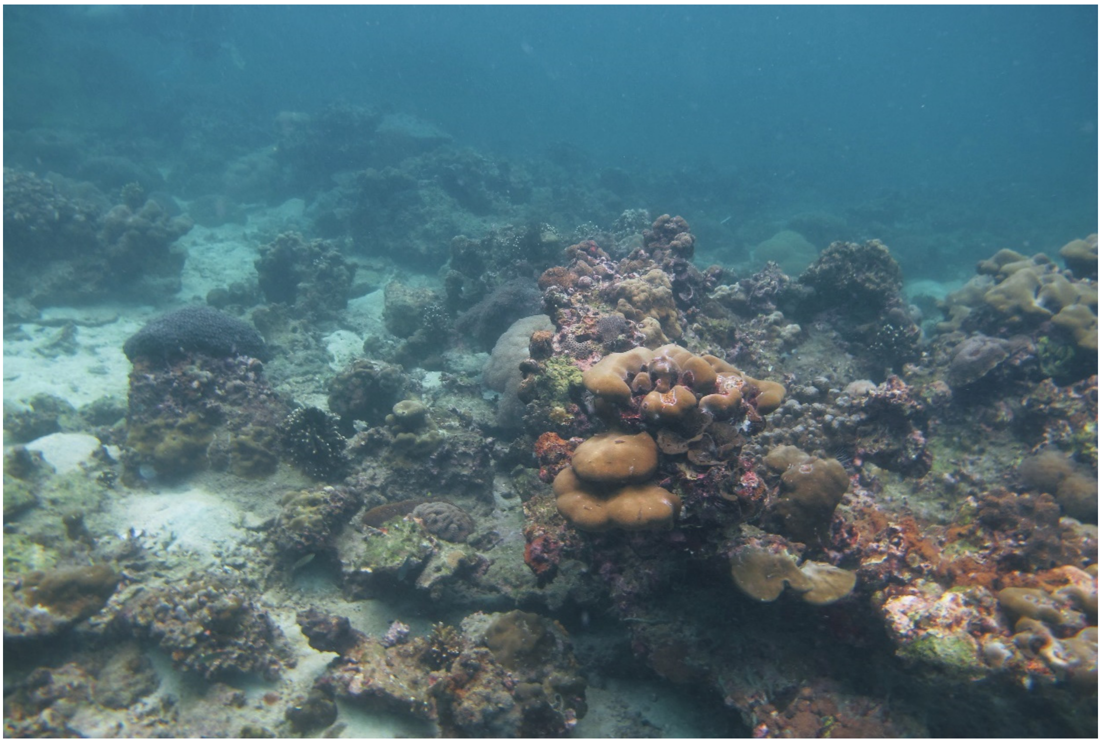


Figure 2.19 The offshore reef environments of the north of Dong Island.

Figure 2.20 The terrestrial landscape and vegetation of the North-East of Yang Island.

Figure 2.21 The offshore reef environments of the North-East of Yang Island.

Figure 2.22 The terrestrial landscape and vegetation of the Ruea Bai Bay, Adang Island.

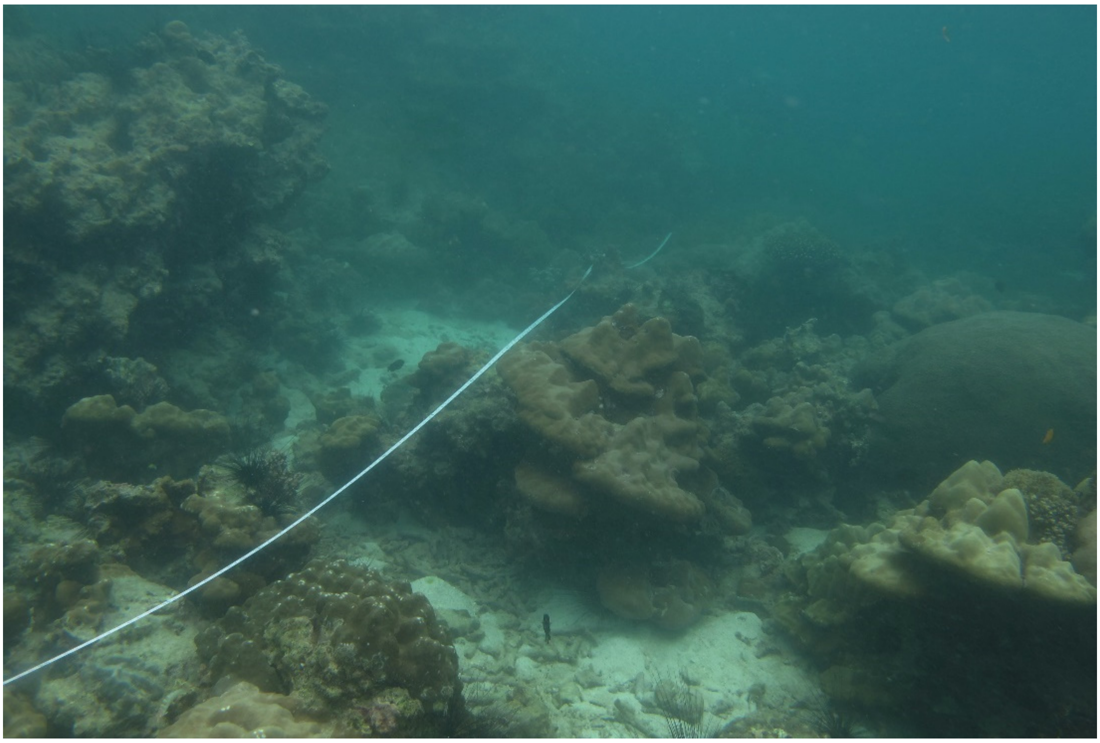


Figure 2.23 The offshore reef environments of the Ruea Bai Bay, Adang Island.

Figure 2.24 The terrestrial landscape and vegetation of the south of Adang Island.

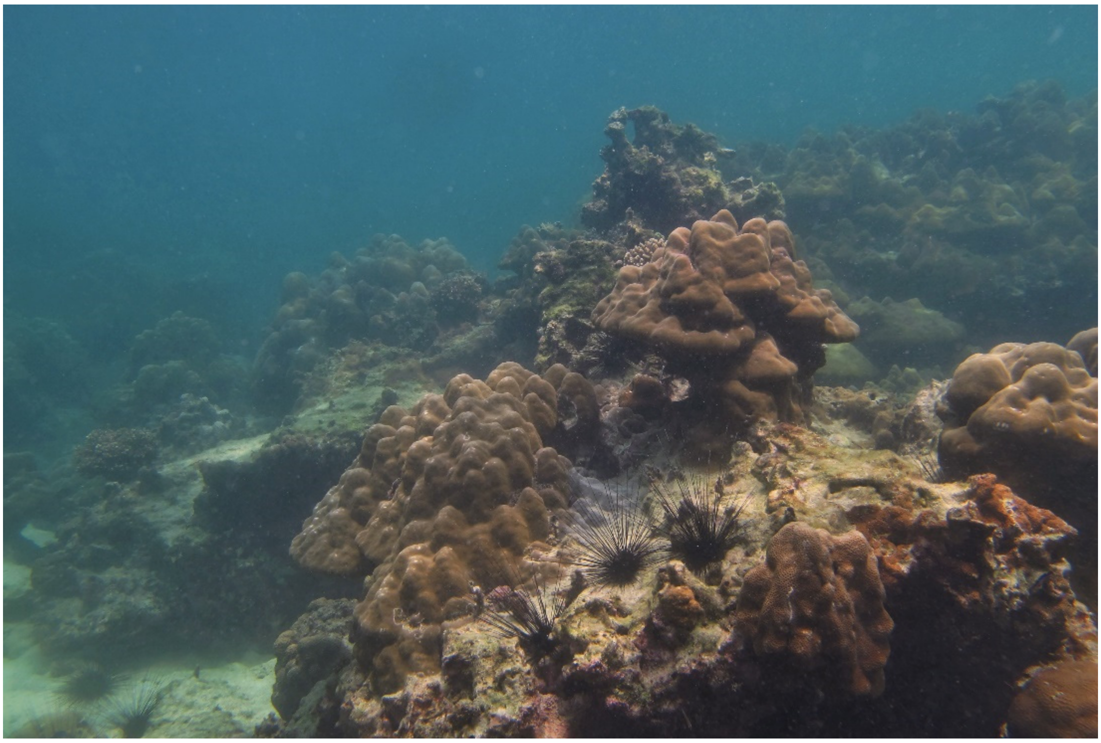


Figure 2.25 The offshore reef environments of the south of Adang Island.

2.2 The influence of monsoon seasons on the study area

The weather in the area is dominated by the tropical monsoon; conditions are influenced by southwest monsoon during May - October and the northeast monsoon during October - February. The southwest monsoon is generally unsettled, with frequent strong winds, storms and heavy rainfall; amount of rainfall during the monsoon in Satun province was 200 - 300 mm/month with more than 15 rainy days/month (DNP, 2011). During this monsoon, the study area experiences strong winds and turbulent waters (Thai Meteorological department, 2013); additionally, heavy, sustained rainfall associated with the monsoon might provide large inputs of terrestrial runoff in coastal areas. Influence of the monsoon is likely to increase surface wave actions and stir the water column which induce sediment suspension in the coastal water and create high turbid water environment (Jing and Ridd, 1996; Lesht *et al.*, 1980). The northeast monsoon is characterised by dry and cool weather. It is associated with generally calm conditions and little rainfall in this area (Thai Meteorological department, 2013).

2.3 Coral community composition field survey and data collection

The field survey was conducted during December 2013 - July 2014. Each site was surveyed once according to a standard protocol; i.e. three 25x1m belt-transects at constant depth along the upper part of the reef slope zone (following the method of Adjeroud *et al*. (2010), albeit using a different transect size). Twenty - one reef sites were examined by three replicates of belt-transect.

Data collection was undertaken by divers using SCUBA. Three transects were laid at constant depth along the upper of reef slope zone. Colonies up to distance 50 cm from each side of transect were included in the transect area. All scleractinian colonies in survey area were identified to generic level (e.g. *Porites*, *Goniastrea*, *Favia*, *Favites* and *Acropora*). Genus-level identification was considered a suitable taxonomic level for this study because genus-level classification provided a suitably sensitive metric for rapid comparison of community structure between localities in a pilot study. There was no specimen collecting undertaken, since any specimens that appeared difficult to identify in the field were photographed using a high-resolution underwater camera for later confirmation using taxonomic references (a reliable technique for this taxonomic level), and it was considered unnecessary to sacrifice any of the extant coral population. Numbers of colonies in each genus were recorded separately.

To document the obvious environmental differences of reef habitat, reef morphology and reef environments were visually observed during the field data collection. Maximum depth of the reef stations was recorded by the observer swam across the reef to the end; substrate type of the reef bottom also record. Level of underwater visibility, suspended particulate matter, and hydrographic conditions were observed during the coral community survey and recorded as site description shown in Table 2.2). The underwater visibility was categorized into 3 levels: poor, moderate and high. The “poor” visibility category described turbid water conditions; divers were able to see surrounding environments through a haze of suspended material (Figure 2.26). An object can be readily identified at a horizontal distance of 3 m in waters described as “poor” visibility level. The “moderate” visibility category described quite clear water conditions; divers were able to see surrounding environments (Figure 2.27) out to a horizontal distance of approximately 3 - 5 m for moderate visibility level. The “high” visibility description refers to clear water conditions; divers were able to see surrounding environments clearly (Figure 2.28) to a horizontal distance exceeding 5 m at the high visibility level.

The suspended particulate matter in the water column was likewise categorized into 3 levels: low, moderate and high (Figure 2.29 - 2.31). These three levels were ranked retrospectively with regards to upper and lower bounds of observed conditions after field work in all 22 reef sites was finished. The hydrographic conditions of reef sites was categorized into 3 levels: low, moderate, and high. As for the suspended particulate matter, these three levels were ranked retrospectively with regards to upper and lower bounds of observed conditions after finished field work in all 22 reef sites was finished. The low hydrographic conditions described sites with little to no water motion/current during the surveying period. The moderate hydrographic conditions described sites with moderate water motion/current during the surveying period. The high hydrographic conditions described sites with strong water motion/current during the surveying period.

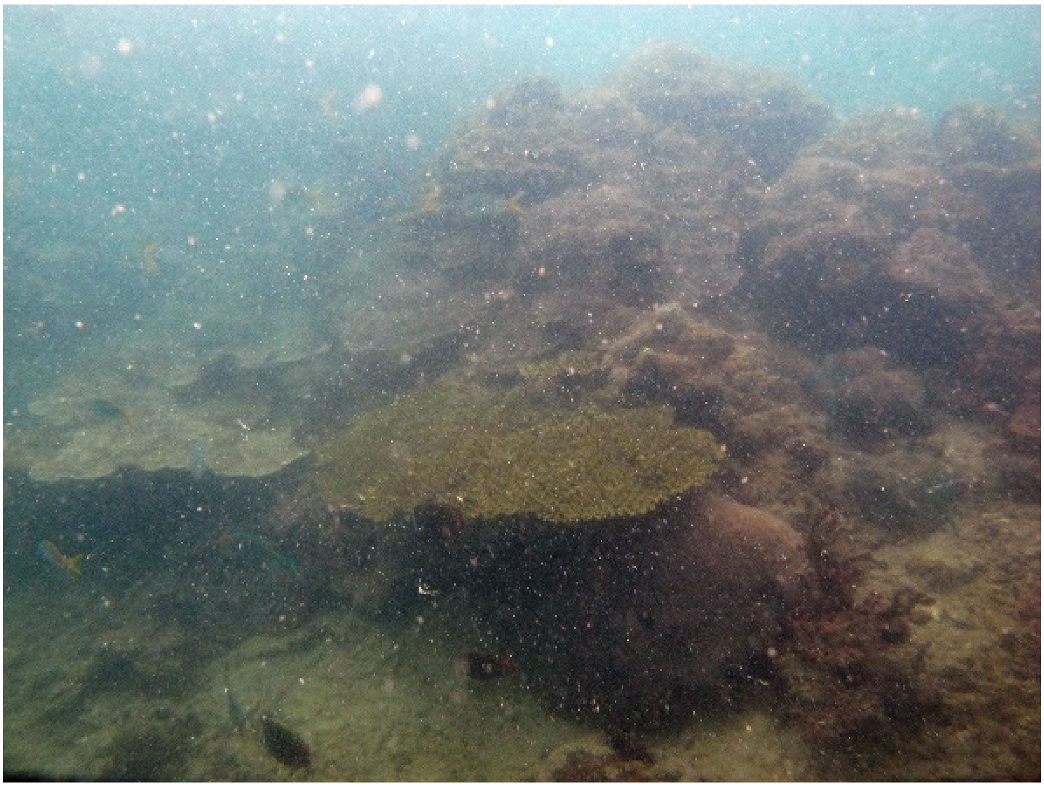


Figure 2.26 The poor visibility reef environments (less than 3 m distance).

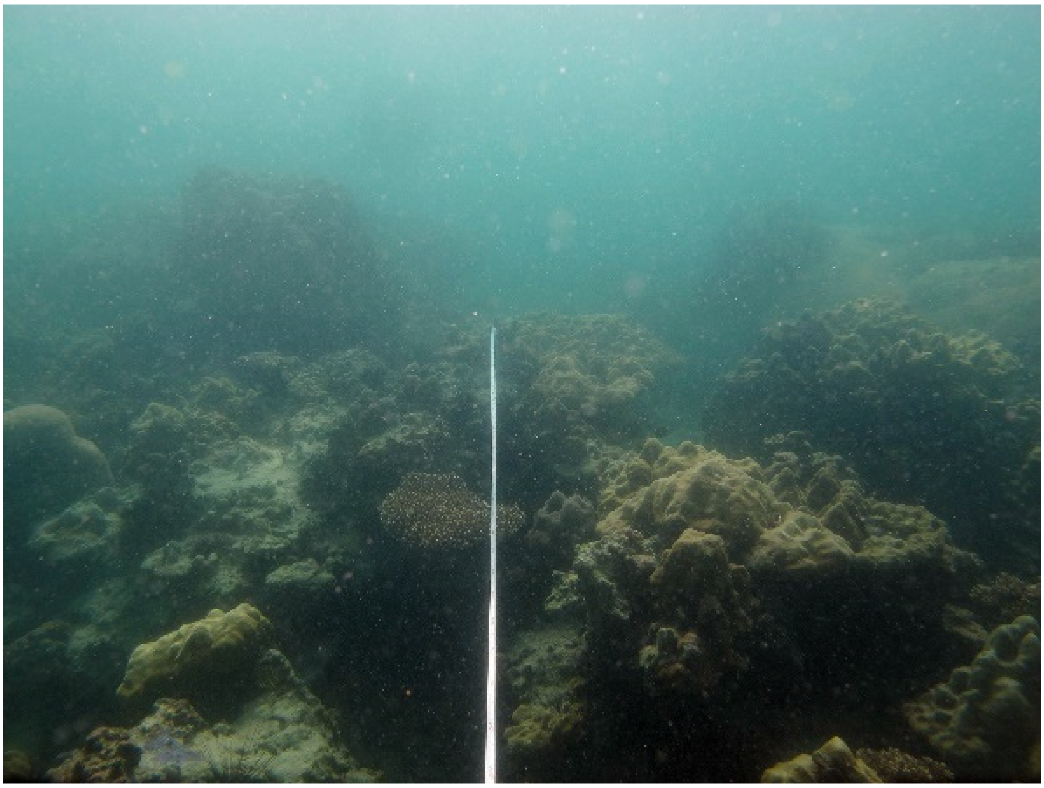


Figure 2.27 The moderate visibility reef environments (3 - 5 m distance).

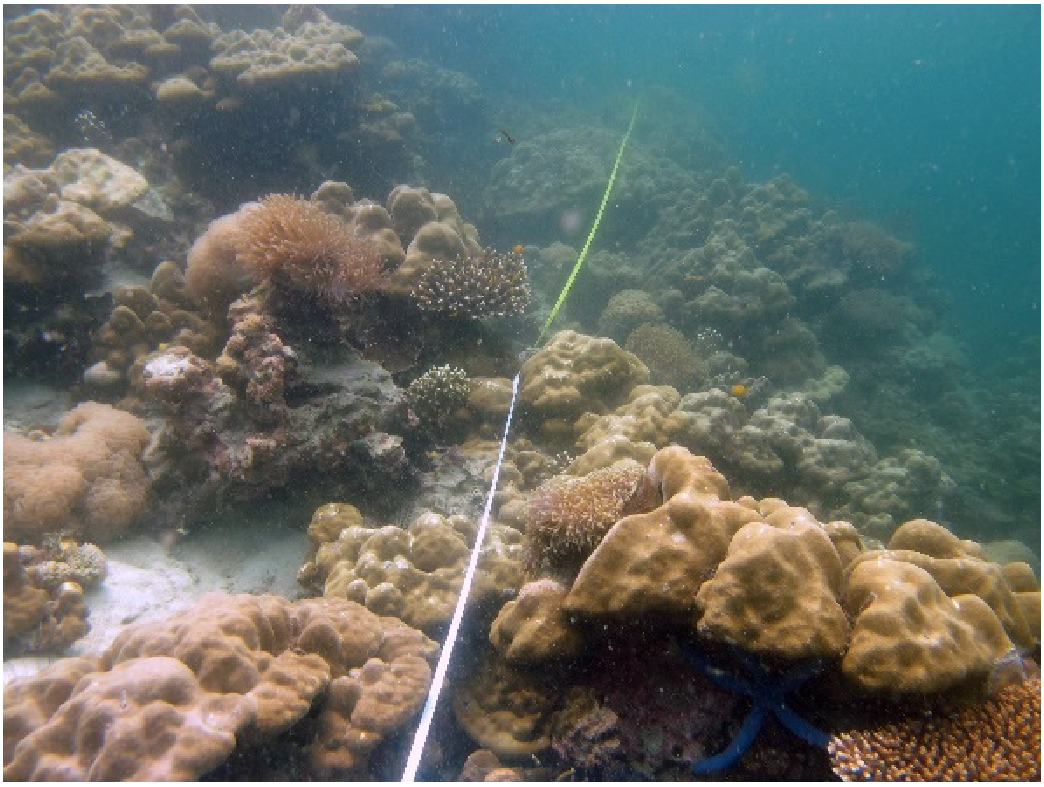


Figure 2.28 The high visibility reef environments (exceed 5 m distance).

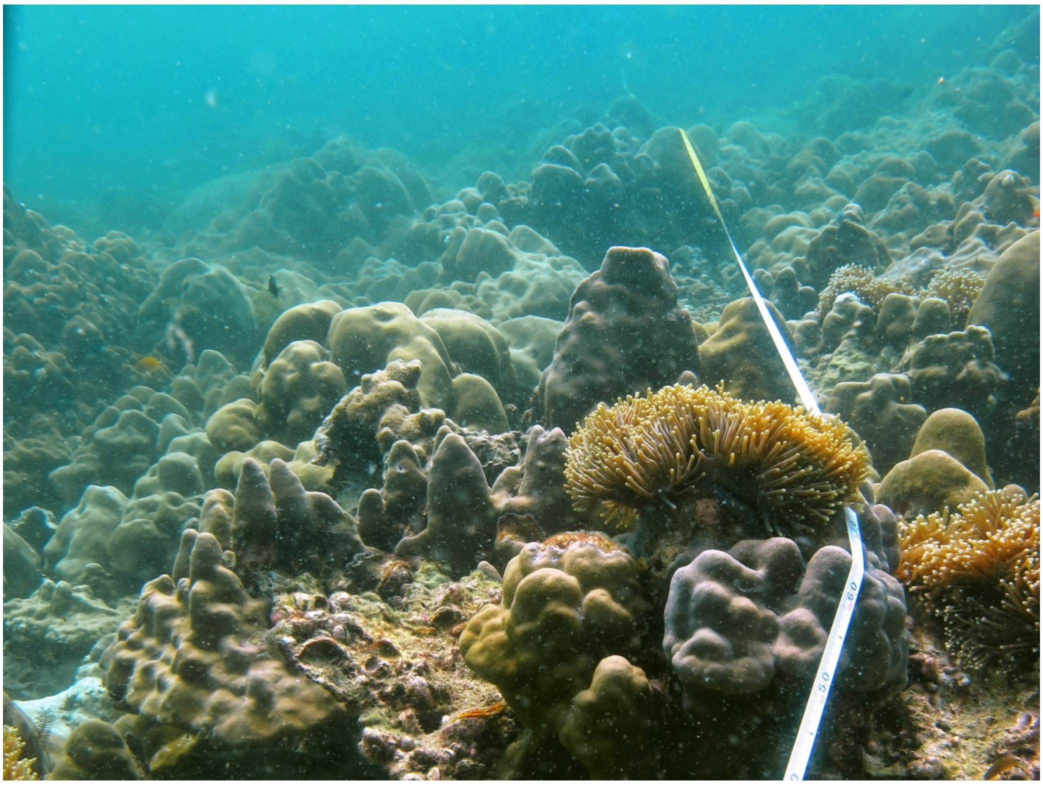


Figure 2.29 The low level of suspended particulate matter in the water column.

Figure 2.30 The moderate level of suspended particulate matter in the water column.

Figure 2.31 The high level of suspended particulate matter in the water column.

Table 2.2 The environmental description of twenty - two study reef sites.

Reef site	Crest depth	Max. depth	Transect depth	Coastal type	Reef bottom substrate	Relative visibility	Relative suspended particulate matter	Relative water motion/current
BMP-N	2.5	6.0	3.5	Sandy beach	Muddy - sand	Moderate	High	Moderate
BMP-E	1.0	5.5	2.5	Sandy beach	Muddy - sand	Moderate	High	High
BLL-SE	2.0	6.0	4.0	Rocky shore	Muddy - sand	Moderate	High	High
BLD-NE	2.0	7.5	3.5	Sandy beach	Muddy - sand	Moderate	High	Moderate
TKG-NE	1.0	5.0	2.0	Sandy beach	Muddy - sand	Poor	High	None - low
TRT-NE	2.0	7.0	3.0	Rocky shore	Muddy - sand	Poor	High	None - low
TRT-RS	1.5	6.0	3.0	Rocky shore	Muddy - sand	Poor	High	None - low
LAN-N	1.0	6.0	2.5	Sandy beach	Muddy - sand	Poor	High	None - low
KLG-SE	1.0	5.0	3.0	Rocky shore	Muddy - sand	Poor	High	None - low
KLL-E	1.0	6.0	2.5	Rocky shore	Muddy - sand	Poor	High	None - low
DNG-N	no crest	10.0	6.0	Rocky shore	Sand	High	Low	High

Table 2.2 The environmental description of twenty-two study reef sites (continued).

Reef site	Crest depth	Max. depth	Transect depth	Coastal type	Reef bottom substrate	Relative visibility	Relative suspended particulate matter	Relative water motion/current
DNG-NE	2.0	10.0	5.0	Rocky shore	Sand	Moderate	Low	Moderate
DNG-SE	no crest	10.0	6.0	Rocky shore	Sand	Moderate	Low	Moderate
DNG-PG	2.0	7.0	3.0	Rocky shore	Sand	High	Low	High
RWI-S	2.0	10.5	4.0	Sandy beach	Sand	Moderate	Moderate	None - low
YNG-NE	3.5	15.0	6.5	Rocky shore	Sand	Moderate	Low	Moderate
HNG-S	no crest	6.0	4.0	Rocky shore	Sand	Moderate	Low	None - low
ADG-AS	2.0	12.0	4.0	Sandy beach	Sand	Moderate	Moderate	High
ADG-RB	2.0	8.0	3.5	Sandy beach	Sand	Moderate	Moderate	High
ADG-S	no crest	7.5	3.0	Sandy beach	Sand	Moderate	Moderate	Moderate
ADG-SE	2.5	9.0	6.0	Sandy beach	Sand	Moderate	Moderate	High
ADG-MM	2.0	10.0	4.0	Sandy beach	Sand	Moderate	Moderate	High

2.4 Coral replenishment field survey and data collection

Data concerning juvenile coral abundance was provided by the annual monitoring database of the Marine National Park Operation Center (MNPIC - Trang) for a period of 2 years (Marine National Park Operation Center 3, Trang, 2014, 2015). The juvenile coral abundance data applying to 11 of the reef sites were surveyed according to the protocol in section 2.4 were available. There were 6 reef sites in the inshore reef habitat and 5 reef sites in the offshore reefs habitat (shown as highlighted rows in Table 2.2).

In the annual monitoring of the MNPIC - Trang, each site was monitored one time a year by their standard protocol; i.e. three 30 x 1m permanent belt - transects in the reef crest - upper slope zone in less than 6 m depth of water. Juvenile coral colonies in the belt transects were identified at generic levels and grouped into three size classes: ≤2 cm, <2 - 4 cm and <4 - 7 cm; colonies that could not be identified were recorded as unknown.

Since growth rates for different coral families varies greatly (Gladfelter *et al.*, 1978; James *et al.*, 2005; Kongjandtre *et al.*, 2014), numbers for the different juvenile size classes were pooled. The MNPIC - Trang data presented abundance as per transect, and so the data for each transect was multiplied by 25/30 to standardize the transect size to the same unit with the adult coral abundance data.

2.5 Data analysis

Multivariate analysis was used on both the environmental parameters and coral community generic composition data to explore the differences in parameters governing the composition of the coral communities. The resulting hierarchies were used to examine associations between different locations and coral genera. A canonical analysis was undertaken to examine relationships between environmental parameters and the components of the coral communities, Results from this part were intended to define patterns in spatial variation in environments or community composition among reef habitats.

I used nonparametric statistics to compare the differences in juvenile coral abundance between inshore and offshore reef habitats. Furthermore, χ^2 - contingency tables were used to test the homogeneity of the relationship between adult coral population and juvenile coral population. “Repeated measures” analyses of variance (RM-ANOVA) was conducted to examine the difference in juvenile recruitment between years amongst sites.

CHAPTER 3

Coral Communities of the Southern Andaman Sea

3.1 Introduction

Studies comparing inshore and offshore reef systems around the world usually conclude that there are fundamental differences between them. Several characteristics of coral reef habitat such as species richness, live coral cover, coral community composition as well as environmental parameters were reported spatial variation along the costal o offshore reefs (Browne *et al.*, 2012; Cleary *et al.*, 2005, 2008; Cooper *et al.*, 2007; Done, 1982; Fabricius *et al.*, 2012; Lirman and Fong, 2007). However, the results of previous studies likely created a false expectation of the nature of inshore - offshore reef systems in Thailand. Most of the reefs in Thai water are continental island fringing reefs, unlike reef systems described in overseas studies, in which the offshore components tend to be barrier/atoll/patch reefs. This means that the usual model assumes terrigenous influences diminish with distance from the mainland whereas offshore reefs in Thailand are still exposed to some of these influences (Department of Fisheries, 1999; Phongsuwan *et al.*, 2013). With geographical and morphological differences of reefs in Thai water, the fundamental understanding of inshore - offshore islands fringing reefs should be assumed to work differently from the literature. In the southern Andaman Sea, Satun province, its coastal area is edged by estuaries and mangrove forests and the coral reefs are fringing reefs formed around continental islands. There are three island groups existing in the same latitude (6°28'N - 6°51'N) along approximately 70 km transect from the mainland. They form an east - west line out from the mainland which is hypothetically influenced by the gradient of terrestrial influence and terrigenous sediments. Therefore, this study aim to redress an understanding about spatial variations in fringing reef communities in Thai water and define key characters of reef habitats in the southern Andaman Sea of Thailand.

3.2 Objectives

To examine differences in coral community composition in the inshore and offshore reef environments in the southern Andaman Sea of Thailand

To determine whether coral assemblages are correlated to environmental differences in inshore or offshore reefs

3.3 Research questions

Are the compositions of coral communities of inshore and offshore reef sites in the southern Andaman Sea different according to distance from the mainland?

What environmental factors are associated with inshore and offshore coral assemblages?

3.4 Materials and methods

Study area

The study area was continental island fringing reefs in the southern Andaman Sea of Thailand consisting of 3 island groups: Tarutao, Bulon, and Adang - Rawi. The reef area around the various islands were surveyed initially by snorkel divers to establish broad patterns of diversity and coverage within groups; 22 sites were selected randomly from amongst those exhibiting relatively high live coral coverage: 6 stations in the Tarutao islands, 4 stations in the Bulon islands and 12 stations in the Adang - Rawi islands as shown in Figure 3.1.

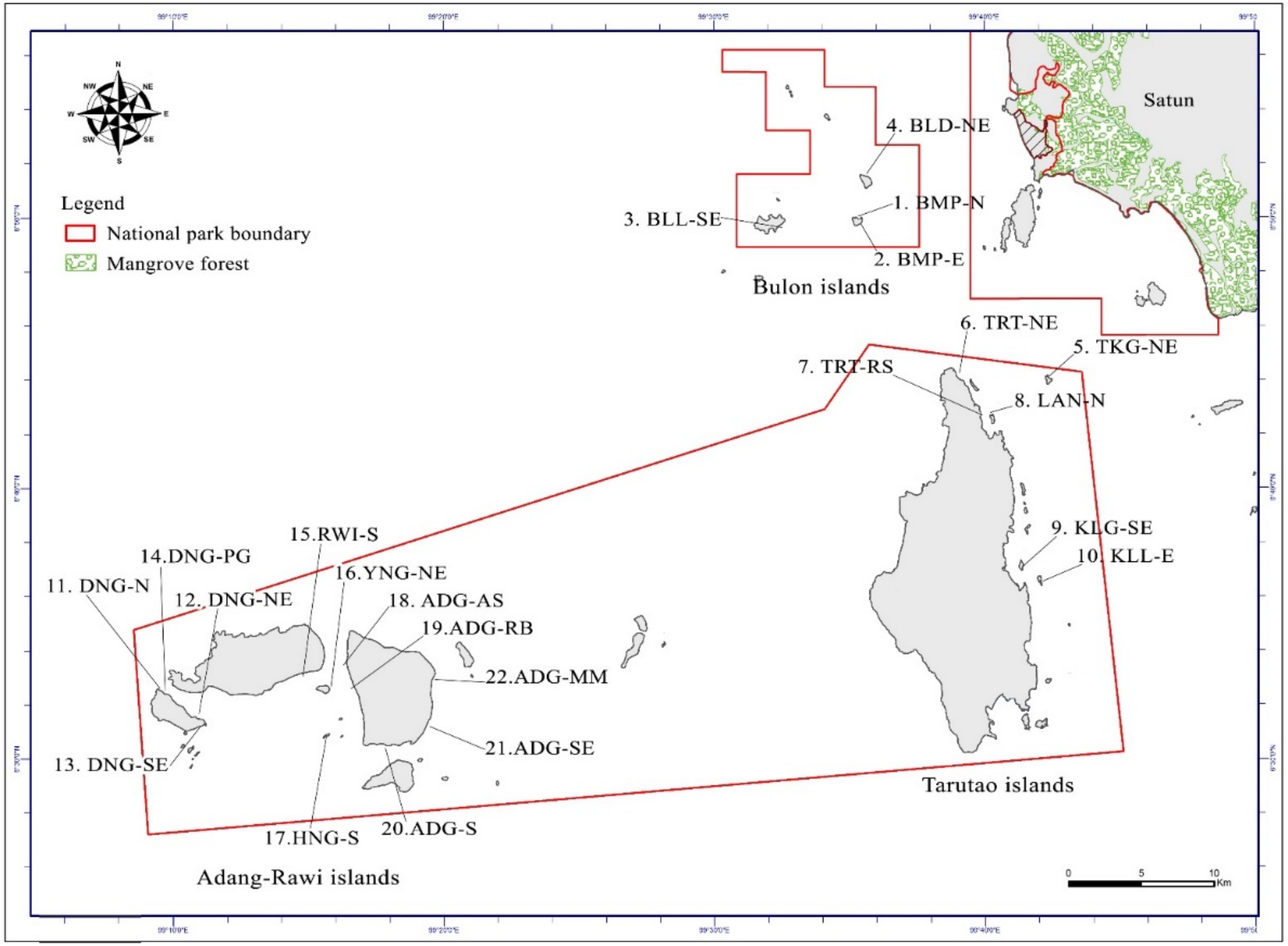


Figure 3.1 The study sites in Satun province, including 22 inshore and offshore stations in Bulon, Tarutao and Adang - Rawi island group.

Data collection

Primary data collection for this study was undertaken between December 2013 - July 2014. Three replicate 25 x 1m belt-transects were laid at 1 - 2 m below the reef edge (reef crest) at each site (Figure 3.2). Scleractinian colonies in the transect area were identified to genus level and recorded on underwater paper. Colonies that appeared difficult to identify underwater were photographed using a high - resolution underwater camera for later comparison with a taxonomic reference (Veron, 2000). No physical specimens collecting in this study, since identification of a coral to genus level from photographs was feasible in all cases. Key characteristics of the reef sites (such as reef morphology and visibility, and gross estimates of suspended material and substrate type of the reef bottom) were obtained by visual inspection during the field data collection. Maximum depth of the reef at each of the stations was recorded by the observer in situ using SCUBA instrumentation. Underwater visibility and levels of suspended particulate matter were categorized during the coral community survey into three levels, low - high.

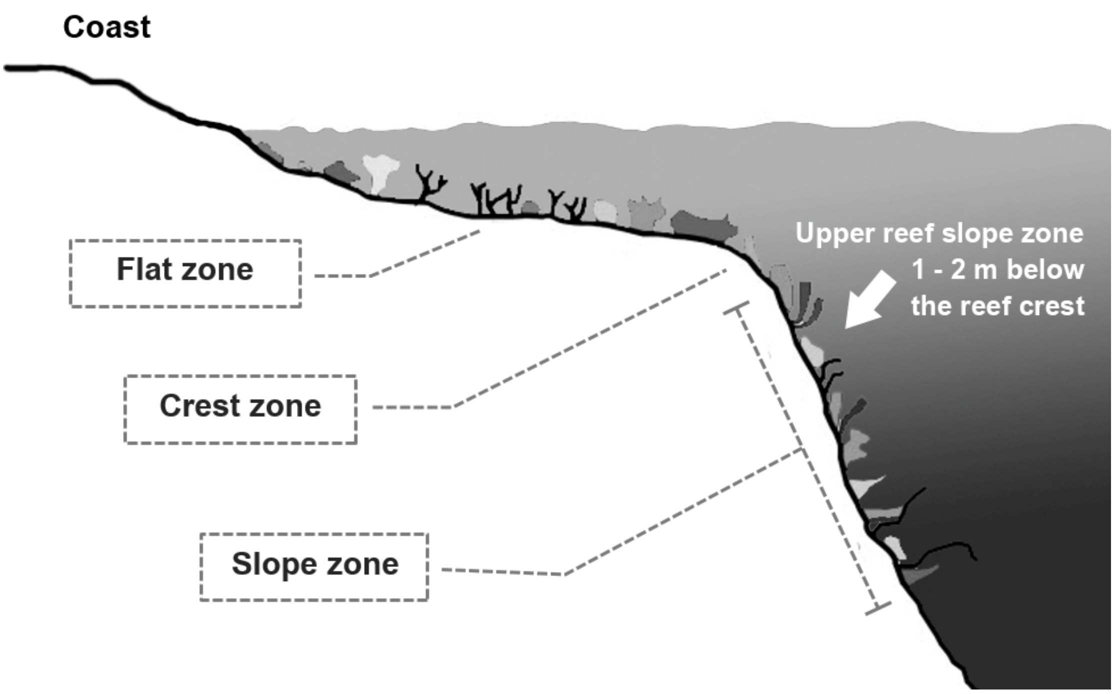


Figure 3.2 Belt-transects were laid along the upper reef slope zone, where coral diversity on most reefs is usually greatest (Tomascik *et al.*, 1997), approximately 1 - 2 m below the reef crest indicating in this figure with the arrow.

Data analysis

Six physical characters were used to examine any associations between the reef stations and coral community composition: coastal geography, bottom substrate, visibility, level of suspended matters, maximal reef depth, and hydrographic conditions Data for each site were analyzed by Principle Component Analysis (Cooper *et al.*, 2007).

For this study, I used average number of colonies of each coral genus per transect (colony/25 m^2) to describe coral community composition. Since the composition of each coral community varied (sometimes quite widely) between stations, and even within reef sites, the data set contained a large number of “zero values”, and the raw data were heteroscedastic to the point where standard parametric statistics were not possible. Therefore, average colony numbers in each transect were subjected to Log x+1 transform before subjecting them to a series of multivariate analyses to examine different patterns in coral community composition. Cluster analysis (CA) was used as an oversight statistic to examine groupings of coral assemblages in the study area (Mumby and Harborne, 1999). I then used PCA to examine the association between the coral community compositions amongst sites. Canonical correspondence analysis (CCA) was used to examine the association between the occurrence and abundance of the different coral genera and environmental conditions recorded for each site (Adjeroud *et al.*, 2010). All analyses were performed using the statistical software PCORD5.10 (McCune and Mefford, 2006).

3.5 Results

3.5.1 The environmental differences between inshore and offshore reefs

The PCA of environmental and geological parameters across the reef sites (Figure 3.3) highlighted several differences between the environmental conditions experienced by coral communities at inshore and offshore sites. The first 2 principal components explained more than 80% of variance and were comprised by relative suspended particulate matter, relative underwater visibility, relative hydrographic conditions (water motion), maximal reef depth, bottom substrate composition, coastal geography and distance from the mainland. The offshore reef stations tended to locate further from the coast of Satun province and were characterized by moderate - high visibility, low - moderate suspended matter and mode rate - strong water motion. The reef bottom tended towards sandy substrate, with the maximum depth of the reef at each station ranging from 6 - 15 meters deep. The inshore reefs typically were characterized by high amounts of suspended particulate matter and having poor - moderate visibility. They were muddy sand bottom substrate and located closer to the coast of Satun province than the offshore reefs as well as maximal reef depth varying from 5 - 8 meters deep. However, the environmental conditions of inshore reefs varied widely, and were affiliated with proximity to a source of terrestrial influence. For example, the Tarutao reefs, which are located closer to mangrove forest than the Bulon reefs, were more turbid and were subject to higher levels of suspended matter than the sites near Bulon. The coastal geography showed a weak association on both axises and across the reef stations.

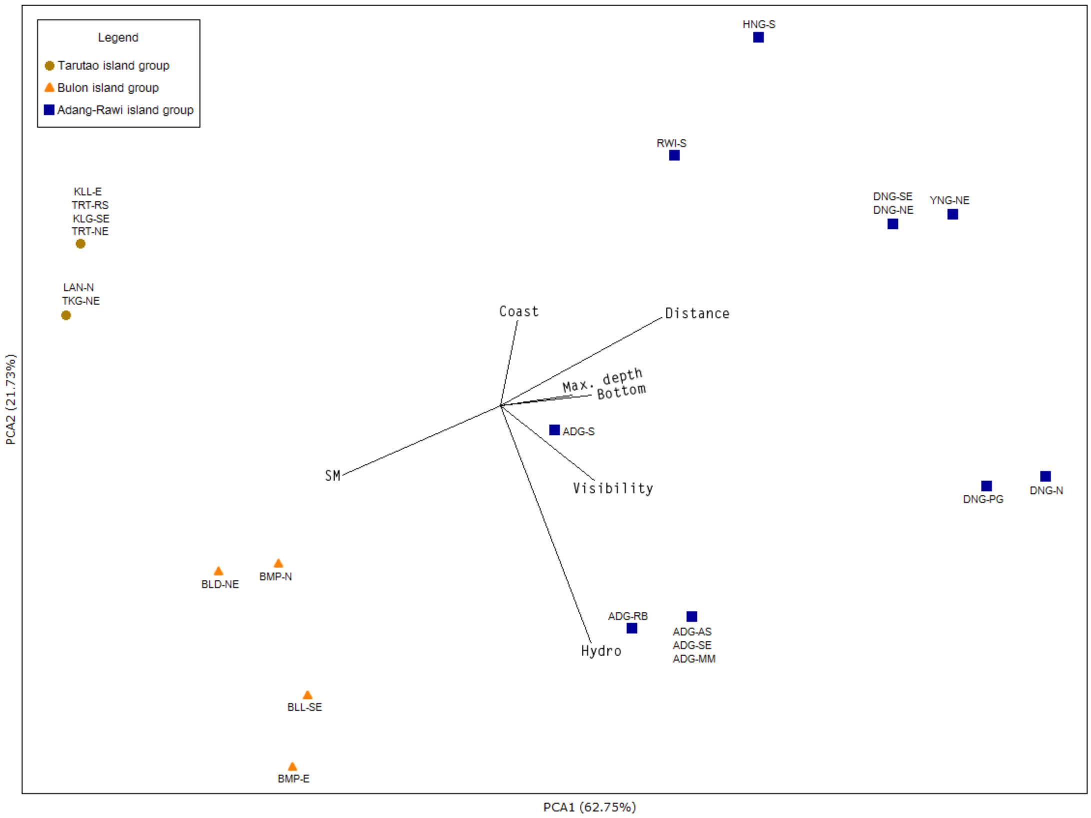
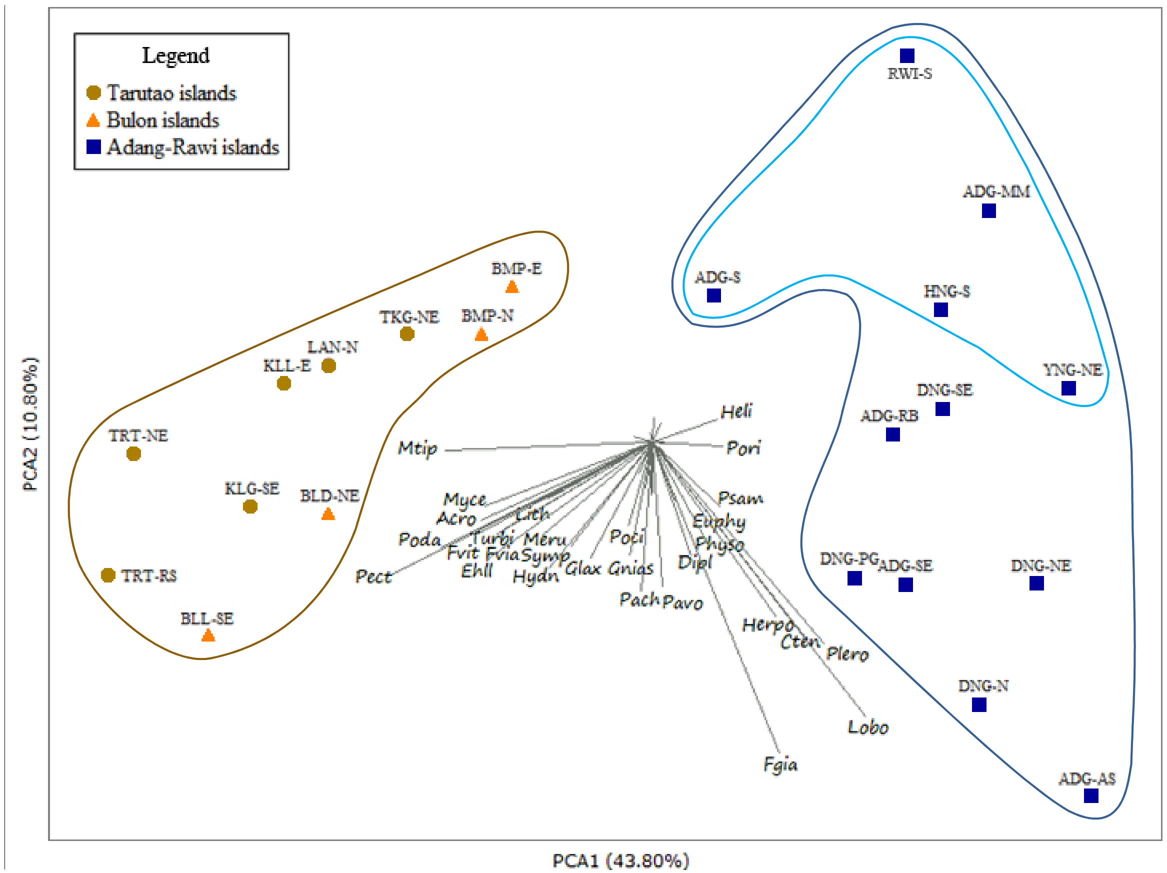


Figure 3.3 PCA biplot of environmental conditions observed across the reef sites. Distance, distance from the mainland; SM, level of suspended matters in the water column; Visibility, levels of underwater visibility; Max. depth, maximal depth of reef; Hydro, hydrographic conditions; Bottom, reef bottom substrate and Coast, coastal geography.

3.5.2 Overview of coral communities in the southern Andaman Sea

Forty - two genera of scleractinian corals (from fourteen families) were recorded during this study. Eleven genera were found at all stations. They include: *Acropora*, *Pavona*, *Cyphastrea*, *Favia*, *Favites*, *Goniastrea, Leptastrea, Platygyra*, *Symphyllia*, *Goniopora*, and *Porites*. Coral genera *Astreopora*, *Tubastrea*, and *Oxypora* rarely were found within the study area. The most common growth form in the study sites was massive corals. Overall, massive *Porites* spp. were the most common coral found in all stations.

The generic composition of coral assemblages in the study area showed a division into two groups that were associated with their locations. These groupings were highlighted by PCA result which the first two axes explained 54.6% of the total variability of the data. The first group was comprised of 10 stations in the inshore island reefs, including four stations in the Bulon Islands and six reef stations in the Tarutao Islands as shown in Figure 3.4 by brown circular and orange triangular symbols, respectively. The Bulon and Tarutao Islands had a high occurrence of *Pectinia* spp., *Montipora* spp. and *Podabacia* spp., when compared to another group. The cluster analysis (Figure 3.5) suggested that the inshore island reefs had 51% similarity of the generic compositions among reefs within this group. The second group included twelve stations in offshore island reefs (the Adang-Rawi Islands) as shown with blue square symbols in Figure 3.4. Generally, the Adang - Rawi coral assemblages were characterized by a presence of *Lobophyllia* colonies and relatively high numbers of *Plerogyra* and solitary Fungiid corals, but they was not homogenous throughout the island group; the cluster analysis (Figure 3.5) suggested only 13% of similarity for generic compositions among reefs within the offshore stations. The coral assemblage composition of Rawi Island station (RWI-S), south of Adang Island station (ADG-S), Mae Mai Bay (ADG-MM), South of Hin Ngam Island (HNG-S) and northeast of Yang Island station (YNG-NE) showed a subordinate character which is implicitly different from most of the Adang-Rawi reefs. They tended to have a low generic richness and low abundance of *Lobophyllia*, *Plerogyra* and *Fungia*, which were key genera of the Adang-Rawi assemblage.



Acronym	Coral Genus
Acro	*Acropora*
Astr	*Astreopora*
Coel	*Coeloseris*
Cosc	*Coscinaraea*
Cten	*Ctenactis*
Cyph	*Cyphastrea*
Dipl	*Diploastrea*
Ehll	*Echinophyllia*
Epora	*Echinopora*
Euphy	*Euphyllia*
Fvia	*Favia*
Fvit	*Favites*
Fgia	*Fungia*
Glax	*Galaxea*
Gardi	*Gardineroseris*
Gnias	*Goniastrea*
Gnio	*Goniopora*
Heli	*Heliopora*
Herpo	*Herpolitha*
Hydn	*Hydnophora*
Lptas	*Leptastrea*
Lpto	*Leptoria*
Lith	*Lithophylon*
Lobo	*Lobophyllia*
Meru	*Merulina*
Mtas	*Montastrea*
Mtip	*Montipora*
Myce	*Mycedium*
Oxyp	*Oxypora*
Pach	*Pachyseris*
Pavo	*Pavona*
Pect	*Pectinia*
Physo	*Physogyra*
Platy	*Platygyra*
Plero	*Plerogyra*
Poci	*Pocillopora*
Poda	*Podabacia*
Pori	*Porites*
Psam	*Psammocora*
Symp	*Symphyllia*
Tubas	*Tubastrea*
Turbi	*Turbinaria*

Figure 3.4 PCA biplot of Log x+1 transformed generic abundance in the 22 reef stations suggested an association among coral genera and reef stations in the southern Andaman Sea. Vectors represented the association of genera on coral community characteristics. The brown boundary highlighted 51% similarity of inshore coral communities. The navy boundary highlighted 13% similarity of offshore coral communities; the light blue boundary proposed a subgroup within the offshore coral communities.

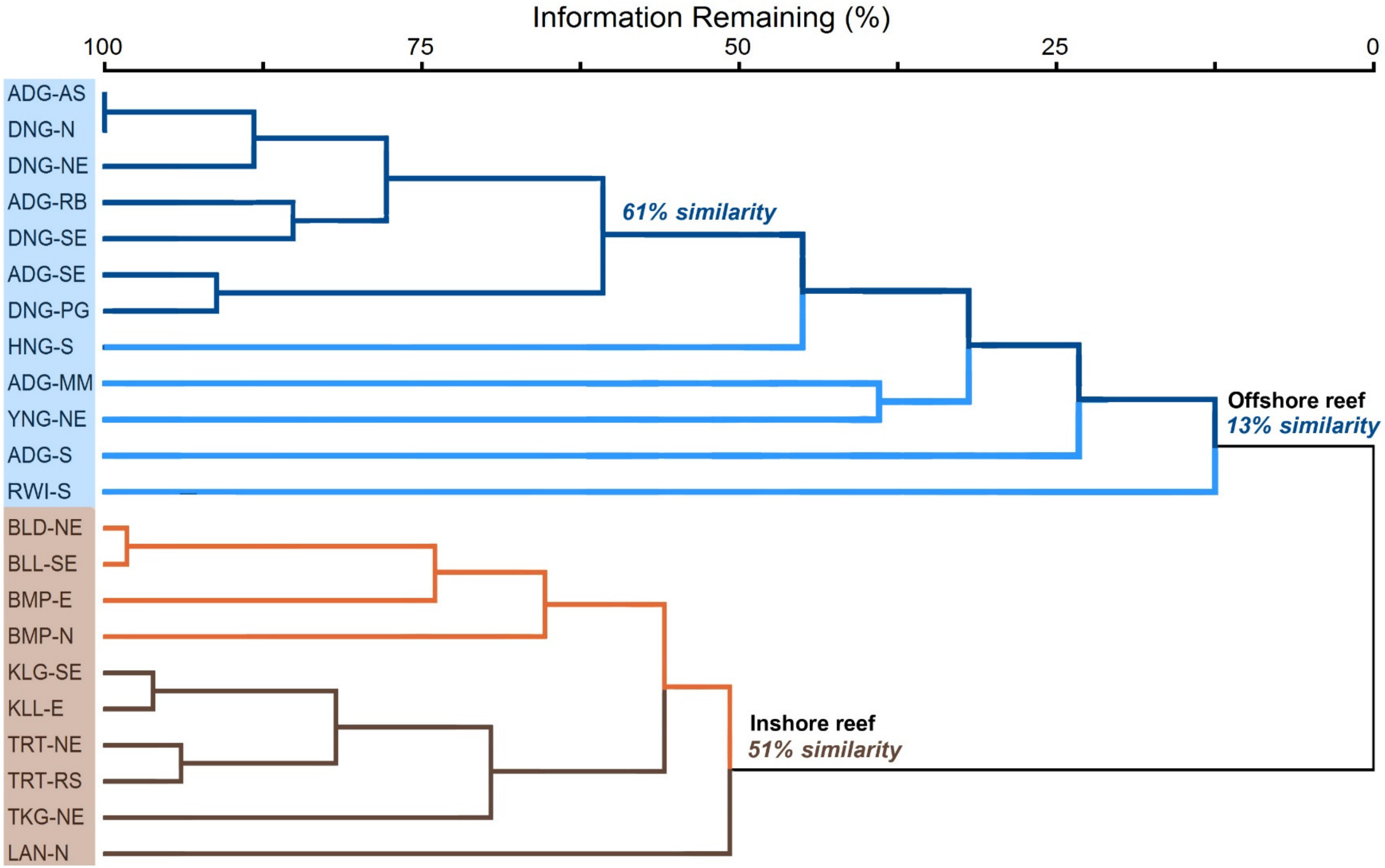


Figure 3.5 Cluster analysis dendrogram of coral community composition of 22 sites in the southern Andaman Sea suggests 2 types of the coral community according to inshore - offshore reef habitats and indicated the similarity of coral communities in the groups.

3.5.3 Environmental factors influencing the spatial distribution of corals

The relationship between coral generic abundance and the environmental conditions of the station was examined by Canonical Correspondence Analysis (CCA). The first two axes explained 42.6% of variance. The Monte Carlo test results in Table 3.1 indicate that there was a significant correlation on CCA1 ($p<0.01$). Visibility, hydrographic conditions, maximum depth of reef, and reef bottom substrate were negatively associated with CCA1, whereas suspended matter was positively associated. On the second axis (CCA2), 7.4% of variance was explained. Maximum depth of reef ($r = 0.411$) and type of coast ($r = 0.343$) were slightly associated with CCA2. The association between coral genera and reef environments (Figure 3.6) suggested a distributed preference of coral genera to bottom substrate and environmental parameters. *Herpolitha*, *Ctenactis*, *Montastrea*, *Plerogyra* and *Lobophyllia* were associated with high visibility and low suspended matter conditions, and they prefer sandy reef bottom and deep maximum depth of reef which attribute Adang - Rawi reef environments. On the other hand, *Lithophyllon*, *Astreopora*, *Pectinia*, *Mycedium* and *Turbinaria* were associated with high suspended matter, low visibility, and muddy-sand bottom.

Table 3.1 Canonical correspondence values and percent explained variance associated with the first two axes for habitat and substrate variables measured.

	CCA1	CCA2
Eigenvalue	0.181	0.039
% Explained variance	35.4	7.7
Variance accumulated	35.4	43.1
Monte Carlo Test for eigenvalues (999 permutations)		
Mean	0.689	0.851
Pearson correlation	0.988	0.936
P =	0.001	-
Variables		
Distance from the mainland	-0.913	0.337
Maximal depth of reef	-0.718	-0.391
Suspended matter	0.917	-0.278
Underwater visibility	-0.702	0.235
Hydrographic condition	-0.546	-0.286
Maximum depth of reef	-0.788	0.411
Coastal geography	0.043	0.174
Reef bottom substrate	-0.973	0.103

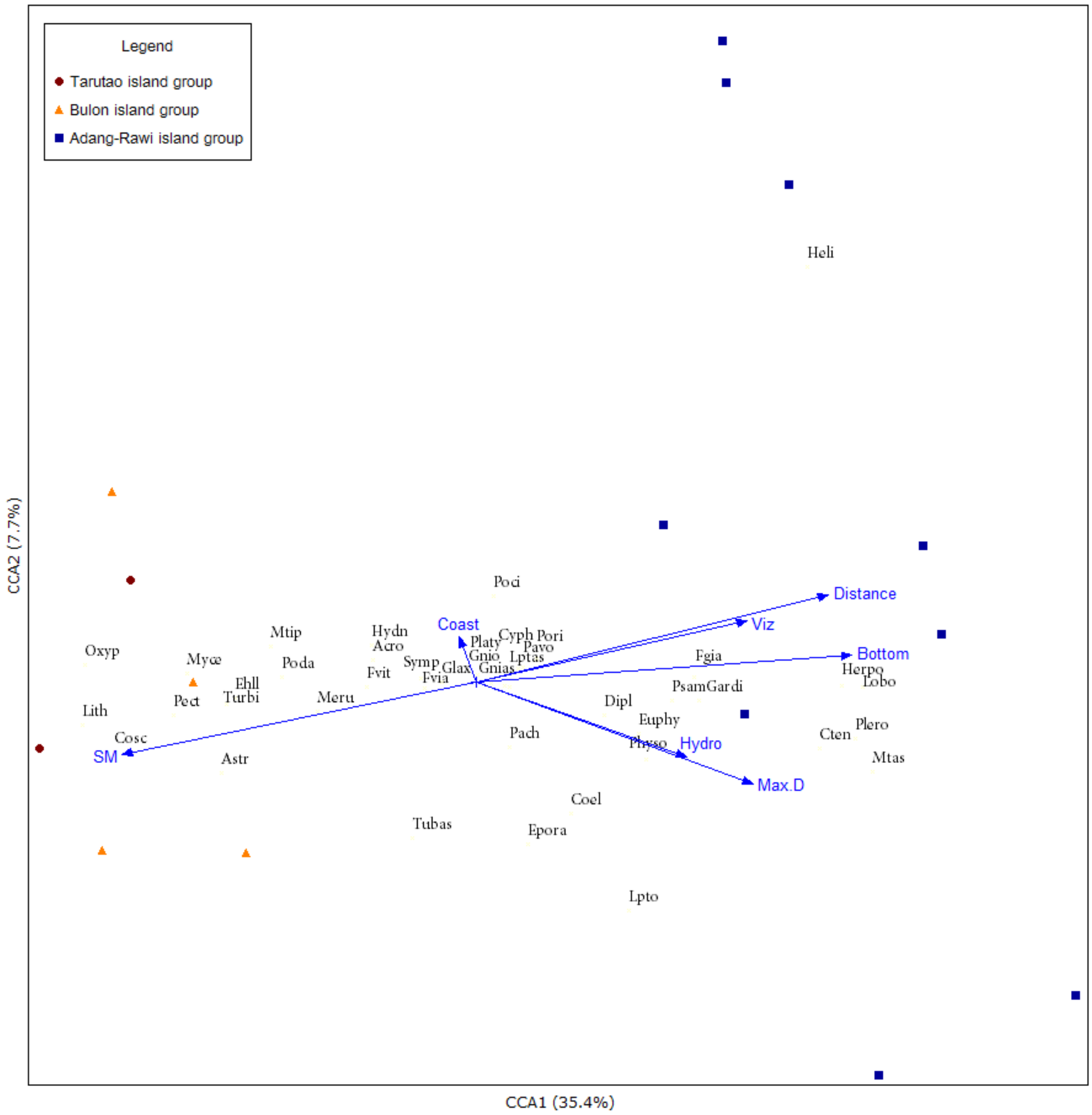
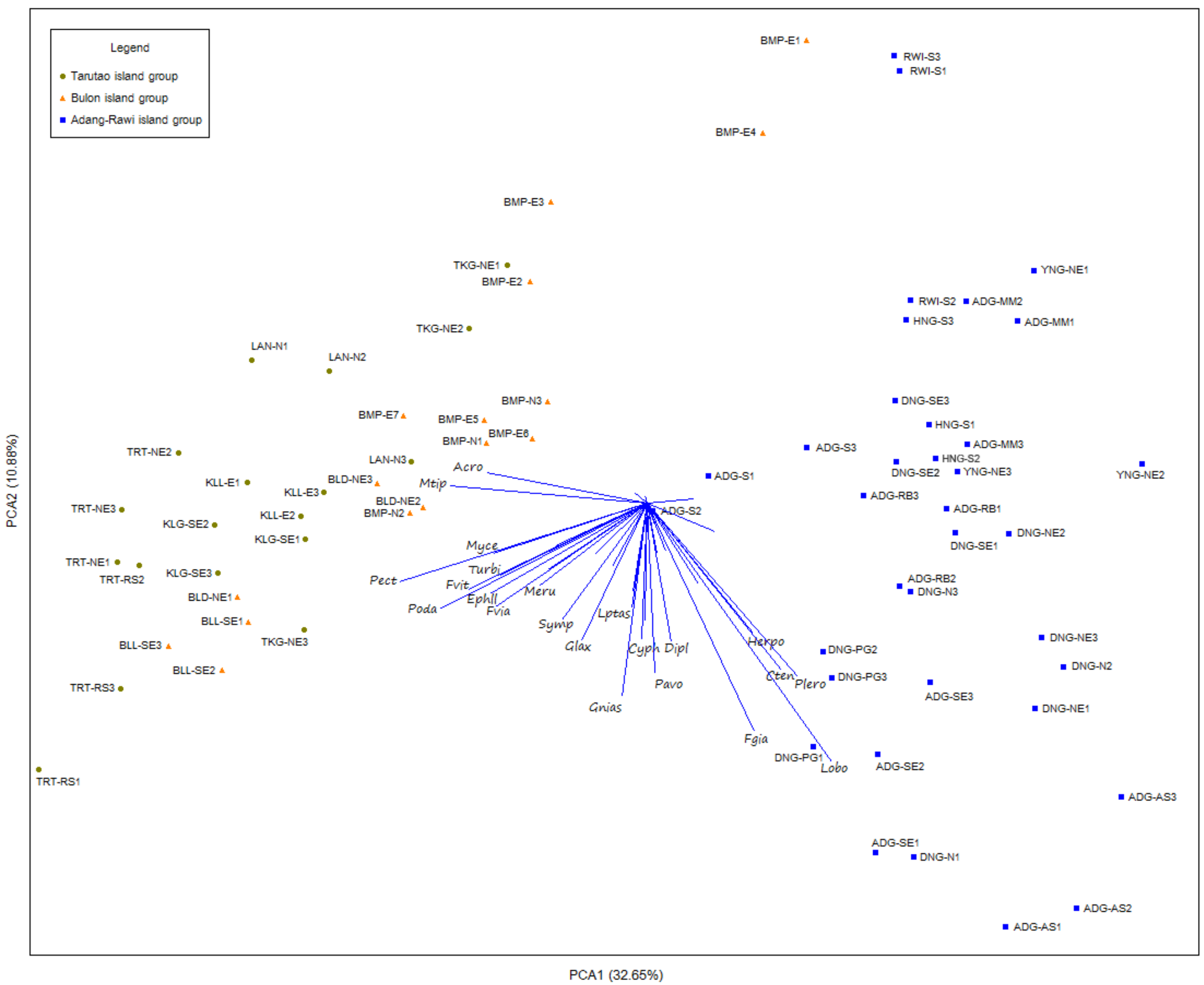


Figure 3.6 Canonical correspondence analysis (CCA) biplot performed the relationships between spatial variation in the abundance of coral genera and the environmental conditions. Each symbol represents a reef station. Labeled lines indicate the direction of each environmental variable changes: SM, Suspended matter; Coast, Coastal geography; Distance, Distance from the Satun coast; Viz, Visibility; Bottom, Reef bottom substrate; Max.D, Maximum depth of reef; Hydro, Hydrographical conditions.

3.6 Coral community composition variation amongst reefs

In general, the coral community in the southern Andaman Sea could be divided into two groups that are associated with inshore and offshore reef habitats. Offshore reef communities were associated with the presence of *Lobophyllia* and *Plerogyra* and relatively higher visibility, lower level of suspended materials, and a deeper maximal reef depth. Contrastingly, the inshore reef community in both island groups were more abundant in certain genera: *Pectinia*, *Montipora, Acropora* and *Podabacia*, when compared to the offshore community. The inshore reef moreover exhibited typically low visibility and relatively high amounts of suspended matter as well as quite shallow maximal reef depth.

Additionally, the results of the PCA of coral composition at transect level reiterated the separation of coral communities in this region as well as the association between coral genera and reef sites (Figure 3.7). It explored variation within sites and among the three island groups; the PCA result showed in Figure 3.7 suggests that the coral communities of Tarutao Islands and Adang - Rawi Islands were completely different from each other. All transects of Tarutao - inshore sites (brown circular symbol in Figure 3.7) were separately scattered from all transects of Adang - Rawi sites (blue square symbol in Figure 3.7). However, the coral community of Bulon Island group showed an overlap between both communities; the transects of Bulon - inshore sites (orange triangle symbol in Figure 3.7) were distributed between the Tarutao and Adang - Rawi sites, and had some transects: east of Bulon Mai Pai transect number 1 and 4 (BMP-E1 and BMP-E4) that seem to be grouped with the Adang - Rawi group. The overlap of Bulon community was consistent to its environmental conditions that the Bulon reefs were less turbid and subject to lower levels of suspended matter than the sites closer to mangrove forest like Tarutao Islands.



Acronym	Coral Genus
Acro	*Acropora*
Astr	*Astreopora*
Coel	*Coeloseris*
Cosc	*Coscinaraea*
Cten	*Ctenactis*
Cyph	*Cyphastrea*
Dipl	*Diploastrea*
Ehll	*Echinophyllia*
Epora	*Echinopora*
Euphy	*Euphyllia*
Fvia	*Favia*
Fvit	*Favites*
Fgia	*Fungia*
Glax	*Galaxea*
Gardi	*Gardineroseris*
Gnias	*Goniastrea*
Gnio	*Goniopora*
Heli	*Heliopora*
Herpo	*Herpolitha*
Hydn	*Hydnophora*
Lptas	*Leptastrea*
Lpto	*Leptoria*
Lith	*Lithophylon*
Lobo	*Lobophyllia*
Meru	*Merulina*
Mtas	*Montastrea*
Mtip	*Montipora*
Myce	*Mycedium*
Oxyp	*Oxypora*
Pach	*Pachyseris*
Pavo	*Pavona*
Pect	*Pectinia*
Physo	*Physogyra*
Platy	*Platygyra*
Plero	*Plerogyra*
Poci	*Pocillopora*
Poda	*Podabacia*
Pori	*Porites*
Psam	*Psammocora*
Symp	*Symphyllia*
Tubas	*Tubastrea*
Turbi	*Turbinaria*

Figure 3.7 Principle component analysis (PCA) result based on station transect level suggested pattern in coral community of the study area. Each symbol represents a reef station and island group. Vectors indicate the association of coral genera and coral community characteristics.

3.6.1 Bulon Islands

In general, the coral community of the Bulon Islands was dominated by abundant massive *Porites* spp. A large majority of *Porites* colonies exhibiting traces of partial mortality throughout the area. Coral genera *Acropora*, *Favia* and *Podabacia* were frequently the second or third most abundant and were a major component of the overall assemblage. The coral genus *Lobophyllia* was not present in the surveyed area. All Bulon stations were composed of several genera of corals, except for the station that was east of Bulon Mai Pai, which displayed an unusually low generic diversity.

Station 1 North of Bulon Mai Pai Island (BMP-N)

Station North of Bulon Mai Pai Island was dominated by massive *Porites* spp. A total of 23 genera of scleractinian corals were found. The most common growth forms were massive and encrusting. The coral community was mainly composed of Poritidae, Faviidae, Mussidae and Acroporidae. Massive *Porites* was the most abundant throughout the 3 transects (average 39.3 ± 4.9 colonies/25 m^2); followed by massive *Favia* spp. averaging 17.3 ± 1.5 colonies/25 m^2, *Cyphastrea* spp., *Symphyllia* spp. and *Acropora* spp. averaging 13.7 ± 1.2; 12.7 ± 2.9; 11.3 ± 2.3 colonies/25 m^2, respectively).

Station 2 East of Bulon Mai Pai Island (BMP-E)

The station east of Bulon Mai Pai Island was dominated by massive *Porites* spp. There were 23 genera of scleractinian corals found in this station. The most common growth forms were massive, encrusting and submassive. The coral community was mainly composed of Poritidae, Acroporidae, Faviidae and Agariciidae. Massive *Porites* was the most abundant in 7 transects (average 54.0 ± 12.7 colonies/25 m^2); followed by *Acropora* spp. averaging 18.0 ± 3.6 colonies/25 m^2, *Favia* spp., *Pavona* spp. and *Platygyra* spp. (average 11.3 ± 2.3; 6.3 ± 1.6; 6.3 ± 1.2 colonies/25 m^2, respectively). A PCA biplot based on each transect (6) highlighted a large variation among transects. The two of transects were distinctly separated from the remaining Tarutao-Bulon stations. BMP-E1 and BMP-E4 both had a low diversity of coral genera; they each had a high abundance of *Porites* spp. and *Acropora* spp., and a few colonies of *Favia*, *Pavona*, *Platygyra*, *Hydnophora*, *Montipora*, *Leptastrea*, *Cyphastrea*, *Galaxea*, *Psammocora*, *Goniastrea*, *Fungia* and *Pocillopora*.

Station 3 Southeast of Bulon Le Island (BLL-SE)

The reef station southeast of Bulon Le Island was dominated by *Porites*. There were 32 total genera of scleractinian corals found in this station. The most common growth forms were massive and encrusting. The coral community was mainly comprised of Poritidae, Acroporidae, Faviidae, Fungiidae, Agariciidae and Pectinidae. Massive *Porites* was the most abundant (average 39.7 ± 5.8 colonies/25 m^2); followed by *Acropora* spp. averaging 24.7 ± 2.8 colonies/25 m^2, *Podabacia* spp., *Favia* spp., *Favites* spp., *Pavona* spp. and *Echinophyllia* spp. (average 21.0 ± 0.6; 16.0 ± 2.1; 14.0 ± 1.5; 12.7 ± 5.2; 11.0 ± 0.0 colonies/25 m^2, respectively).

Station 4 Northeast of Bulon Don Island (BLD-N)

The northeast station of Bulon Don Island was dominated by massive *Porites* spp. A total of 28 genera of scleractinian corals were found. The most common growth forms were massive and encrusting. The coral community was mainly composed of Poritidae, Acroporidae, Fungiidae, Faviidae, Agariciidae and Pectinidae. *Porites* abundance averaged 41.3 ± 2.0 colonies/25 m^2. The second most abundant was Acropora spp. (average 27.7 ± 5.5 colonies/25 m^2) followed by *Podabacia* spp. (average 24.0 ± 3.0 colonies/25 m^2), *Favia* spp., *Pavona* spp., *Cyphastrea* spp., *Hydnopora* spp., *Fungia* spp., *Montipora* spp. and *Echinophyllia* spp, (average 16.7 ± 2.4; 11.7 ± 3.8; 8.3 ± 2.3; 7.3 ± 1.3; 6.7 ± 1.8; 6.0 ± 0.0 colonies/25 m^2, respectively)

3.6.2 Tarutao Islands

The coral community of the Tarutao Islands was typically dominated by abundant massive *Porites* spp. or *Favia* spp. All of the stations had a high level of generic diversity. This community was most abundant with *Porites* spp., *Favia* spp., *Pectinia* spp. and *Montipora* spp. Faviid corals, including *Leptastrea* spp., *Platygyra* spp., *Cyphastrea* spp. and *Favites* spp. were common and numerous genera of Tarutao coral community.

Station 5 Northeast of Ta Kiang Island (TKG-NE)

A total of 29 genera of scleractinian corals were found at the northeast of Ta Kiang Island, with massive growth form being the most common. The majority of the coral community was composed of Poritidae, Faviidae, Acroporidae, Fungiidae, and Pectinidae. The three most abundant species were *Porites* spp., *Favia* spp. and *Montipora* spp. averaging 30.7 ± 5.5; 22.7 ± 9.7; 14.7 ± 2.0 colonies/25 m^2, respectively. PCA results based on each transect (Figure 3.7) presented great variation among transects at this station. Transect number 3 (TKG-NE3) scattered separately from the rest (TKG-NE1 and TKG-NE2). This is likely due to a high occurrence of *Favia* colonies (42 colonies/25 m^2), whereas the remaining two transects had far fewer, averaging 13 colonies/25 m^2.

Station 6 Northeast of Tarutao Island (TRT-NE)

The most common growth forms found were massive and encrusting, among the 27 genera of scleractinian corals at the station northeast of Tarutao Island. The coral community mainly consisted of Faviidae, Poritidae, Acroporidae and Pectinidae. Massive and encrusting *Favia* spp. were the most abundant (average 25.7 ± 2.7 colonies/25 m^2). Massive *Porites* spp. was the second most abundant (average 21.7 ± 3.7 colonies/25 m^2) followed by *Montipora* spp. (average 16.3 ± 0.9 colonies/25 m^2), *Platygyra* spp. (average 15.3 ± 1.2 colonies/25 m^2), *Pectinia* spp. (average 13.3 ± 2.7 colonies/25 m^2) and *Acropora* spp. (average 13.0 ± 1.2 colonies/25 m^2).

Station 7 Rue Si Bay, Tarutao Island (TRT-RS)

Massive colony growth form was common in the Rue Si Bay station. The coral community consisted of various families such as Pectinidae, Poritidae, Faviidae, Agariciidae and Acroporidae. The coral community was dominated by massive *Porites* spp cover, but the *Pectinia* spp., *Porites* spp. and *Favia* spp. were the three most abundant genera averaging 30.3 ± 2.6; 29.7 ± 2.9; 28.0 ± 4.9 colonies/25 m^2, respectively. *Cyphastrea* spp. was the fourth most abundant averaging 22.0 ± 3.2 colonies/25 m^2, followed by *Favites* spp., *Mycedium* spp. and *Goniastrea* spp. (average 18.7 ± 2.4; 18.0 ± 4.0; 14.7 ± 5.2 colonies/25 m^2). These three transects in Rue Si Bay possessed several key genera associated with Bulon-Tarutao community including: *Pectinia*, *Favia*, *Favites*, *Mycedium* and *Acropora*.

Station 8 North of Laen Island (LAN-N)

A total of 27 genera of scleractinian corals were found in station north of Laen Island, with the most common growth forms being massive and encrusting. The coral community was mainly comprised of Acroporidae, Poritidae, Faviidae, Pectinidae and Pocilloporidae. Coral genus *Montipora* was the most abundant within the 3 transects surveyed (average 25.3 ± 6.1 colonies/25 m^2); followed by massive *Porites* averaging

18.3 ± 4.4 colonies/25 m^2. The third most abundant were genera *Favia* and *Pectinia* averaging 11.7 ± 1.8 colonies/25 m^2; followed by *Pocillopora* and *Acropora* (average 10.0 ± 4.6; 9.7 ± 3.7 colonies/25 m^2, respectively).

Station 9 Southeast of Klang Island (KLG-SE)

The southeastern station of Klang Island had a total of 28 genera of scleractinian corals with massive corals being the most common growth form. The coral community was primarily composed of Poritidae, Faviidae, Pectinidae and Acroporidae. The most abundant genus was *Porites* spp. with a mean of 41 ± 8.1 colonies/25 m^2. *Favia* spp. (29.3 ± 3.2 colonies/25 m^2) and *Pectinia* spp. (average 25.3 ± 0.9 colonies/25 m^2) were the second and third most abundant. The fourth most abundant species was *Acropora* spp. averaging 18.7 ± 2.6 colonies/25 m^2; followed by *Favites* spp. and *Cyphastrea* spp. (average 15.7 ± 1.8 and 12.3 ± 2.4 colonies/25 m^2).

Station 10 East of Klua Lo Island (KLL-E)

A total of 23 genera of scleractinian corals were found in the east of Klua Lo Island. The most common growth form was massive and the coral community was commonly composed of Faviidae, Poritidae and Pectinidae. Coral genus *Favia* was the most abundant throughout the three transects (average 36.3 ± 2.3 colonies/25 m^2); followed by massive *Porites* spp. averaging 20.7 ± 4.8 colonies/25 m^2. The third most abundant genus was *Pectinia* averaging 20.0 ± 3.2 colonies/25 m^2; followed by *Favites* spp., *Goniopora* spp., *Galaxea* spp. and *Cyphastrea* spp. (average 19.7 ± 4.7; 14.7 ± 5.0; 12.7 ± 3.7; 12.3 ± 1.2 colonies/25 m^2, respectively).

3.6.3 Adang-Rawi Islands

Coverage in the Adang - Rawi coral community was dominated by massive *Porites* spp. Additionally, the highest number of individuals in all of the reef stations was colonies of *Porites* spp. The community was also composed of both massive and encrusting Faviid corals: *Cyphastrea* spp. and *Leptastrea* spp., and *Pavona* spp. The key genera to separate this island group from the Bulon - Tarutao group were *Lobophyllia* spp., *Plerogyra* spp. and solitary Fungiidae (*Fungia* spp. and *Ctenactis* spp.) The presence of these species shows that they are key genera separating this community from the Bulon Islands.

Station 11 North of Dong Island (DNG-N)

Three study transects in the area revealed a total of 32 genera of scleractinian corals. Massive growth form was generally found in this station, as well as solitary colonies of Fungiidae. The bulk of coral composition consisted of Poritidae, Mussidae, Agariciidae, and Fungiidae. Coral genus *Porites* was the most abundant followed by *Lobophyllia*, *Pavona* and *Fungia*; mean colony abundance was 54.7 ± 6.9; 17.3 ± 1.2; 11.3 ± 4.2, 9.0 ± 4.2 colonies/25 m^2, respectively. Transect number 1 (DNG-N1) had a high abundance of *Ctenactis* spp. (10 colonies/25 m^2), while transect number 2 (DNG-N2) had a high number of *Plerogyra* spp. (11 colonies/25 m^2), both being key genera of Adang - Rawi community.

Station 12 Northeast of Dong Island (DNG-NE)

The study site northeast of Dong Island found 30 genera of scleractinian corals throughout three transects with massive and encrusting growth forms being the most common. The majority of the coral composition consisted of Poritidae, Fungiidae, Faviidae and Agariciidae. Coral genus *Porites* was the most abundant, averaging 77.7 ± 4.7 colonies/25 m^2. *Fungia* spp, was the second most abundant (average 15.3 ± 3.5 colonies/25 m^2) additionally, it was highly abundant in DNG-NE1 (22 colonies/25 m^2). *Cyphastrea* spp. and *Pavona* spp. were the third and fourth most common averaging 11.0 ± 2.3 and 8.7 ± 1.8 colonies/25 m^2, respectively.

Station 13 Southeast of Dong Island (DNG-SE)

The southeastern station of Dong Island had 31 genera of scleractinian corals. Massive and encrusting forms of Poritidae, Faviidae, Mussidae, and Agariciidae were generally the most common. *Porites* spp. averaged 61.0 ± 8.6 colonies/25 m^2 and was the most abundant genus followed by *Favia* spp. averaging 7.3 ± 2.2 colonies/25 m^2. The third most abundant coral was *Lobophyllia* spp. averaging 6.3 ± 1.8 colonies/25 m^2 Coral genera *Platygyra* and *Pavona* averaged 6.0 ± 1.5 and 5.7 ± 2.3 colonies/25 m^2.

Station 14 Dong - Phung Island (DNG-PG)

There were 29 genera of scleractinian corals found in Dong-Phung station. Massive and encrusting growth forms were generally present in all three transects. The coral composition was mostly composed by Poritidae, Faviidae, and Agariciidae. The average number of the most common *Porites* colonies was 57.3 ± 5.2 colonies/25 m^2. The second most abundant was *Cyphastrea* spp., followed by *Leptastrea* spp. and *Pavona* spp. (average 18.3 ± 0.3; 10.7 ± 3.0; 10.3 ± 1.5 colonies/25 m^2).

Station 15 South of Rawi Island (RWI-S)

The south of Rawi Island station possessed 23 genera of scleractinian corals with massive growth form being the most common. Principally, the coral community was composed of Poritidae and Faviidae. There was a high density of *Porites* spp. averaging 53.0 ± 12.0 colonies/25 m^2. *Cyphastrea* spp. and *Platygyra* spp. were the second and third most abundant; their mean colony abundance was 7.0 ± 0.6 and 5.0 ± 1.5 colonies/25 m^2. A PCA biplot based on transect level (Figure 3.7) highlighted a great variation among transects. Transect number 1 and 3 (RWI-S1 and RWI-S3) scattered distinctly from the remaining transects. RWI-S1 and RWI-S3 each had a low diversity of coral genera; 62 - 77 percent of coral composition was *Porites* spp. In RWI-S1, the remaining genera were: *Cyphastrea*, *Platygyra*, *Acropora*, *Favia*, *Goniastrea*, *Favites*, *Goniopora*, *Pavona* and *Diploastrea* ranging between 1 - 8 colonies/m^2. In RWI-S3, the minority species contained *Cyphastrea, Platygyra, Acropora, Favia, Favites, Goniopora, Heliopora, Pocillopora, Symphyllia, Ctenactis, Montipora* and *Plerogyra* that ranged between 1 - 6 colonies/m^2.

Station 16 Northeast of Yang Island (YNG-NE)

Reef surveys found a total 26 genera of scleractinian corals in the northeast station of Yang Island. Encrusting and massive growth forms were common and the coral community was composed of Poritidae, Faviidae, Fungiidae and Euphyllidae. The highest colony abundance was massive and branching *Porites* spp. averaging 17.7 ± 1.7 colonies/25 m^2; followed by *Cyphastrea* spp. and *Leptastrea* spp. (average 10.7 ± 0.3 and 9.7 ± 1.7 colonies/25 m^2). The fourth most frequent was Fungia spp. averaging 8.7 ± 7.2 colonies/25 m^2; followed by *Plerogyra* spp. and *Ctenactis* spp. whose mean colony abundance were 5.3 ± 2.6 and 5.0 ± 1.2 colonies/25 m^2, respectively.

Station 17 South of Hin Ngam Island (HNG-S)

The station south of Hin Ngam Island revealed 28 genera of scleractinian corals. The most common growth forms were massive and encrusting. The coral community was mainly comprised of Poritidae, Faviidae and Agariciidae. *Porites* spp. was the most abundant from the three transects (average 72.0 ± 4.0 colonies/25 m^2); followed by *Cyphastrea* spp. averaging 13.3 ± 0.3 colonies/25 m^2. The third most abundant was *Pavona* spp. averaging 8.0 ± 3.5 colonies/25 m^2.

Station 18 Song Bay, Adang Island (ADG-AS)

In Song Bay, on Adang Island, 31 genera of scleractinian corals were found. The massive growth form was generally found in this station; though encrusting growth form and solitary colonies of Fungiidae were also abundant. The coral community composition mainly consisted of Poritidae, Mussidae, Euphyllidae and Fungiidae. *Porites* spp. was the most abundant followed by *Lobophyllia*, *Plerogyra*, *Ctenactis* and *Fungia*; mean colony abundance was 44.3 ± 3.5; 21.7 ± 7.8; 15.3 ± 3.2; 10.7 ± 1.2; 8.7 ± 1.8 colonies/25 m^2, respectively.

Station 19 Ruea Bai Bay, Adang Island (ADG-RB)

There were 30 genera of scleractinian corals found in the area. Massive and encrusting forms were generally found in this station. The coral composition mainly consisted of an assemblage of Poritidae, Faviidae, Agariciidae and Mussidae. *Porites* spp. averaging 81.3 ± 6.6 colonies/25 m^2 was the most abundant genus followed by *Favia* spp. averaging 9.3 ± 3.5 colonies/25 m^2. The third most abundant was *Pavona* spp.;

followed by *Cyphastrea* spp., *Goniastrea* spp. and *Lobophyllia* spp. averaging 9.0 ± 2.1; 7.7 ± 2.6; 7.3 ± 0.3; 7.0 ± 1.7 6 colonies/25 m^2, respectively.

Station 20 South of Adang Island (ADG-S)

South of Adang station had 25 different genera of scleractinian corals. The most common growth forms were massive and encrusting, and coral composition was mainly comprised of Poritidae, Agariciidae, Faviidae and Pocilloporidae. *Porites* spp. was the most abundant from the three transects (average 51.0 ± 3.1 colonies/25 m^2); followed by encrusting *Pavona* spp. averaging 30.3 ± 4.3 colonies/25 m^2. The third most abundant was *Cyphastrea* spp. averaging 16.7 ± 1.8 colonies/25 m^2; followed by *Pocillopora* spp. and *Goniastrea* spp (average 14.3 ± 3.4; 11.0 ± 1.7 colonies/25 m^2,respectively).

Station 21 Southeast of Adang Island (ADG-SE)

There were 32 genera of scleractinian corals found in southeast of the Adang station. Massive growth form was the most common. The coral composition consisted of Poritidae, Faviidae and Agariciidae. The highest colony abundance was massive and submassive *Porites* spp. averaging 73.3 ± 12.8 colonies/25 m^2; followed by *Cyphastrea* spp. and *Leptastrea* spp. (average 20.7 ± 5.0 and 19.7 ± 2.2 colonies/25 m^2). The fourth most abundant was *Favia* spp. averaging 17.3 ± 1.9 colonies/25 m^2; followed by *Goniastrea* spp. and *Pavona* spp. whose mean colony abundances were 14.7 ± 1.3; 11.0 ± 1.7 colonies/25 m^2.

Station 22 Mae Mai Bay, Adang Island (ADG-MM)

A total of 25 genera of scleractinian corals were found at Mae Mai Bay on Adang Island. The massive growth form was generally the most abundant in this station. Most of the coral composition consisted of Poritidae and Faviidae. Coral genus *Porites* was the most common throughout the three transects; mean colony abundance was 79.0 ± 7.8 colonies/25 m^2. The second most abundant genus was *Cyphastrea* spp. averaging 10.7 ± 1.3 colonies/25 m^2; followed by *Platygyra* spp., whose mean colony abundance was 8.3 ± 3.9 colonies/25 m^2.

3.7 Preliminary interpretation and discussion

The association between reef environmental conditions and reef locations highlights the difference of reef characteristics between inshore and offshore habitats in the southern Andaman sea of Thailand. In the inshore habitat, the Bulon and Tarutao Islands which are close to terrestrial influence exhibit high suspended matter, low visibility, fine - grained sediment bottom and shallow reef. On the other hand, water around the offshore habitat at the Adang - Rawi Islands, located 70 km distance from the mainland, possess low suspended matter, consistently higher visibility, sandy reef bottom and deeper reef. These preliminary conclude a general characteristic of inshore and offshore reef habitats in this region that was associated with turbidity conditions and maximal reef depth.

Two distinct groups of coral assemblages (Figure 3.4) revealed by the cluster analysis emphasize an existence of different coral assemblages in the two reef habitats of the southern Andaman Sea. Furthermore, the association between coral assemblage composition and reef habitats reveals the spatial variation of coral community under environmental influences. The inshore - offshore assemblage differentiation was associated with the distribution and abundance of coral genera *Pectinia*, *Montipora*, *Lobophyllia* and *Plerogyra* (Figure 3.5). The inshore coral community was characterized by restricted *Lobophyllia* abundance, a rare occurrence of *Plerogyra* and common occurrences of *Pectinia*, *Montipora, Acropora* and *Podabacia*. In contrast, the offshore reef habitat was able to exist for *Lobophyllia* and *Plerogyra* and abundant solitary Fungiidae, but *Pectinia* and *Montipora* were scarce in this area. These result highlights key characteristics of coral community that are particular with the environmental conditions of inshore and offshore reefs in this region.

The CCA result indicated the habitat preferences of coral genera to bottom substrate and environmental parameters (Figure 3.6). *Herpolitha*, *Ctenactis*, *Montastrea*, *Plerogyra* and *Lobophyllia* had a strong association with offshore reef environments, whereas *Lithophyllon*, *Astreopora*, *Pectinia*, *Mycedium* and *Turbinaria* had a strong association with inshore reef environments. These can lead to the habitat preference coral genera and response coral composition to the inshore - offshore reef environments for the region; *Lithophyllon*, *Astreopora*, *Pectinia*, *Mycedium* and *Turbinaria* which are associated with inshore turbid and high suspended matter conditions could be suggested as turbid-sediment tolerant genera.

In brief, the investigation of the fringing reefs along a 70 km transect from the mainland to offshore islands of the southern Andaman Sea of Thailand displayed a correspondence among reef habitats, coral community composition and reef environmental conditions. It proved that fringing reef in Thai water is more diverse than previously thought; not only *Porites* spp. dominated community but they were also built by several genera that created a specific property for their own.

CHAPTER 4

Coral Replenishment in the Southern Andaman Sea Reefs

4.1 Introduction

Coral recruitment and replenishment can be affected by several factors including: coral composition, the reproductive mode of the population (brooding vs spawning), post - settlement mortality, and water quality and current. The process of coral recruitment is a crucial component of the population dynamics on both inshore and offshore reef systems, and it is an important factor for the regulation of the resilience of coral reef communities to disturbance. The rates of post - settlement success can vary greatly on inshore and offshore reef habitats. Studies in the Pacific Ocean suggest a lesser number of coral recruits in turbid water reefs compared to reefs further from the river mouth (Fabricius *et al*. 2012) due to pre and post - settlement obstructions in the inshore reefs originating from land based sources such as high levels of sediment and nutrient runoff (Birrell *et al.*, 2005; Fabricius, 2005). Moreover, studies in many regions suggest varying views on the relationship between adult and juvenile populations. In the Great Barrier Reef, Hughes *et al*. (1999) proposed there was no correlation between adult colonies and recruitment, which concurred with a similar study by Edmunds (2000) in the Caribbean Sea. Contrastingly, Adjeroud *et al*. (2010) proposed a positively correlated variation between the adult and juvenile abundance in New Caledonia.

4.2 Objective

This study aimed to examine spatial patterns in the replenishment of the scleractinian coral population in the southern Andaman Islands reefs, along a 70 km transect from the inshore to offshore habitats.

4.3 Research questions

Is coral replenishment in the southern Andaman Sea different between inshore and offshore reefs?

Does the replenishment rely on the existing reef population?

Does the coral population in the southern Andaman Sea recruit consistently over the years?

4.4 Material and methods

Study area

The study area traversed both inshore and offshore reef habitats. Reef stations in this study were selected from stations that were used in two studies: community composition study from Chapter 3 and the annual monitoring conducted by MNPIC - Trang. A total of 11 reef stations overlapped between these studies (shown as highlighted rows in Table 2.2) including 3 stations in the Bulon Islands, 3 stations in the Tarutao Islands, and the offshore reef habitat including 5 stations in the Adang - Rawi Islands (Figure 4.1).

Data collection

The juvenile coral density data collected from the annual monitoring database of the MNPIC - Trang were investigated during May - October 2014 and June - July 2015. In their studies, three replicates of 30 x 1 m permanent belt transects were laid on the crest - upper slope zone. Juvenile coral colonies in the belt transects were identified at generic levels and colonies that could not be identified were recorded as unknown. MNPIC - Trang workers collected data in 3 different size classes. Number of juveniles were low compared with data published from places such as the GBR, and each transect had many zero values for most genera. Juvenile numbers were therefore pooled across size classes and genera to create a data set amenable to statistical analysis.

The data of adult coral density in the 11 reef stations was taken from the coral community study in Chapter 3. In the station east of Bulon Mai Pai, the data from transect numbers 2, 3 and 4 were used because they were transects laid in the same area as the MNPIC - Trang's study.

Data analysis

The density of juvenile colonies was compared in inshore and offshore populations using a nonparametric Mann - Whitney U test because the data did not have normal distribution and homogeneity of variance even after the data was transformed.

The adult and juvenile data set of pooled genera and the most five common genera, including *Pocillopora*, *Favites*, *Porites Pavona* and *Acropora* from 2014 was used to analyze the relationship between adult coral population and juvenile coral population. The sum of the colony numbers was used to compare across sites using a χ^2 - contingency table (site x [adult colony vs juvenile colony]). The χ^2 - contingency table determined whether the number of juveniles was affected by their adult populations, the relationship was examined with correlation analysis by using 11 stations as replicates.

Pooled data for number of juvenile colonies in each station was compared between 2014 and 2015. Repeated measures Analyses of Variance (ANOVA) were conducted to examine juvenile recruitment between year 2014 and 2015. Log transformation was applied with the data set to meet the assumption of normal distribution and homogeneity of variance; however, juvenile data in 2014 did not meet the assumption of normal distribution, so the p - value was set to 0.01 to increase the confidence levels of the test.

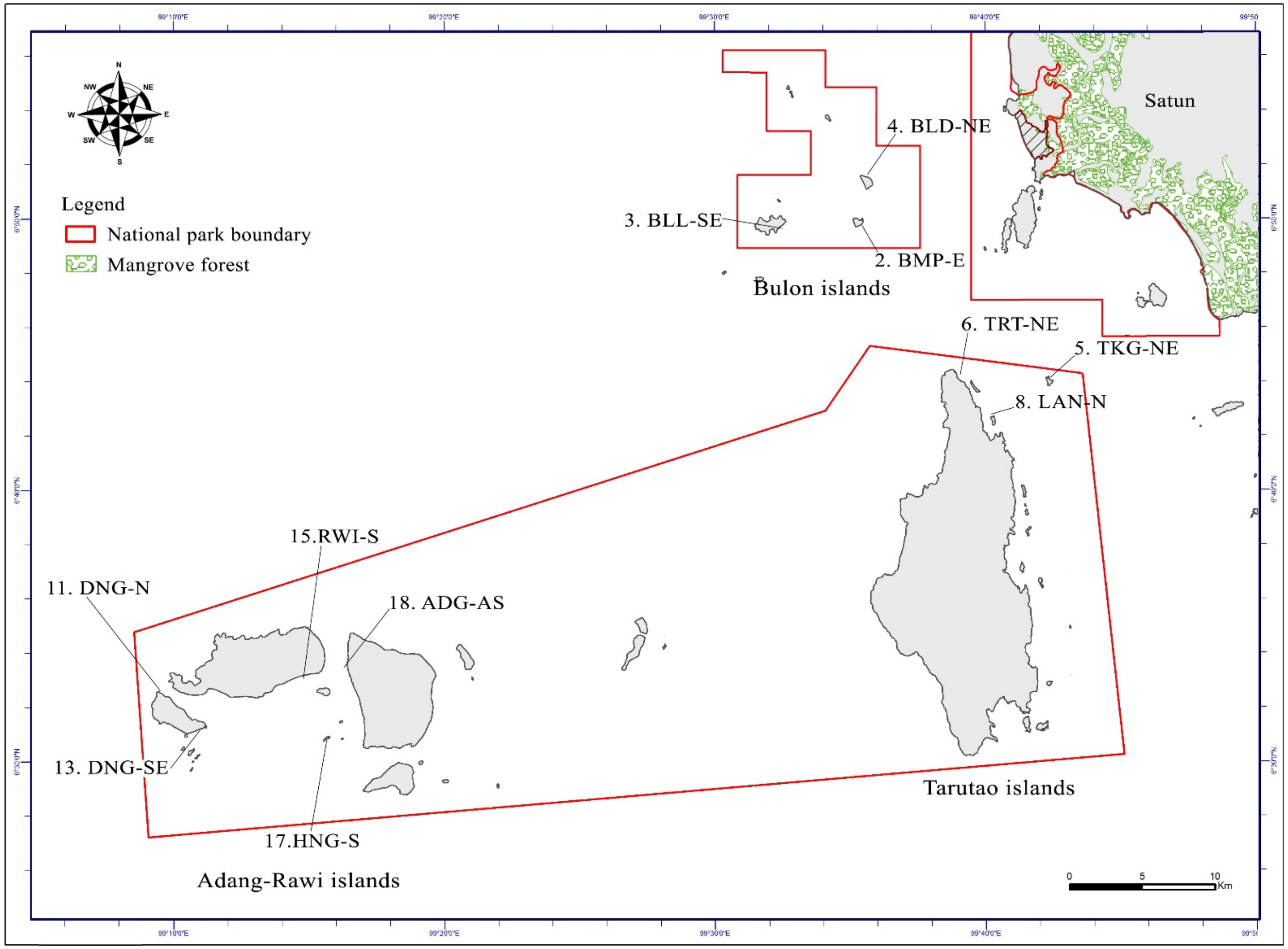


Figure 4.1 Study sites in Satun province, including 11 stations in Bulon Islands, Tarutao Islands and Adang - Rawi Islands.

4.5 Results

4.5.1 Coral replenishment patterns in the southern Andaman Sea

A total of 5294 adult coral colonies from 42 genera, and 1181 juvenile colonies from 24 genera and 220 unknown juvenile colonies were recorded in 11 reef stations. The average density of adult colonies was 481.27 colonies/25 m^2 and the juvenile colony average was 88.11 colonies/25 m^2 in 2014 and 39.32 colonies/25 m^2 in 2015.

The abundance of juvenile corals in the inshore reef stations tended to be higher than the offshore reefs (Figure 4.2 and 4.3). In 2014, the average density of juvenile colonies in inshore reefs ranged from 21.39 - 70.83 colonies/25 m^2 and 5.56 - 48.33 colonies/25 m^2. In 2015, average juvenile colony density in inshore reefs ranged from 13.06 - 26.67 colonies/25 m^2 and 1.94 - 8.89 colonies/25 m^2. The colony number of juvenile corals in 2014 was not significantly different between the inshore and offshore reefs (Mann - Whitney U = 92.5, n1 & n2 = 33, p = 0.124), but they were significantly different in 2015 (Mann - Whitney U = 13.5, n1 & n2 = 33, p < 0.001).

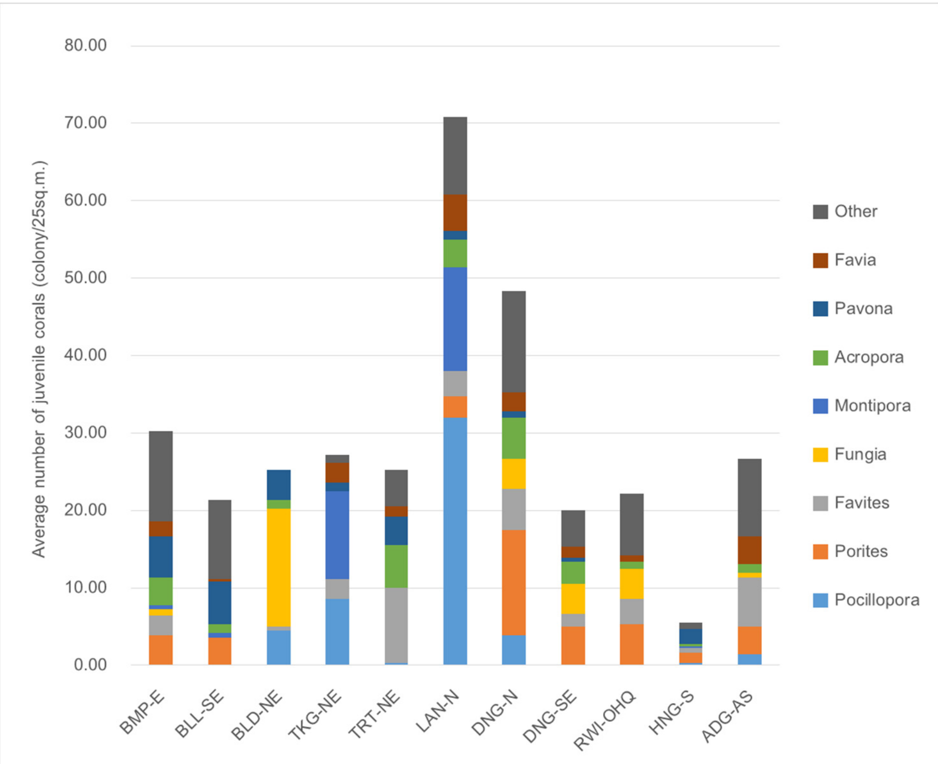


Figure 4.2 Abundance of juvenile corals in 11 inshore and offshore reef sites in 2014.

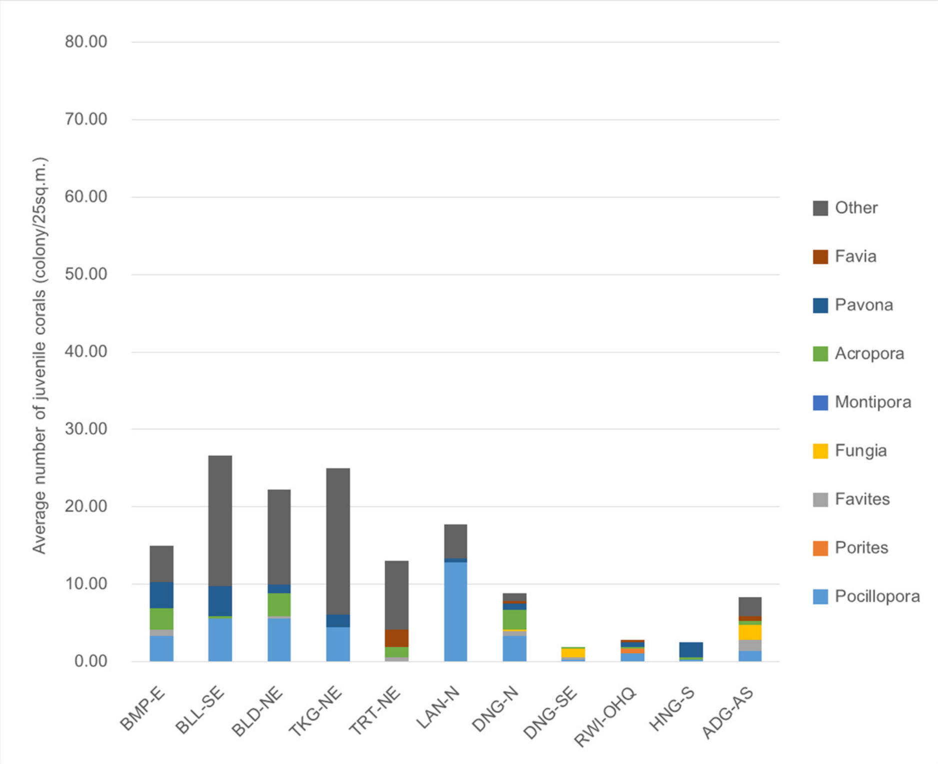


Figure 4.3 Abundance of juvenile corals in 11 inshore and offshore reef sites in 2015.

4.5.2 The relationship of adult and juvenile population in the southern Andaman Sea

The abundance of adult and juvenile corals in the southern Andaman Sea showed that there was no correlation between adult and juvenile populations at the overall scale (pooling genera, χ^2 = 285.23, df = 10, p < 0.001). The five most abundant genera, including *Pocillopora*, *Favites*, *Porites Pavona* and *Acropora*, also showed no correlation between adult and juvenile population across sites (*Pocillopora*, χ^2 = 53.38, df = 9, p < 0.001; *Favites*, χ^2 = 56.99, df = 10, p < 0.001; *Porites*, χ^2 = 103.65, df = 10, p < 0.001; *Pavona*, χ^2 = 36.22, df = 10, p < 0.001; *Acropora*, χ^2 = 76.38, df = 10, p < 0.001). For the reef scale level, in the inshore reefs, the abundances of juvenile coral pooling and the most five abundant genera were not correlated with their abundances of their adult population (pooling genera inshore, χ^2 = 198.17, df = 5, p < 0.001; *Pocillopora*, χ^2 = 34.54, df = 5, p < 0.001; *Favites*, χ^2 = 29.01, df = 6, p < 0.001; *Porites*, χ^2 = 30.45, df = 6, p < 0.001; *Pavona*, χ^2 = 15.53, df = 6, p < 0.05; *Acropora*, χ^2 = 34.75, df = 6, p < 0.05). In the offshore reefs, there was no correlation between juvenile and adult populations (pooling genera offshore, χ^2 = 81.13, df = 5, p < 0.001), but the number of *Pocillopora,* *Favites, Pavona* and *Acropora* juvenile corals were correlated with their adults (*Pocillopora*, χ^2 = 4.20, df = 4, p > 0.05; *Favites*, χ^2 = 2.23, df = 4, p > 0.05; *Pavona*, χ^2 = 7.29, df = 4, p > 0.05; *Acropora*, χ^2 = 5.27, df = 5 p > 0.05). Only *Porites* juveniles were not correlated with adult abundance in the offshore reefs (*Porites*, χ^2 = 30.45, df = 6, p < 0.001).

4.5.3 Temporal variation of replenishment in the southern Andaman Sea

Corals in the southern Andaman Sea were not recruited consistently over years. There was high variability in colony number and composition. A total of twenty - five juvenile coral genera in thirteen families were found in this study. Twenty - four juvenile coral genera were found in 2014. The most common genera were *Acropora, Favites, Pavona* and *Favia.* However, juvenile corals found in 2015 were reduced to thirteen genera, and the most common genera in 2015 were *Pocillopora, Pavona* and *Acropora* (Figure 4.1 and 4.2). Throughout the two - year study *Pocillopora* juveniles in the North of Lean station were the highest number in both years. The number of juvenile corals was significantly different between 2014 and 2015 (repeated measures ANOVA; F = 9.449, df = 1, p = 0.013)

4.6 Preliminary interpretation and discussion

The high abundance of juvenile corals in the turbid inshore reef environments contradicted with former findings that recruitment tended to be higher in clean - water environments in offshore reefs (Birrell *et al*. 2005, Fabricius *et al*. 2012). However, the replenishment of scleractinian coral in this study was highly variable; data indicated higher numbers of coral juvenile in the inshore reefs, but they are only significantly different in 2015. Higher abundance of juvenile corals in the inshore reefs was speculated as an association with a difference of reef topography; the inshore reefs have a high prevalence of dead coral or rock, whereas the offshore reefs were dominated by massive *Porites* colonies over the sampling area in the juvenile census. Readily available substrates in the inshore reefs may allow more larvae to settle in the area than in the offshore reefs.

The abundances of juvenile coral recorded in this study were relatively low compared to other regions. For instance, recruits on 11x11 cm terracotta tiles in the GBR was >25,619 recruits/25m^2 (Hughes *et al.*, 1999); 40 mm diameter juvenile colonies in the in St. John, US Virgin Islands ranged from 0 - 800 colonies/25m^2 (Edmunds, 2000); juvenile abundance in the New Caledonia reefs were >62.5 colonies/25 m^2 (Adjeroud *et al.*, 2010). Nevertheless, a large difference between the number of the recruits in the Hughes *et al*. (1999) study is due to differences in defining juvenile recruitment. The Hughes *et al*. (1999) study estimated the number from the early stage of post - settlement, which varies from the method used in this study, which counted the number of juveniles that survived 6 months after settlement.

A lack of correlation between adult and juvenile corals across the stations suggests a disconnection between recruitment and community composition. At the regional scale, the coral population in the southern Andaman Sea is supposed to rely on outside sources and have low larvae retention at the reefs. Furthermore, larvae settled in the southern Andaman reefs may not survive after settlement. However, these speculations cannot be confirmed in this study because we have no quantitative data on larval settlement and survival in this area. This highlights an important gap in our understanding of this reef system: no upstream source reefs have been identified and the post settlement processes of larvae has never been studied in the southern Andaman reef systems.

CHAPTER 5

General Discussion

This study has documented fundamental differences of inshore - offshore reefs in the southern Andaman sea of Thailand that were based on the environmental attributes, patterns in the coral community composition and coral replenishment. The inshore - offshore differences in Thai waters revealed in this study generally were not consistent with literature describing patterns found on the GBR, the Caribbean Sea or in south - east Asia barrier reef systems. There is a similar trend in southern Thailand to the other regions in those environmental attributes which show a gradient dependent on proximity to terrestrial influences, however, the composition of coral assemblages and population attributes respond differently.

In the broadest terms, reefs located further from the mainland experienced less input from rivers, and thus tended to be surrounded by less turbid waters; moreover, even though the slop of the continental shelf in the southern Andaman Sea is gentle, the more offshore sites tended to be surrounded by deeper waters, and coral communities thus extended to greater depths below the water surface. The environmental differences showed in this study generally are consistent with several studies reported the water quality gradient along the proximity from the mainland (Boyer and Briceño, 2006, 2006; Caccia and Boyer, 2005; De'ath, 2007; Fabricius, 2005; Schaffelke *et al.*, 2012). Within the broad inshore habitat, I found that there are subtle differences between the Bulon Islands and Tarutao Islands. Both of these sites are notionally affected by the terrestrial influence of the mainland, being only a few kilometres offshore, but the mangrove channels and waterfalls flow through the eastern side of Tarutao Island may enhance the effects of the proximity of the mainland. The terrestrial influence from the Tarutao Islands makes their reef environments are more turbid and have higher suspended matter in the water column which Cooper *et al*. (2009) report that light availability can influence on the maximal reef depth in the inshore reef. In the offshore group, although water quality indicators were quite different to those from the inshore sites, many of the same characteristics of the reefs were apparent. It may be that there is a range of island sizes that are too small to exert significant “terrestrial influences”; the nature of the reefs at Tarutao, and to a certain extent Adang - Rawi, suggest they fall outside that range. This observation may be of some significance when considering the development of islands for tourism, since land use changes are linked to increased discharges of terrigenous sediments and nutrients.

Composition patterns amongst the coral assemblages suggests that the coral community is at least partly shaped by the environmental difference of reef localities. However, the fringing reef system in the southern Andaman Sea do not show the strong patterning evident from barrier or atoll reef systems in other regions. In general, the southern Andaman reef is dominated by massive *Porites* in both inshore and offshore locations, but the coral composition reflects the inshore - offshore environmental characteristics. Inshore reef communities often had high numbers of corals of genera *Pectinia*, *Montipora, Acropora* and *Podabacia*, Offshore reef communities tended to be characterized by the presence *Lobophyllia* and the relatively high number of *Plerogyra* colonies. The distribution of *Acropora* corals in this study showed a contradicting pattern to the study of Done (1982), who suggested *Acropora* dominated communities in the offshore reefs and Fabricius *et al*., (2012), who proposed *Acropora* as an indicator of clean water, clear and low nutrient conditions. High abundance of *Acropora* corals in turbid water of the southern Andaman Sea has been speculated to be a result of the mass coral bleaching in 2010, in which *Acropora* in the Andaman reefs suffered more than 80% mortality (CBiPT, 2012). However, there are reports that have suggested that inshore reefs could be more resistant to bleaching events than offshore reefs due to turbid water providing protection from UV - radiation by light absorption as well as scattering light by suspended particulate matter and colored dissolved organic matter (Alemu I and Clement, 2014; Phongsuwan, 1998; van Woesik *et al.*, 2012).

Apart from the *Acropora,* other groups of corals behaved more or less as predicted by previous reports. In the coastal locations, the association of *Pectinia* and *Montipora* corals with turbid water inshore reefs was expected, since this is one of their defining characteristics (Veron, 2000). The association of *Turbinaria* spp. with turbid environments also consistent with reports from the GBR (Fabricius *et al.*, 2012) that propose a negative relationship between *Turbinaria* coral and water quality gradient with distance from a river mouth.

The abundances of juvenile coral recorded in this study were relatively low compared to other regions, although few studies used comparable units. For instance, extrapolation of the density of spat on 11x11 cm terracotta tiles in the GBR (Hughes *et al.*, 1999) equates to >25,000 recruits/25m^2; 40 mm diameter juvenile colonies in the in St. John, US Virgin Islands ranged from 0 - 700 colonies/25m^2 (Edmunds, 2000); juvenile abundance in the New Caledonia reefs were >60 colonies/25 m^2 (Adjeroud *et al.*, 2010). Here, the MNPIC - Trang surveys recorded an average of juvenile abundance in 2014 was 21 - 70 colonies/25 m^2 at the inshore reefs, and 13 - 26 colonies/25 m^2 at the offshore sites; an average of juvenile abundance in 2015 was 13 - 26 colonies/25 m^2 at the inshore reefs, and 1 - 8 colonies/25 m^2 in 2015 at the offshore sites. Although there were extremely large differences between inshore and offshore groups on the averages of juvenile abundance, the variability between years in this study was of greater magnitude.

The coral replenishment in the southern Andaman reefs is highly variable over space and time. At the regional scale, the juvenile abundance tends to be higher in the turbid inshore reefs than the offshore reefs, but only one from two years study showed a significant difference of juvenile abundance between inshore and offshore reefs (Figure 4.3). This contrasts with the expectation from literatures that turbid water reef is supposed to have low coral recruits due to pre and post-settlement obstructions originating from land based sources such as high levels of sediment and nutrient from runoff (Birrell *et al.*, 2005; Fabricius, 2005). Furthermore, study in the Great Barrier reef suggest that high numbers of coral juveniles are associated with clear - water environments in the offshore reefs (Fabricius *et al.*, 2012). The variation in juvenile abundance between inshore and offshore reefs also reported in the Florida Keys; the proportion of inshore coral recruitment was lower their first year study, but higher in the second year (Lirman and Fong, 2007). The unexpected higher abundance of juvenile corals in the inshore reefs was speculated as result of high prevalence of available substrate such as dead coral and rock in the inshore reef that may allow more larvae to settle in the area than in the offshore reefs, which mostly are covered by massive *Porites*.

The high variability in colony number and composition of juvenile corals (Figure 4.1 and 4.2) over sites and years in the southern Andaman reef suggests that replenishment is unreliable, and does not conform to inshore/offshore patterns. Rather, it would seem that supply of larvae is stochastic, and except for a couple of sites, depends on the vagaries of currents and location. These results are similar to studies in the other regions, such as a population of juvenile corals in the Caribbean Sea varied among 4 years study (Edmunds, 2000), Lirman and Fong's (2007) Florida Keys findings, or a significant difference in numbers of coral recruits among 3 years study in the Moorea, French Polynesia (Adjeroud *et al.*, 2007).

The non - relationship between adult and juvenile corals across the stations at the regional scale suggests that the recruitment of coral population in the southern Andaman Sea are decoupled from the extant population in the area. This study did not look at reproductive output from the southern Andaman reefs, but the disconnection between adult and juvenile populations implies that the coral population in this region relies on outside sources for replenishment (which have not been identified) and have low rates of larvae retention at the reefs. Otherwise, some of the patterns may be explained in the way that the post - settlement process in the southern Andaman reef may be failed; larvae settled in the reefs may not survive after settlement which can result from several factors, such as water quality, sedimentation, predation and competition (Richmond, 1997). However, all these questions still cannot be answered due to a lack of quantitative data on larval supply, larval settlement and their survival in this area. This highlights an important gap in our understanding of this reef system: no upstream source reefs have been identified and the post settlement processes of larvae has never been studied in the southern Andaman reef systems.

In conclusion, this study has shown that patterns in inshore and offshore reef systems in various parts of the world (including Thailand) are different. Thailand's reef system of fringing reefs around high continental islands is composed differently from most published accounts of inshore/offshore systems. This study demonstrated that reefs are extremely heterogeneous in nature - composition at the generic level varies widely between reefs, even those in close proximity. At least some of those differences can be attributed to the effects of inputs from the mainland, however the proximity of large islands such as Tarutao can mask many of these differences. The coral replenishment moreover showed difference in abundance and composition of the coral recruits between the inshore and offshore reefs. The large differences in juvenile abundances and composition between sites and years may reflect current patterns or larval supply, and do not reflect the composition of the extant coral community. These findings are important background information for management of Marine Protected Areas based on the ecological knownledge rather than the geographic location. Also, these findings can be background information for predicting the reaction of a coral community to indicate terrestrial influences or monitor the environmental change of reef.

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