MARINE PROFILING OF MARUDU BAY, SABAH, MALAYSIA

Coastal and Marine Resources Management in the Coral Triangle-Southeast Asia (TA 7813-REG)

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WorldFish

Tehcnical Report

MARINE PROFILING OF MARUDU BAY, SABAH, MALAYSIA

Final Report[1]

PACIFIC RIM INNOVATION AND MANAGEMENT EXPONENTS, INC., PHILIPPINES

UMS UNIVERSITI MALAYSIA SABAH

Jabatan Perikanan Malaysia

[1] Manjaji-Matsumoto, B.M., Saleh, E., Waheed, Z., Muhammad Ali, S.H., and Madin, J., eds. 2017. *Marine Profiling of Marudu Bay, Sabah: Final Report*. Prepared for PRIMEX. May 2017. Borneo Marine Research Institute, Universiti Malaysia Sabah.

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LIST OF ABBREVIATIONS

ANOVA	analysis of variance
BMRI	Borneo Marine Research Institute
CFU	colony-forming unit, used to estimate the number of viable bacteria or fungal cells in a sample
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DBA	diameter at breast height
DO	dissolved oxygen
DOF	Department of Fisheries of Malaysia
EEZ	exclusive economic zone
GBH	girth at breast height
GPS	Global Positioning System
HAT	Highest Astronomical Tide
IVI	importance value index
JKKK	Jawatankuasa Kemajuan dan Keselamatan Kampung (Village Development and Security Committee), an institution/entity appointed by the State Government
NaCl	sodium chloride, also known as salt
NED	N-(1-Naphthyl)ethylenediamine

NHC	National Hydrographic Centre
PAST	Paleontological Statistics
PCA	Priority Conservation Area
PPT	parts per thousand
PSS	practical salinity scale
PSU	practical salinity unit
RM	Malaysian ringgit
SAN	sulphanilamide
Sg.	*Sungai* (river)
sp.	species (singular)
spp.	species (plural)
SPSS	Statistical Package for the Social Sciences
St	station
Tg.	*Tanjung* (cape)
TMP	Tun Mustapha Park
TSS	Total suspended solids
UMS	Universiti Malaysia Sabah
UPM	Universiti Putra Malaysia
WoRMS	World Register of Marine Species

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EXECUTIVE SUMMARY

This study was originally planned to gather information for the marine profiling of Marudu Bay, including its coastline, during the northeast monsoon season. However, due to unavoidable delays, surveys were conducted instead during the southwest monsoon season, between June and December 2015. During this season, most afternoons are defined by rain beginning late October.

In this report, we present the results of a comprehensive review of literature on the biota (fishes, marine invertebrates, other aquatic vertebrates like marine mammals and reptiles, corals and coral reef indicators, seagrasses, and mangroves) and abiotic factors (oceanographic parameters, water quality, and marine pollutants) of Marudu Bay, and the results of the field surveys in the bay.

We recorded higher species diversity for fishes (188 species), marine invertebrates (35 species), hard corals (168 species), seagrasses (four species), and mangroves (26 species), compared with previous studies. The primary database (raw data) of the biodiversity studies, including photographs of the species observed, are appended to this report as Excel spreadsheets.

Mangrove species composition in Marudu Bay varies between the three surveyed areas: Kudat (five species), Marudu (11 species in Sg. Matunggong and 10 species in Bandau), and Pitas (18 species). The species include both mangrove-associated species and true mangrove species. Sungai Telaga in Pitas is the location of Malaysia' largest and controversial shrimp aquaculture farm. Estimated to be at least 1,000 hectares, the farm is largely within a virgin mangrove forest.

Recent studies suggest the high relative abundance of phytoplankton *Chaetocerotaceae* in Marudu Bay is the main limiting factor to the growth of green mussels.

Editors' note: Tun Mustapha Park, which encompasses almost all of Marudu Bay, was declared a marine park under Parks Enactment 1984 (Amendment 2007) on 19 May 2016. It is the largest marine park in Malaysia, spanning close to 900,000 hectares, and is the ninth park under Sabah Parks Management. (https://www.theguardian.com/world/blog/2016/may/30/malaysia-just-established-a-one-million-hectare-marine-park).

I. INTRODUCTION

Marudu Bay is located in the northernmost part of Sabah (North Borneo), Malaysia, and is flanked by the Kudat and Bengkoka peninsulas. This semi-enclosed bay supports a diverse array of coastal and underwater habitats. Three peri-urban district municipalities border Marudu Bay: Kudat to the west, Marudu to the south, and Pitas to the east. Kudat is the busiest of the three towns, with commercial fish landing ports lining its waterfront (Manjaji-Matsumoto & Jumin, 2011).

Scientists have identified several activities, particularly rapid coastal development and destructive fishing practices, as major threats to the survival of the coral reefs in Marudu Bay. Accordingly, the coral reefs in the bay are classified as very highly threatened (Burke, 2003; Burke et al., 2002, 2011).

Marudu Bay is an ecologically important area. It is located within the proposed Tun Mustapha Park (TMP) (Jumin et al., 2008; Jumin & Lim, 2013), which is part of the Coral Triangle and is a marine biodiversity hotspot (Lim & Jumin, 2013; Anon., 2014).It is also located within the Kudat-Banggi Priority Conservation Area (PCA), which is one of two marine PCAs in Sabah identified by WWF-Malaysia (2015). Nevertheless, Marudu Bay remains little known compared to the renowned Tip of Borneo (Liew-Tsonis et al., 2012).

A. Aims and Objectives

The primary aim of this study is to gather information for the marine profiling of Marudu Bay. Data was collected during the southwest monsoon. The findings from this study will be used to prepare an integrated management plan for the area.

The marine profiling of Marudu Bay has the following objectives:

(i) Conduct a comprehensive review of existing data and information on:

- a. status of the coastal and marine ecosystems of Marudu Bay (mangrove forests, seagrass beds, coral reefs, sandy-muddy reef flats, etc.);
- b. biodiversity of the coastal and marine ecosystems of the bay;
- c. oceanographic parameters in the bay, such as tidal patterns (diurnal and seasonal), current patterns (long-shore, internal–seasonal), depth, and substrates; and
- d. water quality of coastal and marine waters within the bay.

(ii) Gather field data on the following parameters:

- a. oceanographic parameters, including tidal patterns (diurnal and seasonal), current patterns (long-shore, internal–seasonal), depth, and substrates of Marudu Bay; and
- b. water quality, quantitative measurements of sediment levels, and physico-chemical parameters, including inorganic characteristics (pH and salinity profile), organic compounds (nitrates, phosphates, potassium levels), anthropogenic inputs (fecal coliform levels, solid waste i.e. floating and beached litter), marine pollution (anti-fouling compounds), and common and abundant seafood in markets in the bay area.

II. LITERATURE REVIEW

A. Biodiversity

1. Fishes

Several earlier studies have provided lists of fishes in Marudu Bay and adjacent waters within the proposed Tun Mustapha Park (TMP). These include a checklist of fish and macro invertebrate species recorded within TMP, which records 94 fish species from 52 families (Manjaji-Matsumoto et al., 2009), and a guide to the "main marine fisheries species" within TMP (Jumin et al., 2010), with examples of fish and prawn species caught in the commercial fishery, also within TMP (Manjaji-Matsumoto et al., 2011).

In 2014, a local paper reported the capture of a juvenile whale shark (*Rhincodon typus*) in Marudu Bay (Daily Express, 2014). According to the report, the whale shark was caught in a *rantau* – a trawl net tied at each end to the stern (rear) of two boats – at around 1:00 in the morning near Pulau Matunggong, a small rocky outcrop overgrown with mangrove trees, approximately 06° 39.0067' N, 116° 47.5083' E. Photographs of the whale shark while intact and after it was hacked subsequently circulated via social media (i.e. Facebook and WhatsApp) (Manjaji-Matsumoto, pers. obs.).

Universiti Putra Malaysia (UPM) researchers carried out gillnet and *bagang* fisheries surveys in Marudu Bay in 2012 and 2013. The gillnet survey covered the southern part of the bay, between 06° 36.169' N, 116° 46.400' E and 06° 37.502' N, 116° 47.775' E. The results of these studies include lists of fish species caught by gill net, and the biology of selected fish species (Mohd Azim et al., 2013; Amin et al., 2014; Arshad et al., 2014; Mohd Azim, 2014; Mohd Azim et al., 2014; Arshad et al., 2015a, 2015b; Siddique et al., 2015). In 2015, Zakaria & Rajpar reported 33 fish species belonging to 22 families from mangrove habitats within the Marudu District boundary (between latitudes 06°15″ to 06°45″ N and longitudes 116° to 117° E) of Marudu Bay, based on their surveys carried out in 2009 and 2010. They noted the three most abundant fish families are *Leiognathidae*, *Lutjanidae*, and *Sciaenidae*.

Based on literature reports, a total of 90 species from 40 families of marine fishes are found in Marudu Bay and adjacent areas, excluding about 10 unidentified species. The family *Leiognathidae* is recorded as the species with the highest occurrence (12 species).

2. Marine Invertebrates

Marudu Bay holds a variety of ecosystems, including mangroves, seagrass beds, and coral reefs. These habitats have been reported to have a high diversity and abundance of invertebrate species. Zakaria & Rajpar (2015) reported 22 species of invertebrates in mangrove habitats in Marudu Bay, including 11 species of crustacea, seven species of molluscs, and four species of worms. Prawns are the most common invertebrate catch in Marudu Bay, caught mainly by Kudat-based commercial prawn trawlers, and by small-scale fishermen using trammel and gill nets based in the districts of Marudu and Pitas (DOFS, 2010; Manjaji-Matsumoto & Jumin, 2011). The recorded prawn species include *Metapenaeus ensis* (Md Yusoff et al., 2012).

Flower crab (*Portunus pelagicus*) is the most commonly caught crab species in the bay, followed by mud crab (*Scylla* spp.), which is commonly found in mangrove areas (Md Yusoff et al., 2012). The fishing gears for crabs are trammel nets and crab pots (*bintoh*).

Besides prawns and crabs, gastropods and bivalves are other invertebrate fisheries resources landed in Marudu Bay. There are raft cultures of green mussel (*Perna viridis*) and oysters (*Crassostrea* sp. and *Oystrea* spp.) along the shores of Tg. (*Tanjung* or cape) Batu. Venus clams (*Meretrix* spp., *Lioconcha* sp.), locally known as *remis*, are harvested from the extensive mudflats that are exposed during low tide. Squids (*Loligo* spp.) are also seasonally available in the bay. Jellyfish are commercially exploited (Biusing, 2001), and at least two species, *Lobonemoides* and *Catostylus townsendi*, are abundant from March to June (Cheong et al., 2015). More studies on species composition of marine invertebrates, which include *Cnidaria*, molluscs, crustaceans, echinoderms, polychaetes, and *Porifera* could be carried out to understand the biodiversity status in the various coastal habitats of Marudu Bay.

3. Other Aquatic Vertebrates

This group includes charismatic marine megafauna: marine mammals and marine reptiles. This underwater wildlife is overwhelmingly endangered and faces threats from human activities.

a. Marine Mammals

There are at least 21 species of cetaceans (three *Mysticeti* and 18 *Odontoceti*) and one sirenian species in the territorial and exclusive economic zone (EEZ) waters of East Malaysia (Sabah and Sarawak) (Jaaman et al., 2009). At least four marine mammal species (*Dugong dugon, Orcaella brevirostris, Sousa chinensis*, and *Neophocaena phocaenoides*) and two other probable species (*Tursiops* spp. and *Stenella* spp.) were reported being caught as by-catch in the fisheries of Pulau Banggi.

Of these, only one species – *Dugong dugon* – is confirmed to occur in Marudu Bay (Rajamani & Marsh, 2010). The dugongs were observed approximately halfway between Tg. Simpang Mengayau and Berungus during an aerial survey along Sabah's coastline. Jaaman et al. (2009) also reported that dugongs comprise the highest incidental trawler catch in the northeastern region of Sabah, an area within the boundaries of the proposed TMP. The dugong is listed as a protected species since 1982 (Amendments to the Sabah Faunal Ordinance, 1963).

b. Marine Reptiles

Two most common marine reptiles in Marudu Bay are saltwater crocodiles and sea turtles. A recent YouTube video clip entitled "How we caught a saltwater crocodile in Marudu Bay, Sabah" (Simbaku, 2014) shows a "stiff" crocodile entangled in a fisher's gill net. (Note: There is only one species of marine crocodile – *Crocodylus porosus* – in the world). According to Simbaku, it was 1.2 meters (m) long, weighed about 20 kilograms (kg), and sold for only RM (Malaysian ringgit) 60.00 ($14.59). Other common names of the saltwater crocodile are estuarine crocodile, Indo-Pacific crocodile, and *buaya tembaga*. It has an extensive range, from the east coast of India to northern Australia. It is listed as a protected species since 1982 (Amendments to the Sabah Faunal Ordinance, 1963), and remains on Schedule 2 of the Sabah Wildlife Conservation Enactment (1997). For Malaysia, it is also listed as endangered under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Of the seven species of marine turtles, two species – the green turtle (*Chelonia mydas*) and the hawksbill turtle (*Eretmochelys imbricata*) – are reported to have a large population in the proposed TMP (Beliku & Saleh, 2013). In Marudu Bay, confirmed sightings have been reported from the far northeast shallow waters around Berungus and Telaga, which are also fishing grounds for commercial fisheries. These two marine turtle species are listed as protected since 1982 (Amendments to the Sabah Faunal Ordinance, 1963).

4. Corals and Coral Reef Indicators

Very little information is available about the coral reefs of Marudu Bay. The only available data is from the Tun Mustapha Park Expedition (TMPE) 2012 that surveyed six reef sites (**Table 2.1a**) for coral diversity and reef status (**Table 2.1a** and **Figure 2.1a**) (Jumin et al., unpublished;

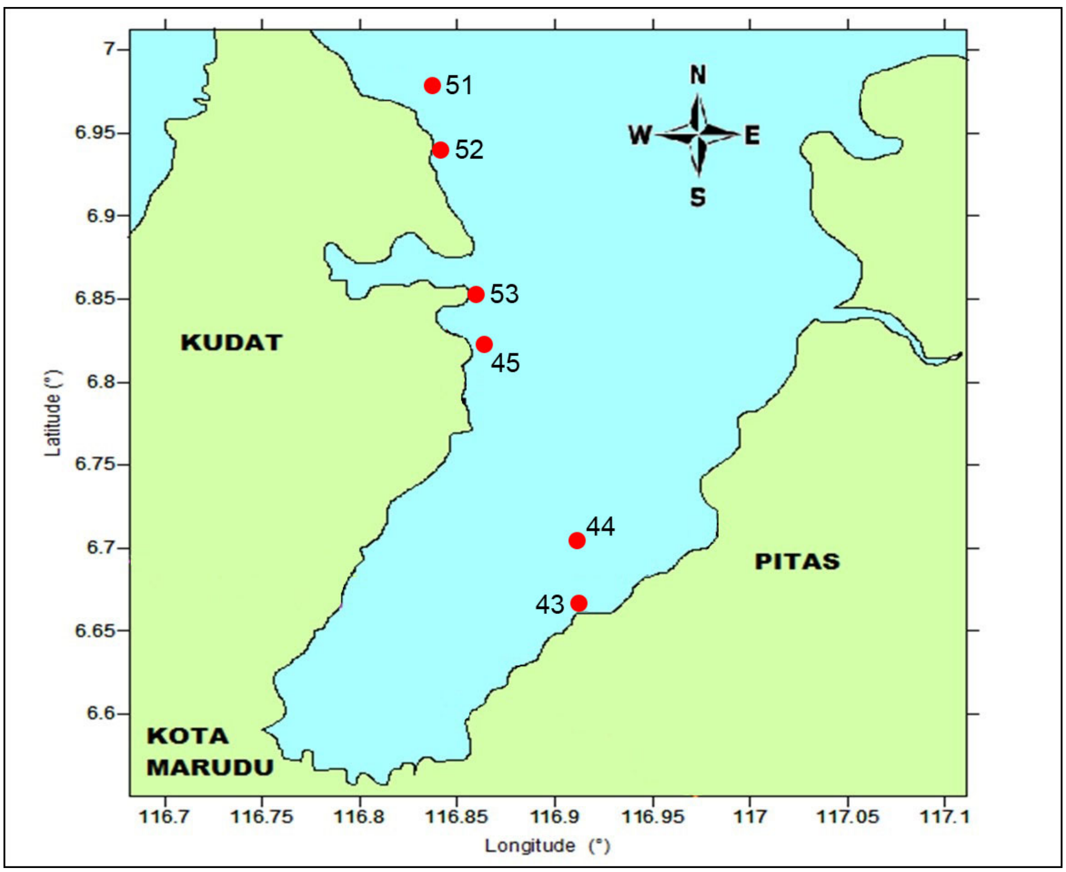
Waheed et al., 2015). Based on TMPE 2012, hard coral cover ranged between 21% and 53%, with an average of 39% cover. Butterflyfish, snapper, parrotfish, and haemulids (i.e. grunts) were present in very few numbers. Invertebrate indicators were represented by *Diadema* urchins, coral banded shrimp, sea cucumber, lobster, and giant clams. Apart from *Diadema* urchins, the rest of the invertebrates were noted only once or twice. The primary impacts on the reefs were caused by blast (dynamite) fishing and trash.

Table 2.1a: Localities Data of Survey Sites in Marudu Bay During TMPE 2012

Site No.	Site Name	Coral Diversity Survey Coordinates	Reef Check Survey Coordinates
43	Rosob	6°40.2083' **N**; 116°54.395' **E**	-
44	Mempakad Reef	6°42.995' **N**; 116°54.2967' **E**	-
45	Limau-Limauan	6°49.35' **N**; 116°52.54' **E**	6°49.4033' **N**; 116°52.4333' **E**
51	Bak-Bak	-	6°57.6433' **N**; 116°50.3833' **E**
52	Pantai Bahagia	6°56.3617' **N**; 116°50.4283' **E**	6°55.1183' **N**; 116°50.9083' **E**
53	Tanjung Tigasamil	6°51.1183 **N** '; 116°51.5' **E**	6°51.3133' **N**; 116°51.6033' **E**

Source: Jumin et al., unpublished

Figure 2.2a: Reef Sites Surveyed in Marudu Bay During TMPE 2012



Hard corals covered 39.1% of the substrate in Marudu Bay, followed by rock (20.2%), rubble (17.8%), and sand (11.7%) (**Figure 2.1b**). Rock, rubble, and sand accounted for almost 50% of the substrate, while the rest of the categories (excluding hard coral, which was approximately

11.2%) was composed of soft coral, recently killed coral, nutrient indicator algae, sponge, silt, and other substrate. Site 52 had good coral cover condition (53.1%), sites 45 and 51 had fair coral cover (43.8% and 38.1%, respectively), while site 53 had poor coral cover (21.3%) (**Figure 2.1c**). Nutrient indicator algae was most dominant at site 52 (11.9%).

Out of the nine reef fish indicators, only four were present (butterflyfish, haemulids, snappers, and parrotfishes), while barramundi cod, grouper, humphead wrasse, bumphead parrotfish, and moray eel were absent during the surveys (**Figure 2.1d**). Butterflyfish and snapper were observed at all sites, the haemulids were found at sites 45 and 53, and parrotfish at sites 51 and 53. The haemulids and parrotfish were reported in very low numbers.

The reef invertebrate indicators were primarily dominated by the *Diadema* urchin, particularly at site 45 (**Figure 2.1e**). The coral banded shrimp was only noted at site 53, sea cucumber at site 51, and lobster at site 45. Giant clams were encountered at sites 45 and 53. Impacts due to blast fishing and trash were observed at sites 52 and 53 (**Figure 2.1f**). Although the impact of blast fishing was considered low, trash ranked high at both sites.

Figure 2.1c: Percentage Cover of Each Substrate Category at Four Survey Sites

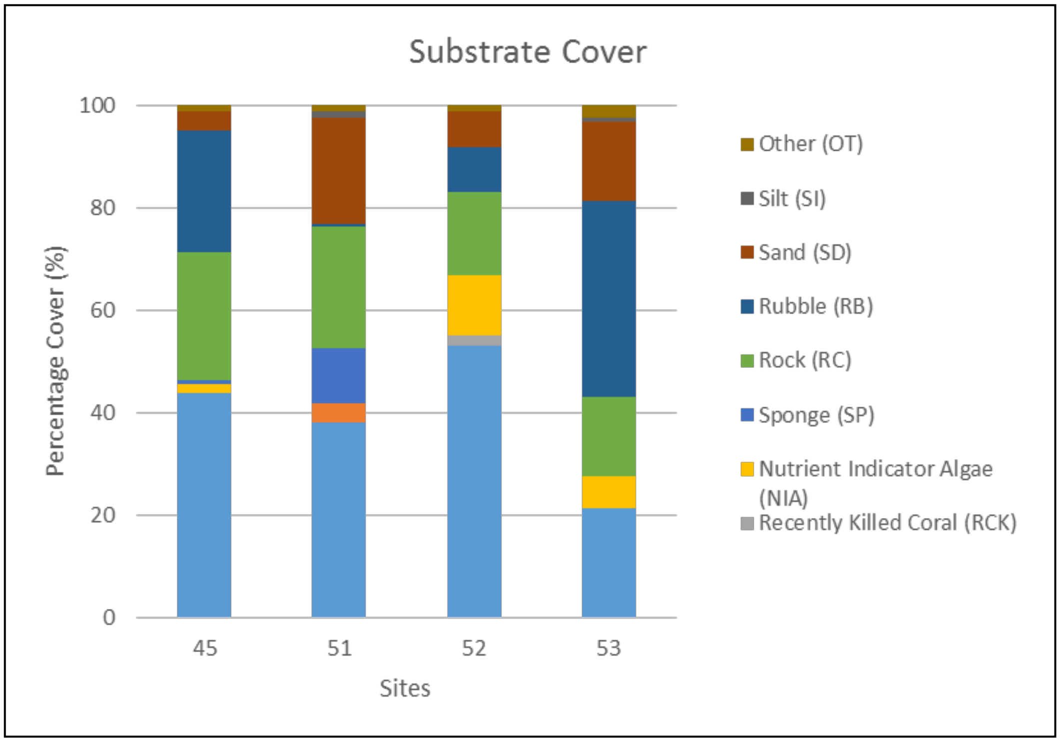


Figure 2.1d: Mean Abundance of Reef Fish Indicators at Four Survey Sites

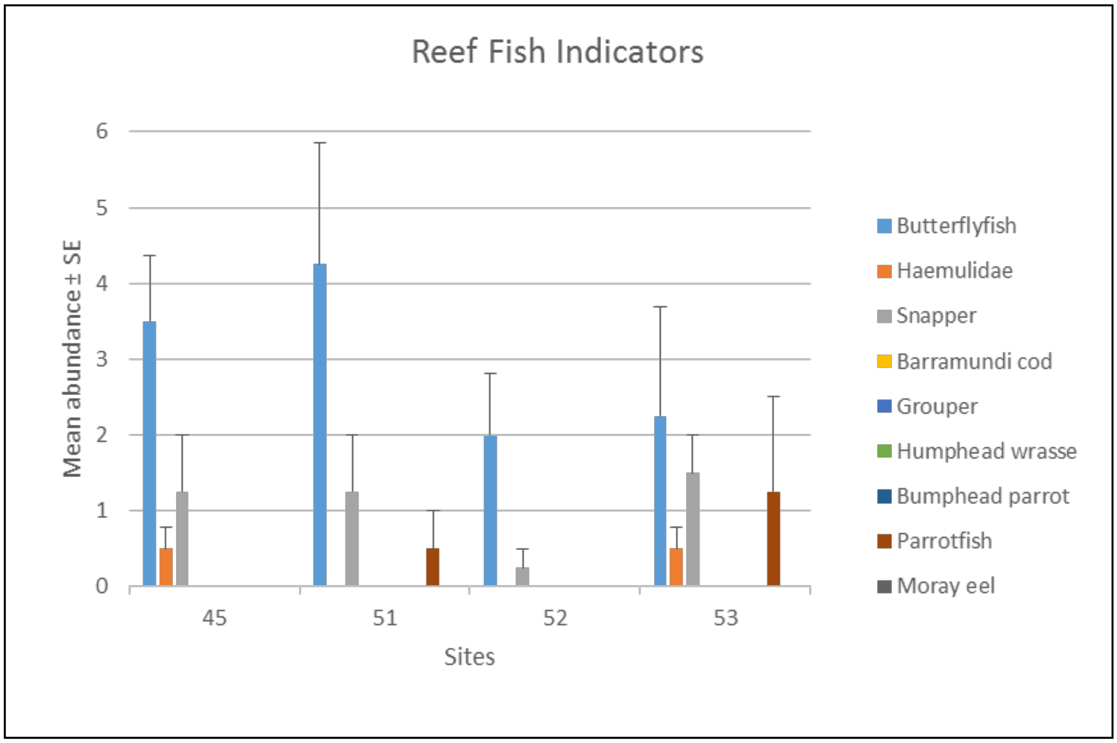


Figure 2.1e: Mean Abundance of Reef Invertebrate Indicators at Four Survey Sites

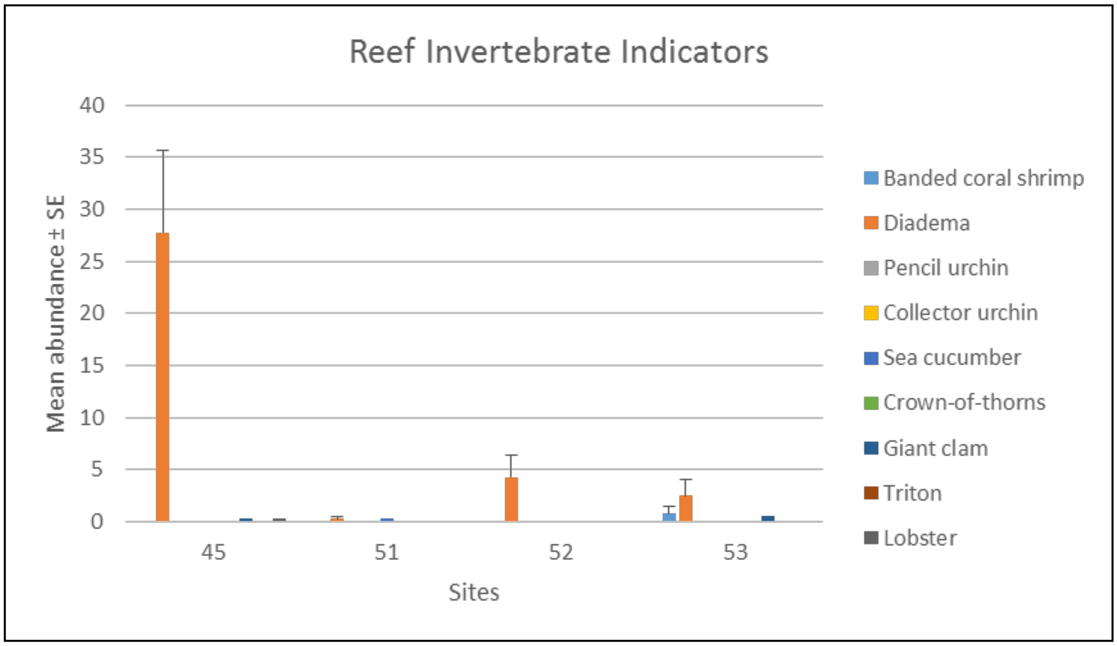
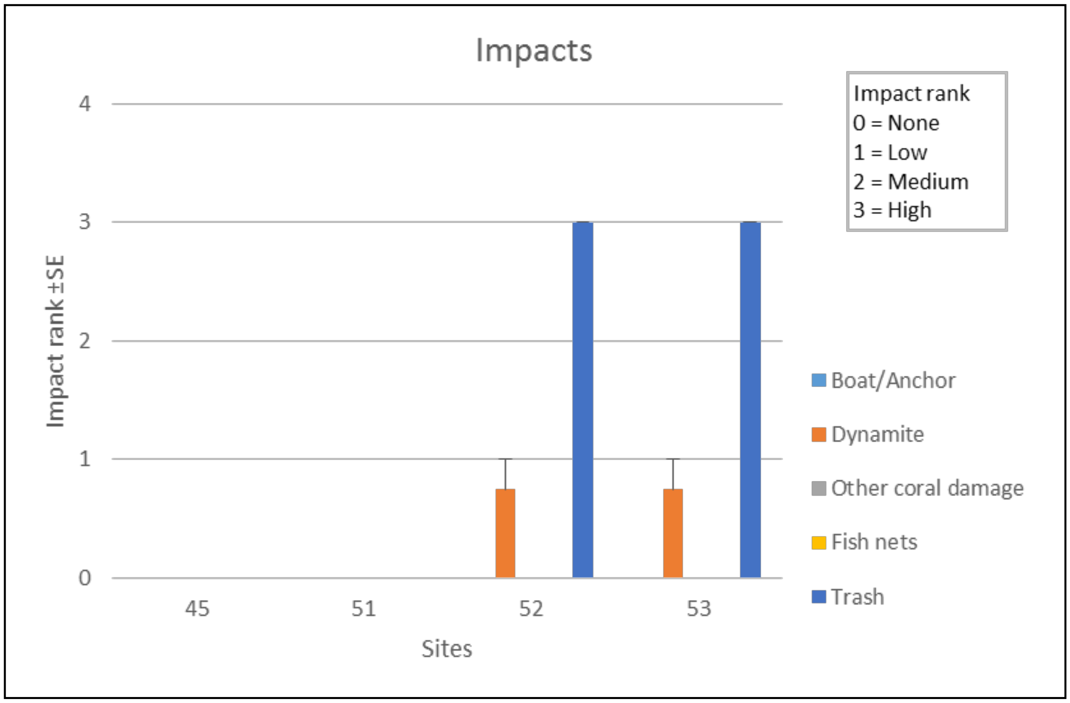


Figure 2.1f: Impact Levels on the Survey Sites in Marudu Bay



In terms of coral species, the only list available for Marudu Bay is for coral families *Fungiidae*, *Agariciidae*, and *Euphylliidae*, with 45 species documented (**Table 2.1b**) (Waheed et al., 2015). For the proposed TMP, a total of 312 coral species were reported from the southeast of Pulau Banggi to the north of Pulau Jambongan (Kalangan) (Fenner, 2001; Waheed et al., 2015; Waheed et al., unpublished).

Table 2.1b: Coral Species Incidence for Families Fungidae, Agariciidae, and Euphyliidae During TMPE 2012

No.	Coral Species	Site 43	Site 44	Site 45	Site 52	Site 53
	Fungiidae	**18**	**16**	**9**	**19**	**18**
1	*Ctenactis crassa* (Dana, 1846)	0	0	1	1	0
2	*Ctenactis echinata* (Pallas, 1766)	1	1	1	1	1
3	*Cycloseris costulata* (Ortmann, 1889)	1	1	0	1	1
4	*Cycloseris cyclolites* (Lamarck, 1815)	0	1	0	1	0
5	*Cycloseris fragilis* (Alcock, 1893)	0	0	0	0	1
6	*Cycloseris mokai* (Hoeksema, 1989)	1	1	0	0	1
7	*Danafungia horrida* (Dana, 1846)	1	1	0	1	1
8	*Danafungia scruposa* (Klunzinger, 1879)	1	1	0	1	1
9	*Fungia fungites* (Linnaeus, 1758)	1	1	1	1	1
10	*Heliofungia actiniformis* (Quoy and Gaimard, 1833)	1	0	0	1	1
11	*Herpolitha limax* (Esper, 1797)	1	1	1	1	1
12	*Lithophyllon concinna* (Verrill, 1864)	1	1	0	0	1
13	*Lithophyllon repanda* (Dana, 1846)	1	1	0	1	1

No.	Coral Species	Site 43	Site 44	Site 45	Site 52	Site 53
14	*Lithophyllon scabra* (Döderlein, 1901)	1	0	1	1	1
15	*Lithophyllon undulatum* Rehberg, 1892	1	1	0	1	1
16	*Pleuractis granulosa* (Klunzinger, 1879)	1	1	1	1	1
17	*Pleuractis gravis* (Nemenzo, 1955)	0	0	0	1	0
18	*Pleuractis moluccensis* (Van der Horst, 1919)	1	1	0	1	1
19	*Pleuractis paumotensis* (Stutchbury, 1833)	1	1	1	1	1
20	*Podabacia crustacea* (Pallas, 1766)	1	1	0	1	0
21	*Polyphyllia talpina* (Lamarck, 1801)	1	1	1	1	1
22	*Sandalolitha robusta* (Quelch, 1886)	1	0	1	1	1
	Agariciidae	**10**	**10**	**3**	**12**	**14**
23	*Coeloseris mayeri* Vaughan, 1918	1	0	1	1	1
24	*Leptoseris foliosa* Dinesen, 1980	0	0	0	0	1
25	*Leptoseris glabra* Dinesen, 1980	0	1	0	0	1
26	*Leptoseris mycetoseroides* Wells, 1954	1	1	0	0	1
27	*Leptoseris scabra* Vaughan, 1907	1	1	0	0	1
28	*Leptoseris tubulifera* Vaughan, 1907	1	1	0	1	1
29	*Pachyseris rugosa* (Lamarck, 1801)	0	1	0	1	1
30	*Pachyseris speciosa* (Dana, 1846)	1	1	0	1	1
31	*Pavona cactus* (Forskål, 1775)	1	1	0	1	0
32	*Pavona decussata* (Dana, 1846)	1	1	0	1	1
33	*Pavona duerdeni* Vaughan, 1907	0	0	0	1	0
34	*Pavona explanulata* (Lamarck, 1816)	1	1	0	1	1
35	*Pavona frondifera* (Lamarck, 1816)	1	1	0	1	1
36	*Pavona varians* Verrill, 1864	1	0	1	1	1
37	*Pavona venosa* (Ehrenberg, 1834)	0	0	1	1	1
38	*Pavona* sp. 1	0	0	0	1	1
	Euphylliidae	**3**	**4**	**1**	**4**	**5**
39	*Catalaphyllia jardinei* (Saville-Kent, 1893)	1	1	0	0	0
40	*Euphyllia ancora* Veron and Pichon, 1980	0	1	0	1	0
41	*Euphyllia divisa* Veron and Pichon, 1980	0	0	0	0	1
42	*Euphyllia glabrescens* (Chamisso and Eysenhardt, 1821)	1	1	0	1	1
43	*Euphyllia paraancora* Veron, 1990	0	0	0	0	1
44	*Physogyra lichtensteini* (Milne Edwards and Haime, 1851)	0	0	1	1	1
45	*Plerogyra sinuosa* (Dana, 1846)	1	1	0	1	1
	Grand Total	**31**	**30**	**13**	**35**	**37**

5. Seagrasses

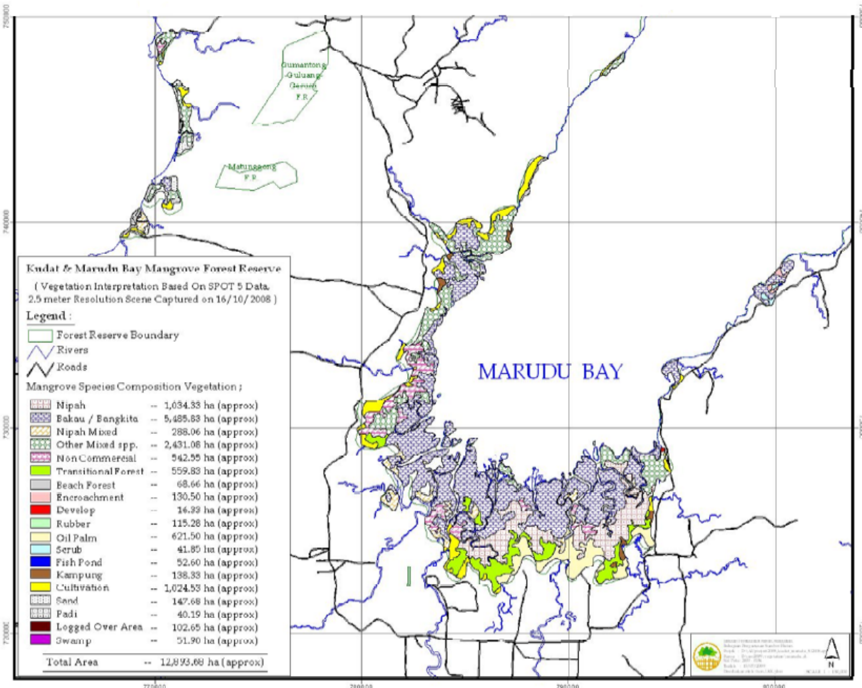
There are approximately 60 species of seagrasses worldwide (Short et al., 2007). In Sabah alone, 18 species have been recorded, and Malaysia in general is one of the countries with a naturally high density of seagrasses (Fortes, 1990; Sidik et al., 2003, 2006; Freeman et al., 2008). Seagrasses grow along intertidal areas, with preferred substrates such as sand, muddy sand, and coral rubble (Ismail, 1993; Sidik et al., 1997, 1999, 2000; Gumpil, 1997; Rajamani, 2004, 2008).

Seagrass areas are found throughout the coast of Sabah, including offshore islands. These areas are located in Tunku Abdul Rahman Park, Sepangar Bay, Tg. Kaitan, Karambunai, Salut-Mengkabong estuary, Layang-layang Island (Is.), Tg. Simpang Mengayau, Bak Bak, Mantanani Is., Banggi Is., Balambangan Is., Jamboangan Is., Sandakan, Darvel Bay, Sipadan Is., and Labuan Is. Although seagrasses are widely reported in Sabah waters, there are few reports of its occurrence in the inner (southern) part of Marudu Bay. Based on anecdotal reports, seagrass occurs in remote areas of Limau-limauan in Kudat and the estuary of the Bengkoka River.

6. Mangroves

The open coastlines of Marudu Bay are mostly formed by mangrove forests covering the districts of Kudat, Marudu, and Pitas. On the other hand, the southern part of the bay is formed entirely by large tracts of mangrove forests along estuaries and river mouths (**Figure 2.1a**). Faridah-Hanum et al. (2012) recorded 16 species from 12 genera and nine families of mangroves in Marudu Bay. The dominant species are *Rhizopora apiculata* and *R. mucronata*. Nipah, bakau/bangkita, nipah mixed, other mixed species, non-commercial/transitional forests, and beach forests are also commonly found along the coastal areas. The distribution and estimated coverage area of mangrove species in the southern part of Marudu Bay are shown in **Figure 2.1g.**

Figure 2.1g: Distribution of Mangrove Species in the Southern Part of Marudu Bay



Source: Faridah-Hanum et al., 2012.

Zakaria and Rajpar (2015) reported that the mangrove cover of Marudu District alone is approximately 12,894 hectares. Furthermore, they identified that these mangrove habitats harbored a diversity of fauna species, including 22 aquatic invertebrate species (comprising 11 species of crustaceans, six species of molluscs, and four species of worms), 36 fish species, 74 bird species, four reptile species, and four mammal species.

B. Oceanographic Parameters

The coastline of Marudu Bay is dominated by fringing mangroves, with parts of the shoreline formed by white sandy beaches on the bay's west and east sides. Marudu Bay is exposed to the southwest monsoon (occurring from early June to late September) and northeast monsoon (early November to late March) (MMD, 2013). These seasonal monsoons may affect the water properties, current patterns, and marine life in the bay.

1. Tidal Pattern

There are two types of tides, semi-diurnal and mixed, both of which can be experienced in coastal areas. Semi-diurnal tide can be expressed as two nearly equal high and low tides occurring in a day, while mixed tide refers to two uneven tides, or one high tide and one low tide, occurring in a day (Than et al., 2013). According to Koon (2007), Kudat waters have mixed and semi-diurnal tides. The estimated tidal range here is 0.2-2.2 meters (m) (NHC, 2015). Siringan et al. (2013) predicted that a higher tidal range would increase the potential of inundated areas during typhoon and storm surges.

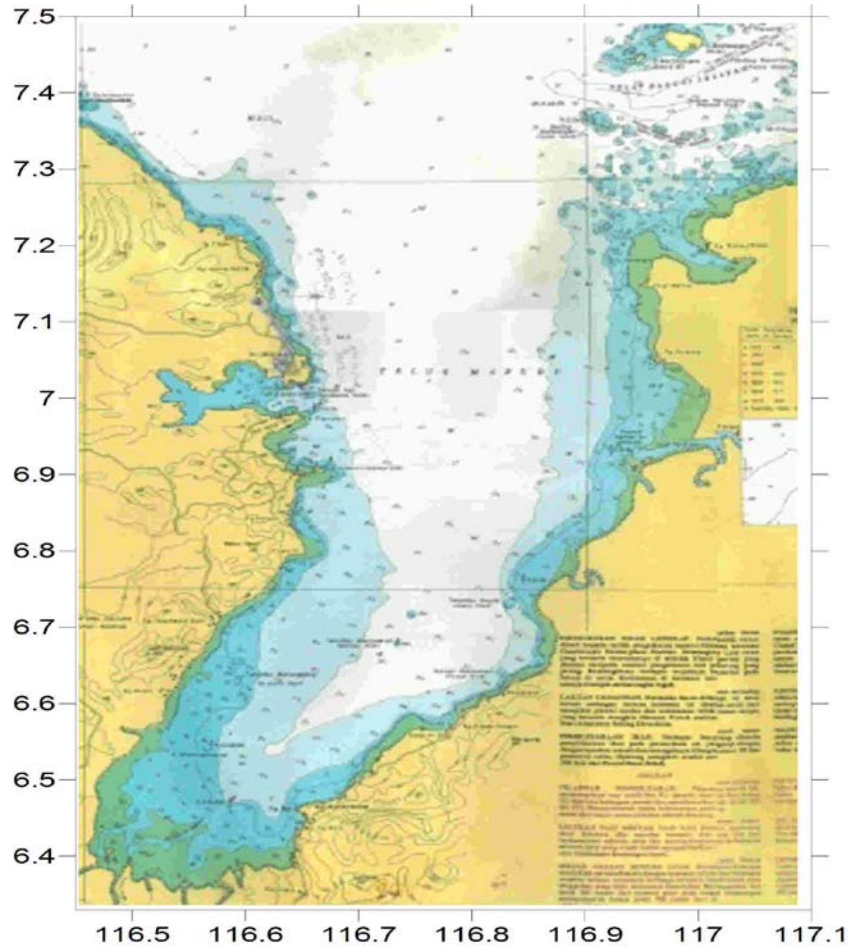
2. Bathymetry

Based on the marine chart of Marudu Bay, the inner (southern) half of the bay is dominated by shallow water over an extensive intertidal zone surrounding the coastline, while the northern half is formed by narrow intertidal areas. The average depth along the shore is 0.5 m, while the average depth around the deeper northern part is 21.5 m, with the deepest part around the middle of the bay reaching a maximum depth of 31 m (**Figure 2.2**).

3. Physico-Chemical Characteristics

It is reported that the salinity of Marudu Bay during the southwest monsoon ranges between 20.78 psu and 31.86 psu, with the lowest salinities detected at estuaries on the inner part of the bay (Jakobsen et al., 2007). The salinity during the northeast monsoon can be as low as 26 psu in the middle of the bay, due to the large amount of freshwater input from the surrounding areas. The salinity range is affected by wind-driven currents during different monsoons (Islam et al., 2011). Higher salinity is related to limited river inflow and limited water exchange. However, strong currents during the southwest monsoon can also result in higher salinity through the mixing of waters in Marudu Bay.

Figure 2.2: Bathymetry of Marudu Bay Based on Marine Chart



C. Quality of Coastal and Marine Waters

Degradation of water quality is a prevalent issue in Malaysia, where increasing human activities near coastal areas such as sewage output and agriculture, and deliberate discharge from ships cause marine pollution (Jothy, 1976). Seawater quality degradation is dangerous as it can harm marine organisms as well as people.

Malaysia's marine areas are rich in biodiversity. Major marine ecosystems such as coral reefs, seagrasses, and mangroves are found in the country. These ecosystems are service providers of marine-based economic activities such as mariculture, while fisheries provide locals with sources of food and income. For these reasons, the effects of land-based agricultural activities to the quality of seawater should be looked into. Many such activities exist in areas around Marudu Bay, particularly in timber, oil palm, paddy, coconut, and rubber plantations (Aris et al., 2014). However, the few available reports on the seawater quality of Marudu Bay (Aris et al., 2014; Tan & Ransangan, 2015) are limited to areas in the middle and southern parts of the bay. Nevertheless, these data provide useful baseline information in selecting seawater quality parameters for Marudu Bay.

4. Marine Pollutants

Seawater is a component that interacts with the terrestrial environment, which is the primary source of wastes that pollute the sea. Moreover, the sea acts as a catchment for pollutants (contaminants) from the atmosphere. Wastes containing pollutants eventually end up in coastal and marine ecosystems. Pollutants that are partially soluble in water sink to the bottom and accumulate in the sediment. These find their way into the body tissues of marine organisms through the food chain. Such pollutants typically follow the marine food chain, from phytoplankton to predatory fish and ultimately humans. In high concentrations, pollutants disrupt not only the marine food chain but also the various marine habitats, and are hazardous to human health.

Marine pollution has been reported to be harmful to many marine invertebrates throughout the world (e.g. Beaumont & Budd, 1985; Lee, 1985). Anti-fouling paint, applied to the hulls of ocean-going vessels, and tributyltin (TBT, used as a biocide in anti-fouling paint) have been found to be harmful to several gastropod species. Blaber (1970) first reported the occurrence of imposex (disorder that causes a female organism to have a penis-like organ) in arkshells in Australia, which he showed was caused by anti-fouling paint. Since then, the effects of anti-fouling paint and TBT have become a focused study on marine pollution. Since many invertebrates are filter and detritus feeders, studies have reported a variety of TBT-contaminated mollusc species, including the Asiatic hard clam/Venus clam *Meretrix meretrix*, Pacific oyster *Crassostrea gigas*, green mussel *Perna viridis*, Mediterranean mussel *Mytilus galloprovincialis,* great scallop *Pecten maximus*, and mud crab *Scylla serrata* (e.g. Hong et al., 2002; Jadhav et al., 2011).

In Malaysia, Tong et al. (1996) conducted a study on the distribution of TBT in the coastal areas of Selangor and Negeri Sembilan (on the west coast of Peninsular Malaysia). Their study found Port Dickson and Port Klang areas to be highly polluted by TBT. The green mussel *Perna viridis* was found to have the highest accumulation of TBT, although lower than in other known polluted areas. Another study reported on the heavy metal contamination in gastropod species *Thais* spp. and in rock oyster *Saccostrea* spp., as derived by cadmium (Cd) and lead (Pb) in the Malaysian aquatic environment (Shazili et al., 2006). In these studies, bivalves (*Perna viridis*, *Saccostrea* spp.) and gastropods (*Thais* spp.) were used as bio-indicators.

Marine stranded debris and microplastics are another type of marine pollutants. According to Masura et al. (2015), microplastic debris is operationally defined as any solid material that is resistant to wet peroxide oxidation, exhibits floatation in a 5 M NaCl (d=1.15g/ml) or lithium metatungstate (d=1.62 g/ml), and passes visual inspection under a microscope at 40x power.

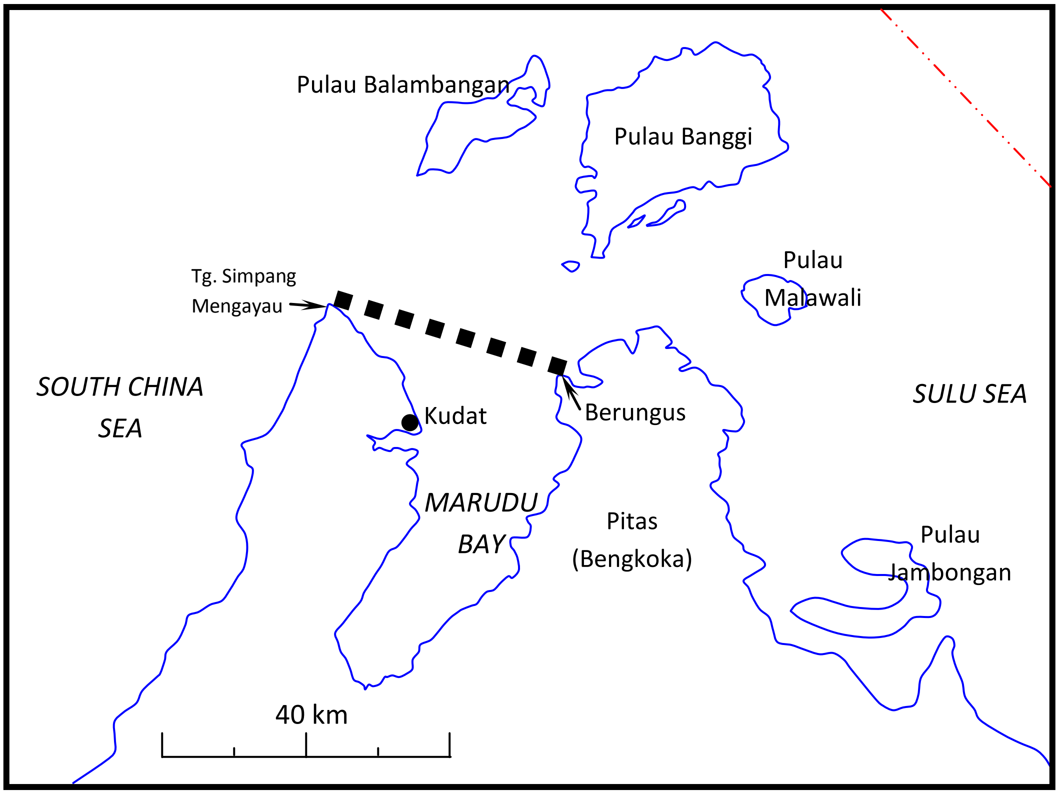
Hence, marine pollution is a threat that must be addressed seriously. One way to determine the level of seawater contamination is by analyzing seawater quality. This will enable us to identify contaminants and the sources of contamination.

III. MATERIALS AND METHODS

A. Study Area

We delimited the field sampling sites to locations within Marudu Bay, setting an arbitrary line between Tg. Simpang Mengayau and Berungus as the open sea entrance to the bay (**Figure 3.1**). The inland boundary follows the Highest Astronomical Tide (HAT) level, which is determined by the presence of fringing mangrove forests and ± 1 km inland. HAT is defined as "the highest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions; this level will not be reached every year, and is not the extreme level that can be reached as storm surges and other meteorological conditions may cause considerable higher levels to occur" (SeaZone, 2006).

Figure 3.1: Limits of Marudu Bay in This Study



Note: Black square-dotted line represents the maritime boundary of the study area. Red dash-dotted line is the international maritime border between Malaysia and the Philippines.

B. Fieldwork

Fieldwork was conducted from June to December 2015.

Sampling of biological and physico-chemical characteristics followed standard survey techniques, with some aspects requiring necessary modifications for local conditions. Primary field data on biological, physico-chemical parameters, and other aspects of Marudu Bay are presented in spreadsheet format and appended to this report.

1. Fish and Fisheries

Samplings were carried out on 25-27 June, 10-12 August, 7-10 October, and 21-23 December 2015. The sites visited for the fish biodiversity survey are presented in **Table 3.2.1** and **Figure 3.2.1**. The sampling localities were accessed by land and by sea (boat), and involved fish market surveys, sampling with fishing gear (gill net, beach seine net, and long line), and underwater observation and sampling via scuba diving.

Table 3.2.1: Sampling Localities for Fish and Fisheries Survey

Site No.	Name of Locality	GPS Coordinates
BY LAND		
1	Kg. Kuyu, Pitas	06° 47.197’ **N**; 117° 05.164’ **E**
2	Kg. Kuyu, Pitas	06° 47.018’ **N**; 117° 05.194’ **E**

Site No.	Name of Locality	GPS Coordinates
3	Kg. Senaja, Pitas* (gill net and long line)	06° 44.438’ **N**; 117° 02.872’ **E**
4	Dataran Bengkoka* (beach seine net)	06° 41.002’ **N**; 116° 56.862’ **E**
5	Kg. Luntuk*	06° 37.716’ **N**; 116° 52.969’ **E**
6	Taritipan	06° 34.912’ **N**; 116° 51.351’ **E**
7	Taritipan	06° 34.203’ **N**; 116° 51.528’ **E**
BY BOAT		
8	Kg. Berungus* (scuba diving)	06° 57.164’ **N**; 117° 01.306’ **E**
9	Kg. Berungus	06° 57.151’ **N**; 117° 01.416’ **E**
10	Sandfish pen Kg. Berungus	06° 57.018’ **N**; 117° 01.804’ **E**
11	Bagang in Kg. Rosob	06° 44.300’ **N**; 116° 57.330’ **E**
12	Bagang in Kg. Rosob	06° 43.082’ **N**; 116° 56.875’ **E**
13	Barraut Reef	06° 42.982’ **N**; 116° 54.263’ **E**
14	Parapat Laut	06° 46.110’ **N**; 116° 51.578’ **E**
15	Limau-limauan (beach seine net)	06° 49.050’ **N**; 116° 51.449’ **E**
16	Limau-limauan	06° 48.854’ **N**; 116° 51.660’ **E**
BY LAND		
17	Kg. Limau-limauan	06° 49.316’ **N**; 116° 51.783’ **E**
18	Kudat Fish Market	06° 52.705’ **N**; 116° 50.938’ **E**
19	Shrimp Farm Sg. Karang Kg. Dampirit	06° 52.559’ **N**; 116° 46.094’ **E**
20	Kg. Parapat Laut*	06° 46.989’ **N**; 116° 51.284’ **E**
21	Kg. Membatu Laut Baru	06° 44.053’ **N**; 116° 49.130’ **E**
22	Kg. Sebayan, Kota Marudu	06° 40.959’ **N**; 116° 47.478’ **E**
23	Enrich Wise Sdn. Bhd. Kg. Toporoi	06° 40.778’ **N**; 116° 45.025’ **E**
24	Kg. Tanah Merah	06° 39.970’ **N**; 116° 45.773’ **E**
25	Kg. Tanah Merah	06° 39.893’ **N**; 116° 45.867’ **E**
26	Kg. Birahan Laut, Kudat	06° 39.223’ **N**; 116° 45.624’ **E**
27	Jeti Perhutanan Kg. Ranau, Kota Marudu	06° 32.675’ **N**; 116° 44.929’ **E**
28	Kota Marudu Fish Market	06° 29.414’ **N**; 116° 46.332’ **E**

Notes:
- Fish recorded were based on specimens purchased from fish sellers or fishers, and/or photographs only, unless otherwise stated.
- GPS = Global Positioning System.

Figure 3.2.1: Sampling Localities for Fish and Fisheries Survey

Note: Numbers correspond to first column in **Table 3.2.**1. Bar scale: 20 km. Google Maps.

Specimens collected and purchased were fixed in 10% unbuffered formalin and preserved in 70% ethanol. Fishes were photographed before fixation and (preferably) soon after death to capture their vivid natural colors (Motomura & Ishikawa, 2013). Additionally, the annual demersal and pelagic fisheries landing trend (2009-2013) for Pitas, Kudat, and Kota Marudu were analyzed (DOFS, 2009-2013).

2. Marine Invertebrates and Seagrass

Field surveys for invertebrates and seagrass were combined for practical purposes, since the same team members were involved in both studies. Nevertheless, the results of the studies are presented separately. Sampling was conducted on 7-8 August 2015. The sites visited are listed in **Tables 3.2.2a** and **3.2.2b**. The sampling localities were accessed by land and by sea (boat), and were selected based on their location within a major river system in Marudu Bay, except for site 1 (Tg. Simpang Mengayau), which is a rocky shore area.

Three coastal areas and two rivers that were surveyed are in the districts of Kudat and Marudu: Tg. Simpang Mengayau, Pantai Bak-Bak (*Pantai* or beach), Limau-limauan, Sg. (*Sungai* or river) Matunggung, and Sg. Bandau (**Tables 3.2.2a** and **3.2.2b**; **Figures 3.2.2a** and **3.2.2b**). Sampling of epifaunal invertebrates was done at Tg. Simpang Mengayau, Sg. Matunggung, and Sg. Bandau. The transect line was set seaward from the shoreline perpendicularly, with three 50-cm by 50-cm quadrats thrown randomly every 10 m along the 50-m long transect line. The coastal areas of all sites (**Table 3.2.2a**) were surveyed to estimate the coverage area of seagrass meadows. Specimens of invertebrates and seagrass collected were air-dried to preserve them, and photographed *in situ* and *ex situ* (in the laboratory).

Table 3.2.2a: Sampling Localities for Marine Invertebrates and Seagrass Surveys

Site No.	Name of Locality	Description	GPS Coordinates
1	Tg. Simpang Mengayau	Intertidal pond	07° 03.555' **N**; 116° 74.588' **E**
2	Sg. Matunggong	Mangrove	06° 66.366' **N**; 116° 76.862' **E**
3	Sg. Matunggong	Mangrove	06° 66.243' **N**; 116° 77.605' **E**
4	Sg. Bandau	Mangrove	06° 57.137' **N**; 116° 76.560' **E**
5	Sg. Bandau	Mangrove/nipah	06° 55.583' **N**; 116° 75.390' **E**
6	Sg. Bandau	Exposed mudflat	06° 59.179' **N**; 116° 77.249' **E**

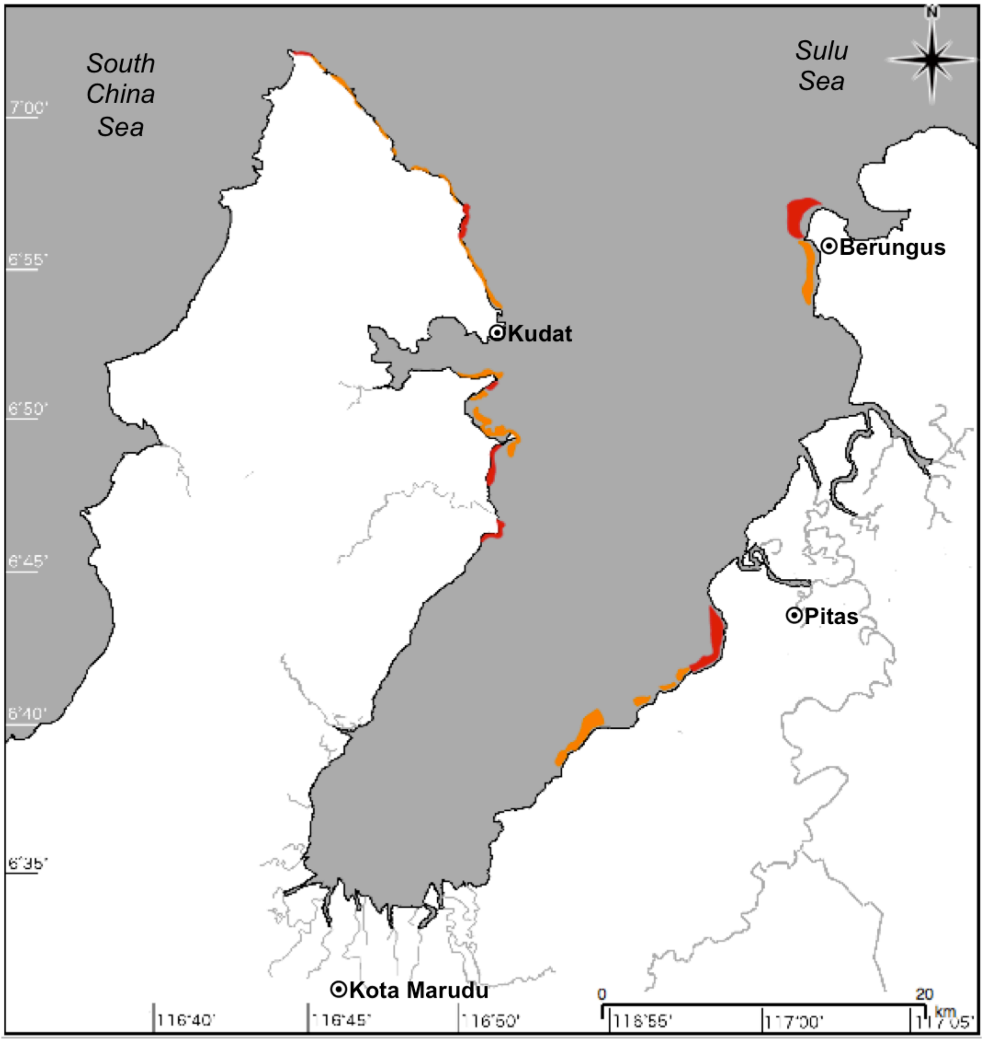
Table 3.2.2b: Sampling Localities with Occurrence of Seagrass Beds

Site No.	Name of Locality	GPS Coordinates
1	Tg. Simpang Mengayau	07° 03.555' **N**; 116° 74.589' **E**
2	Pantai Bak-bak	06° 94.367' **N**; 116° 83.953' **E**
3	Tanjung Limau-limauan	06° 81.919' **N**; 116° 86.017' **E**
4	Kg. Rosob	06° 69.742' **N**; 116° 97.463' **E**
5	Berungus	06° 95.252' **N**; 117° 02.360' **E**
6	Wong Sin Hin Fish Farm	06° 84.926' **N**; 116° 85.202' **E**

Figure 3.2.2a: Sampling Localities (Transect Line Sites) for Invertebrates Survey

Numbers correspond to first column in Table 3.2.2a. Bar scale: 20 km. Google Maps.

Figure 3.2.2b: Seagrass Cover of Marudu Bay



Note: Areas in red were based on *in situ* survey; areas in orange were estimated based on Google Earth Satellite Map.

3. Other Aquatic Vertebrates

Information for this group was opportunistically recorded during the fish surveys, i.e. no additional efforts were made to survey large marine mammals and turtles in this study. The coral reef team came across a floating carcass of an adult female green turtle *Chelonia mydas* in the bay. By the end of the survey period, there were no new records or reports on this group.

4. Corals and Reef Indicators

Field surveys for corals and coral reefs were carried out on 25-29 August 2015. In general, the objectives of the surveys were to determine the status of the coral reefs in Marudu Bay by focusing on:

(i) substrate coverage (represented by Reef Check substrate categories: hard coral, soft coral, recently killed coral, nutrient indicator algae, sponge, rock, rubble, sand, silt, and other substrate);
(ii) diversity of reef indicators (invertebrate and fish); and
(iii) impacts on the reef (such as blast fishing, trash, ghost nets on the reefs, etc.).

Fourteen reef sites were surveyed in Marudu Bay (**Table 3.2.4a** and **Figure 3.2.4**). Eleven sites are fringing reefs, while three sites are patch reefs (sites 4, 5, and 7). In addition to these dives sites, spot checks were made to determine the bottom substrate at nine sites, some of which had very sparse and patchy coral colonies mixed with a sandy bottom substrate (**Table 3.2.4b**, **Figure 3.2.4**).

Table 3.2.4a: Localities Data for Coral Reefs Survey

Site No.	GPS Coordinates	Site Name	Depth (m)	Survey Date
1	06^0 42.359’ **N**; 116^0 49.688’ **E**	-	2.0	25-08-2015
2	06^0 38.660’ **N**; 116^0 53.352’ **E**	-	2.0	26-08-2015
3	06^0 40.402’ **N**; 116^0 54.680’ **E**	Rosob	2.5	26-08-2015
4	06^0 42.999’ **N**; 116^0 54.299’ **E**	Mempakad Reef	2.8	26-08-2015
5	06^0 44.081’ **N**; 116^0 54.647’ **E**	-	5.0	27-08-2015
6	06^0 44.589’ **N**; 116^0 57.768’ **E**	-	3.6	27-08-2015
7	06^0 56.464’ **N**; 116^0 59.593’ **E**	-	6.6	27-08-2015
8	07^0 02.358’ **N**; 116^0 44.777’ **E**	Simpang Mangayau	5.0	28-08-2015
9	07^0 01.412’ **N**; 116^0 46.242’ **E**	-	3.2	28-08-2015
10	06^0 57.918’ **N**; 116^0 49.987’ **E**	Bak-Bak	1.1	28-08-2015
11	06^0 56.601’ **N**; 116^0 50.483’ **E**	Pantai Bahagia	3.0	28-08-2015
12	06^0 57.330’ **N**; 117^0 00.596’ **E**	Kg. Berungus	6.0	29-08-2015
13	06^0 48.997’ **N**; 116^0 52.272’ **E**	Limau-Limauan	2.3	29-08-2015
14	06^0 51.333’ **N**; 116^0 51.645’ **E**	Tanjung Tigasamil	5.5	29-08-2015

Table 3.2.4b: Details and Location of Spot Check Sites in Marudu Bay

Site No.	GPS Coordinates	Notes	Survey Date
S1	06^o 45.765’ **N**; 116^o 51.467’ **E**	Patchy seagrass bed – *Halodule pinifolia*	25-08-2015
S2	06^o 45.755’ **N**; 116^o 51.014’ **E**	Sandy – near mangroves	25-08-2015
S3	06^o 45.400’ **N**; 116^o 50.982’ **E**	Sandy – near land clearing	25-08-2015
S4	06^o 42.188’ **N**; 116^o 49.692’ **E**	Sandy, very patchy corals – Pancang	25-08-2015
S5	06^o 39.105’ **N**; 116^o 47.888’ **E**	Sandy-silty – near Pulau Matunggong	25-08-2015
S6	06^o 36.918’ **N**; 116^o 51.181’ **E**	Sandy – erosion nearshore?	25-08-2015
S7	06^o 38.322’ **N**; 116^o 53.162’ **E**	Sandy – near reclaimed land	25-08-2015
S8	06^o 38.655’ **N**; 116^o 53.350’ **E**	Sandy, rocky – near rocky shoreline	25-08-2015

S9	06° 49.639’ **N**; 116° 59.762’ **E**	Sandy-silty – near river mouth	27-08-2015

Standard Reef Check methodology was applied to assess the substrate cover and invertebrate abundance of the reefs (Hodgson et al., 2006). The depths of the reefs surveyed were between 1 and 6 m. A transect tape of 100 m in length was placed on the reef. Data were collected in four segments of 20 m, leaving a 5-m gap in between each segment (20+5+20+5+20+5+20 = 95 m). Three types of data were recorded: (i) substrate, (ii) invertebrates (indicator species), and (iii) impact on the reefs (**Table 3.2.4c**; Hodgson et al., 2006). Species of corals were identified along the transect line and 2.5 m on both sides of the transect line. Random roving dive was conducted along the same transect line (same transect line as the substrate and invertebrate surveys) to record the fish and invertebrate diversity at each dive site. All species encountered within 5 m on either side and above transects were photographed for identification and enumeration.

Hard corals were identified using descriptions primarily from Veron (2000) and verified using the World Register of Marine Species (WoRMS) online database (2015). Identification of fishes and invertebrates were based on several identification guides for the Indo-Pacific region: (i) Reef Creature Identification: Tropical Pacific (Humann & Deloach, 2010); (ii) Reef Fish Identification Tropical Pacific (Allen et al., 2003); and (iii) Reef Fishes of East Indies (Allen & Erdmann, 2012). The relative abundance of fish and invertebrates were recorded based on the number of individuals estimated in the photographs to calculate Shannon Wiener and Evenness indices using Paleontological Statistics (PAST) software package for education and data analysis version 3.10 (Hammer et al., 2001).

Figure 3.2.4: Coral Reef Survey Sites in Marudu Bay

Note: Numbers 1 to 14 correspond to the first column in Table 3.2.4a, and numbers S1 to S9 to the first column in Table 3.2.4b. Bar scale: 20 km. Google Maps.

Table 3.2.4c: Substrate Categories Using the Reef Check Method (Hodgson et al., 2006)

Substrate Category	Description
Hard Coral (HC)	Live hard coral, including fire coral (*Millepora*), blue coral (*Heliopora*), and organ pipe coral (*Tubipora*) because these are reef builders
Soft Coral (SC)	Including zoanthids
Recently Killed Coral (RKC)	Coral that died in the past year; coral appears fresh and white or with corallite structure still recognizable (intact/not eroded)
Nutrient Indicator Algae (NIA)	Blooms of fleshy algae responding to high levels of nutrient input, excluding coralline, calcareous (such as *Halimeda*), and turf algae

Substrate Category	Description
Sponge (SP)	All sponges (excluding tunicates)
Rock (RC)	Any hard substrate larger than 15 cm, whether covered in turf or encrusting coralline algae, barnacles, oysters, etc., and including dead coral that is more than one year old (structure worn down/covered in thick layer of encrusting organism and/or algae)
Rubble (RB)	Rock or fragment between 0.5 and 15 cm
Sand (SD)	Particles smaller than 0.5 cm (Sand falls quickly to the bottom after being dropped.)
Silt (SI)	Sediment that remains in suspension after being disturbed
Other (OT)	Any other sessile organism, including sea anemones, tunicates, gorgonians, or non-living substrate

5. Mangroves

Field surveys were carried out on 20-22 October 2015, with sampling time between 0900 and 1600 hours. Sampling localities were selected along rivers in the three districts: one river in Kudat, one river in Pitas, and two rivers in Marudu (**Table 3.2.5**). In each river, five subsampling sites (except for Sg. Bandau, which had only three sites) were randomly selected using Global Positioning System (GPS) coordinates, with a minimum distance of 500 m between two sites (**Figure 3.2.5**). Mangrove community data were recorded at each site.

Table 3.2.5: Sampling Localities for Mangrove Survey

Site No.	Name of Locality	Latitude (N)	Longitude (E)
1	Sg. Dualog, Kudat	06° 39.7083’ - 06° 40.065’	116° 45.7717’ - 116° 46.6383’
2	Sg. Matunggong, Marudu	06° 39.7083’ - 06° 40.065’	116° 45.7717’ - 116° 46.6383’
3	Sg. Bandau, Marudu	06° 32.975’ - 06° 35.0733’	116° 45.2017’ - 116° 46.3233’
4	Sg. Telaga, Pitas	06° 49.475’ - 06° 50.4833’	117° 04.9666’ - 117° 22.9317’

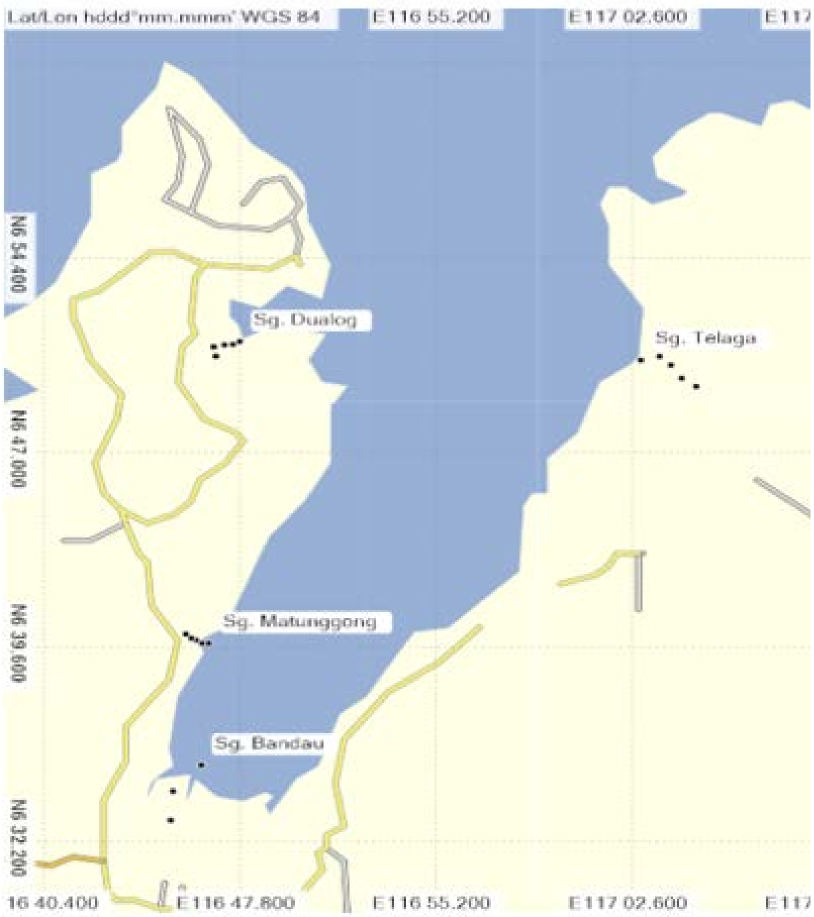
a. Physical Water Parameters

Physical water parameters were recorded using HANA Multi-Parameter. These parameters are water temperature (°C), conductivity (mS/cm), salinity (ppt), dissolved oxygen or DO (% and ppm), and pH. All measurements were made *in situ*, at the body of water where the boat was anchored, as some sites were exposed during spring ebb tide.

b. Mangrove Structural Data Collection

Two random survey plots were established at each subsampling site, except at site 1 of Sg. Dualog, where three plots were established. Each survey plot was 10 m by 10 m, deployed by using two 100-m measuring tapes to outline the plot. Once a plot was established, the GPS coordinates were taken at 0, 0 point, where the two measuring tapes cross. A total of 37 plots were deployed, covering 0.37 hectares.

Figure 3.2.5: Sampling Localities for Mangrove Survey



Note: Black dots indicate subsampling sites. Map was generated using Garmin Homeport trip planning software version 2.2.9.

At each plot, only mature trees above 1 m in height and greater than or equal to 2.5 cm in diameter at breast height (DBH) were measured and recorded. Girth at breast height (GBH) was measured at approximately 1.3 m using a measuring tape wrapped firmly around the tree trunk. Guidelines for measuring DBH followed English et al. (1997). Once a measurement was taken, the tree was marked with a white chalk to prevent its repeated measurement. Mangrove-associated species such as climbers, ferns, and shrubs were also recorded. Mangrove species identification followed Nilus et al. (2010) and Roldan et al. (2010).

A database of GBH data was then created using Microsoft Excel (ver 2013). Based on this data, the mean DBH (cm), basal area (m^2/ha), relative density, relative frequency, relative dominance, importance value index (IVI), Shannon's species diversity (H), and equitability (E_H) were calculated using the following equations:

1. $$Relative\ density, RDe = \frac{number\ of\ individual\ of\ a\ species}{total\ number\ of\ individual} \times 100$$

2. $$Relative\ frequency, RF = \frac{frequency\ of\ a\ species}{sum\ pf\ frequency\ of\ all\ species} \times 100$$

3. $$Diameter\ at\ breast\ height\ (DBH) = \frac{girth\ at\ breast\ height\ (GBH)}{\pi}$$
$$where\ \pi = 3.1416$$

4. $$Basal\ area\ (BA) = \pi \frac{DBH^2}{4} \times 100$$

5. $$Relative\ dominance, RDo = \frac{total\ basal\ area\ of\ a\ species}{total\ basal\ area\ of\ all\ species} \times 100$$

6. $$Importance\ Value\ Index, IVI = RDe + RF + RDo$$

7. $$Shannon's\ diversity\ index, H = \sum_{sp=t}^{T} \left(\frac{IV_{sp}}{IV_T}\right) ln \left(\frac{IV_{sp}}{IV_T}\right)$$
$$where\ T = total\ number\ of\ species$$
$$IV_{sp} = importance\ value\ of\ a\ species$$
$$IV_T = sum\ of\ importance\ value\ of\ all\ species$$

8. $$Shannon's\ equitability, E_H = \frac{H}{\ln S}$$
$$where\ S = total\ number\ of\ species$$

c. Statistical Analysis

Only data on mature woody plants that were possible for GBH measurement were further subjected to statistical analysis, which was done using Minitab (ver 17). Two-way analysis of variance (ANOVA) was used to test if there were any significant differences in plant DBH between surveyed rivers and species. When significant values were detected, Tukey post-hoc test was conducted to identify the source of difference.

6. Oceanographic Physico-Chemical Parameters

Samplings were carried out on 24-26 June and 27-28 August 2015. The objectives of the survey were to conduct a comprehensive review of existing data and gather field data on the following parameters:

(i) tidal patterns (diurnal and seasonal);
(ii) current patterns (long-shore, internal-seasonal);
(iii) depth;
(iv) substrate of Marudu Bay;
(v) total suspended solids (TSS); and
(vi) physico-chemical characteristics.

The sites visited are listed in Tables 3.2.6a and 3.2.6b, and Figure 3.2.6. Water parameters, including water temperature (°C), salinity (psu), DO (mg/L), and pH, were measured *in situ* using a Hydro Lab DS 5. The horizontal water sampler was used to collect water samples for TSS, while the grab sampler (PETITE PONAR® 6" Scoops 008890) was used for sediment samples to identify sediment grain size. The water samples were filtered using the MCE membrane filter (47mm diameter; 0.45 µm pore size), while the sediment grain size was identified using the LISST-PORTABLE Laser Diffraction Particle Size Analyzer. The water and sediment sample analyses followed the standard method (Bartram & Balance, 1996).

Table 3.2.6a: Localities Data for Water Parameter Survey on 25 June 2015

Site No.	GPS Coordinates	Site Name	Depth (m)
J1	06° 57.164' **N**; 117° 01.306' **E**	Berungus	1.6
J2	06° 44.300' **N**; 116° 57.330' **E**	Rosob	22.3
J3	06° 42.982' **N**; 116° 54.263' **E**	Barraut Reef	3.9
J4	06° 46.110' **N**; 116° 54.263' **E**	Parapat Laut	0.6
J5	06° 49.050' **N**; 116° 51.449' **E**	Limau-limauan	1.4

Table 3.2.6b: Localities Data for Water Parameter and Seabed* Surveys on 27-28 August 2015

Site No.	GPS Coordinates	Site Name	Depth (m)
A1	06° 51.774' **N**; 116° 51.762' **E**	-	20.0
A2	06° 47.094' **N**; 116° 51.138' **E**	Parapat Laut	1.4
A3	06° 44.598' **N**; 116° 51.084' **E**	-	1.5
A4	06° 39.444' **N**; 116° 49.59' **E**	Pulau Matunggong	16.0
A5	06° 38.274' **N**; 116° 51.87' **E**	Tg. Batu	10.0
A6	06° 44.676' **N**; 116° 52.764' **E**	-*	14.0
A7	06° 49.074' **N**; 116° 56.154' **E**	-*	22.0
A8	06° 52.086' **N**; 116° 54.03' **E**	-*	28.0
A9	06° 52.632' **N**; 116° 58.554' **E**	-*	10.0
A10	06° 50.97' **N**; 116° 59.508' **E**	Telaga	10.0
A11	06° 45.48' **N**; 116° 56.166' **E**	-	23.0
A12	06° 54.918' **N**; 116° 53.862' **E**	-*	23.0

Figure 3.2.6: Sampling Localities for Water Parameter Survey

Note: Site numbers correspond to first column in Tables 3.2.6a and 3.2.6b. Bar scale: 20km. Google Maps.

7. Water Quality and Marine Pollutants

The objectives of the surveys were to determine the status of the water quality of Marudu Bay by focusing on:

(i) sediment levels and turbidity;
(ii) total suspended solids (TSS);
(iii) physico-chemical characteristics: temperature, pH, dissolved oxygen (DO), and salinity;
(iv) nutrient concentrations: -NH_3-N, NO_2-N, NO_3-N, and PO_4-P;
(v) anthropogenic inputs: fecal coliform, and oil and grease concentrations; and
(vi) marine debris composition.

For the water quality survey, Marudu Bay was divided into three sub-areas: outer, middle, and inner. Four subsampling stations at river mouths were selected in each sub-area (**Tables 3.2.7a** and **3.2.7b**, and **Figure 3.2.7a**).

Table 3.2.7a: Sampling Localities for Water Quality Survey

Area	Station No.	GPS Coordinates
Outer	S1	06° 59.4693' **N**; 116° 48.1237' **E**
	S2	06° 54.8630' **N**; 116° 51.1002' **E**
	S3	06° 55.6667' **N**; 117° 1.3405' **E**
	S4	06° 53.1422' **N**; 117° 1.78117' **E**
	S5	06° 58.0473' **N**; 116° 55.3188' **E**
Middle	S6	06° 52.1087' **N**; 116° 50.5918' **E**
	S7	06° 43.7513' **N**; 116° 49.6902' **E**
	S8	06° 45.7558' **N**; 116° 58.8257' **E**
	S9	06° 40.9478' **N**; 116° 56.5838' **E**
	S10	06° 48.1767' **N**; 116° 56.1288' **E**
Inner	S11	06° 39.5402' **N**; 116° 46.8347' **E**
	S12	06° 37.1463' **N**; 116° 45.6342' **E**
	S13	06° 34.8313' **N**; 116° 49.426' **E**
	S14	06° 38.3278' **N**; 116° 53.2207' **E**
	S15	06° 36.7978' **N**; 116° 48.4307' **E**

Table 3.2.7b: Sampling Localities for Marine Pollutants (Debris and Microplastics) Survey

Area	Station No.	GPS Coordinates
Outer	1	06° 5.670' **N**; 117° 02.040' **E**
Middle	2	06° 50.670' **N**; 117° 2.188' **E**
Middle	3	06° 45.395' **N**; 116° 59.553' **E**
Middle	4	06° 40.580' **N**; 116° 56.633' **E**
Inner	5	06° 38.308' **N**; 116° 53.390' **E**
Inner	6	06° 36.037' **N**; 116° 51.262' **E**

Figure 3.2.7a: Water Quality and Marine Pollutants Survey Sites

Site numbers correspond to second column in Tables 3.2.7a and 3.2.7b. Bar scale: 20 km. Google Maps

At each station, water parameters (pH, temperature, DO, salinity, and turbidity) were taken *in situ* using Hydro Lab DS 5, the depth was measured using a depth sounder, and the sampling site coordinates were obtained using GPS. The nutrient water samples were quickly filtered to ensure nutrient contents were retained for a period of time. All water samples collected for laboratory analysis were stored in 1-L polyethylene (PE) sample bottles, and kept chilled during transportation to the laboratory.

a. Fecal Coliform, Oil and Grease, Total Suspended Solids, and Nutrient Analyses

Water samples for fecal coliform, heavy metal, and nutrient analyses were obtained using a 2-L Van Dorn water sampler at a depth of 1 m. Water samples for oil and grease analysis were collected at the water surface using a PE bottle.

b. Fecal Coliform Determination

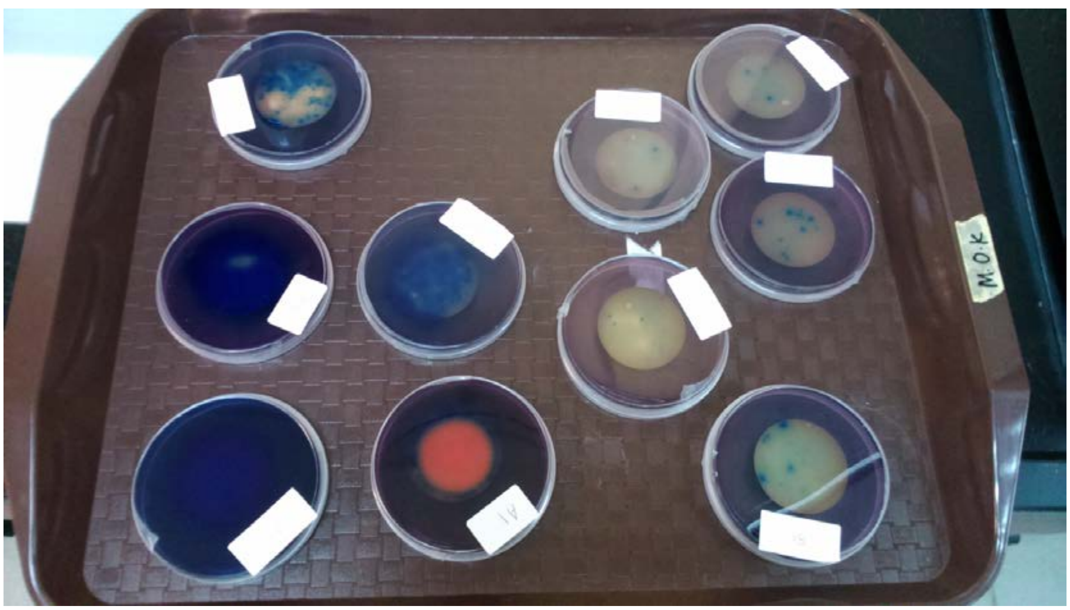
The membrane filtration method was used for fecal coliform determination. This method requires the preparation of agar medium. A solution of 1% rosolic acid was prepared by diluting

1 g of rosolic acid crystals in 100 ml of 0.2 N NaOH prepared from 8 g of NaOH pellets. Fifty-two g of M-FC agar medium was diluted with 1 L of distilled water. The diluted agar medium was then stirred and placed on a hot plate at low to medium temperatures until it started to boil. Ten ml of the 1% rosolic acid solution was added into the agar medium solution when the boiling point was reached. The medium solution was then stirred for one minute before being allowed to cool. When cooled to 55°C, the medium solution was quickly poured into a petri dish, and then allowed to cool and stiffen. The medium preparation was done in a sterile location (fume hood or laminar flow cabinet).

After the agar medium was prepared, the water samples were filtered. One hundred ml of water sample was filtered through a 0.45 µm membrane filter using a filtration set. The membrane filter was placed on the prepared agar medium, and then sealed with parafilm. The petri dish was turned upside down and placed for 24 hours in an incubator with a temperature of 44°C. The growth of shiny blue-grey colonies on the membrane filter indicates the presence of fecal coliforms (Figure 3.2.7b). The analysis for each sampling station was replicated three times to obtain a constant reading. Fecal coliform colony count (colony-forming unit or CFU) was determined using the following equation:

$$Colony\ count, CFU = \frac{Number\ of\ colonies\ found}{Volume\ of\ filtered\ sample\ (ml)}\ x\ 100$$

Figure 3.2.7b: Post Incubation Media



Note: Blue-grey shiny domed-shaped colonies on membrane filter represent fecal coliform colonies.

c. Oil and Grease Determination

Oil and grease were analyzed using the partition gravimetric method. Two hundred ml of water sample was poured into a separator funnel. Two ml of HCL and 30 ml of petroleum ether were added to the water sample in the separator funnel. The separator funnel was then shaken vigorously for 10 to 15 minutes until a visible hydrophobic layer formed between the water layer and the petroleum ether layer. The bottom or water layer was drained and disposed, while the top layer was collected into pre-weighted beakers. The beakers containing the top layer were then placed for one hour in a drying oven at a temperature of 70^{o}C. After drying, the beakers were weighed again. The analysis was replicated three times to obtain a constant reading. The amount of oil and grease was determined using the following equation:

$$Oil\ and\ grease\ (mg/L) = \frac{(A - B)\ \times 1000}{V\ sample} \times 1000$$

$$where\ A\ =\ weight\ of\ empty\ beaker\ (mg)$$

$$B\ =\ Weight\ of\ beaker\ +\ residue\ after\ evaporation\ (mg)$$

$$V\ =\ Volume\ of\ sample\ (ml)$$

d. Total Suspended Solids Analysis

Water samples for measuring TSS value were taken at 1 m below sea surface using a water sampler. Samples were filtered using a 0.45 µm filter paper, after which the residues were weighed. The weight of the residues represents the weight of the TSS. The formula for calculating TSS is as follows:

$$\frac{mg}{L} = \frac{(A\ - B)}{C} \times 1000$$

$$where\ A\ =\ weight\ of\ filter\ and\ dish\ +\ residue\ in\ mg$$
$$B\ =\ Weight\ of\ filter\ and\ dish\ in\ mg$$
$$C\ =\ Volume\ of\ sample\ filtered\ in\ mL$$

e. Nutrient Analyses

The analyses for phosphate, phosphorus, ammonia, nitrate, and nitrite were determined in the laboratory. Nutrient levels in water samples were detected from readings of the absorbance at their respective wavelengths.

f. Ammonia

Twenty-five ml of seawater sample was poured into test tubes. One ml of phenol solution was then pipetted into each sample and mixed by swirling. One ml of sodium nitroprusside solution and 2.5 ml of oxidizing solution were then added to the sample and remixed by swirling. The absorbance of the blue-colored water sample was measured after one hour at 640 nm.

g. Nitrite

Twenty-five ml of seawater sample was poured into test tubes. Afterwards, 0.5 ml of sulphanilamide (SAN) was mixed with the sample in the test tube. The solution was then allowed to rest for two minutes to allow the reagent to fully react with the water sample. This was followed by adding 0.5 ml of N-(1-Naphthyl)ethylenediamine (NED) to the sample. The solution was then immediately mixed. The absorbance of the pink-colored samples were taken at 543 nm, between 10 minutes and two hours after the addition of NED.

h. Nitrate

One hundred ml of seawater sample was poured into 100 ml Erlenmeyer in two replicates. Two ml of concentrated ammonium chloride solution was added and mixed in each sample. Five ml of the mixed seawater sample was poured into the column and allowed to pass through. The remainder of the water sample was added into the column. The first 40 ml of sample that passed through the column was discarded. The remaining sample that passed through the column was then collected using volumetric flasks. Twenty-five ml of the remaining filtered sample was poured into test tubes. The remaining sample was then tested using the same reagents and method used in nitrite analysis.

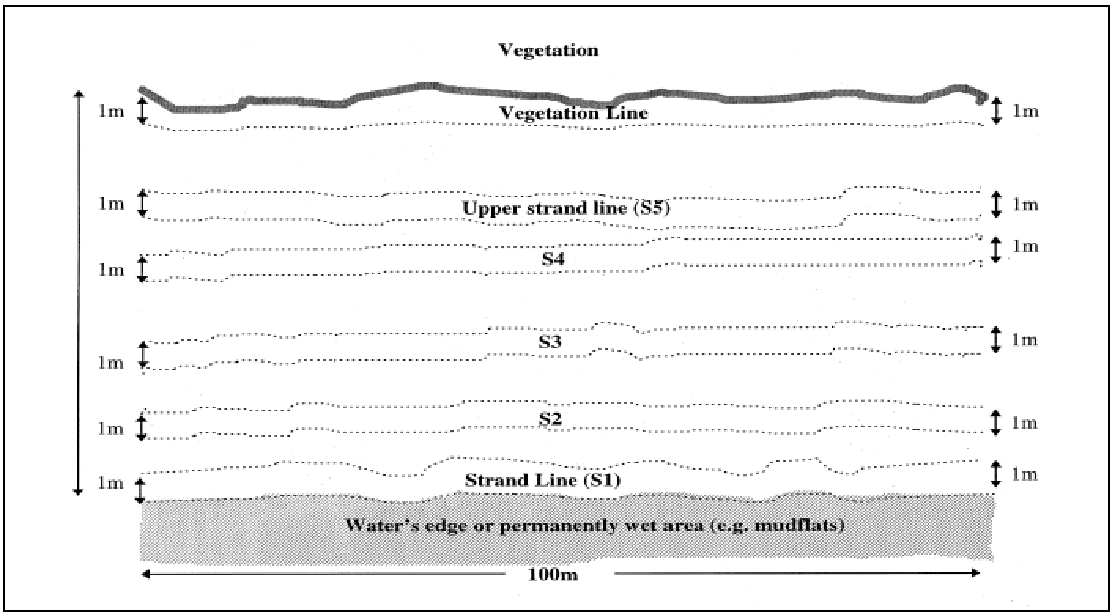
i. Phosphate

For phosphate analysis, 25 ml of seawater sample was poured into test tubes, after which 2.5 ml of mix reagent solution was added to the sample. The absorbance of the blue-colored seawater sample was measured at 885 nm, between five minutes and three hours.

j. Stranded Marine Debris and Microplastics

A transect method was used to estimate the volume of stranded marine debris. A 100-m transect line was set parallel to the water line, which consisted of six strips. Each strip was covered once, and all visible objects within the six transects were classified according to category composition while the recorder walked back and forth along the transect line parallel to the water line. The method chosen for this survey is shown in **Figure 3.2.7c**.

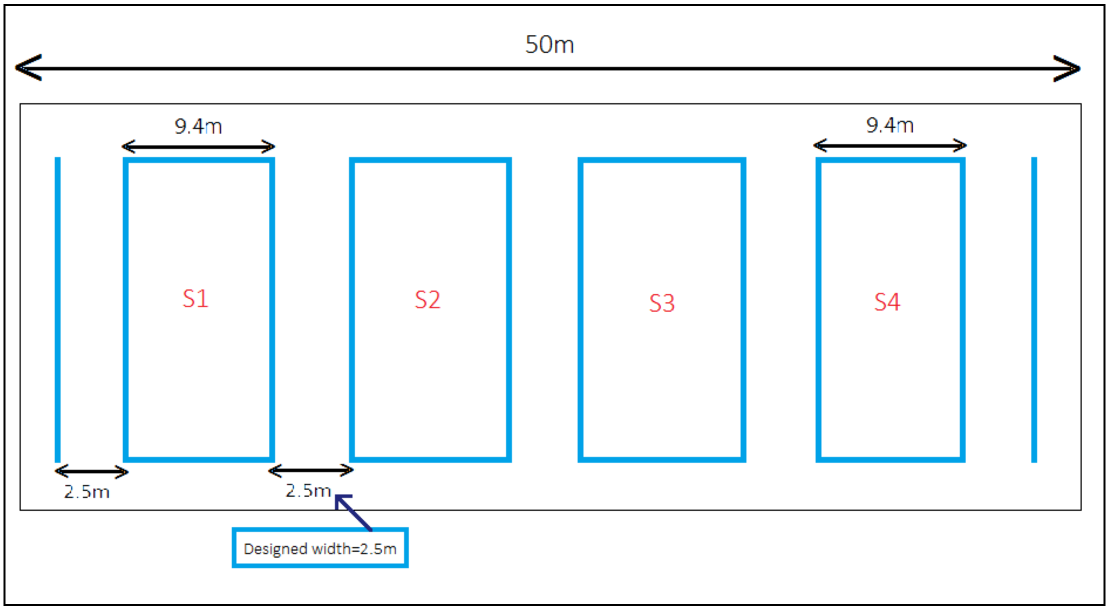
Figure 3.2.7c: Transect Line Parallel to Water Line



Source: Estim and Julirin, 2015.

Apparatus used for field sampling were measuring tapes, PVC pipes tied with a few meters of cable, pen, survey sheet, Ziploc plastic bags, and a hand scope. A 50-m transect line was measured using a measuring tape, and then used to create a standard length for all the beaches surveyed. The starting and end points of the beaches were marked by hammering a PVC pipe into the sand above the high tide mark. The PVC pipes marked a survey area with four stations inside the 50-m transect line. Five 2.5-m wide transects were marked out from the vegetation line to the water's edge, where the 2.5-m gaps were not surveyed but used for the surveyor to walk back and forth while observing the debris (**Figure 3.2.7d**). The types of debris were identified through appearance and any legible labelling (Abentin and Azizul, 2015).

Figure 3.2.7d: Walking Path for Surveyor to Count Debris Within Transects



As for microplastics, bulk sample method was used to collect sediment samples. Bulk sampling is useful when the microplastics are difficult to identify with the naked eye because the debris are covered by sediment particles, the debris are too small, or there are only a few of them, which require sorting or filtering a large amount of sediment. Sediment samples must be completely submerged during low tide. In this study, beach sediments were collected with a trowel, put into Ziploc plastic bags, and then taken to the laboratory for further analysis. The extraction method of microplastics followed Thompson et al. (2004). This method relies on the density of concentrated sodium chloride (NaCl) solution at 1.2g/ml to separate the sediment particles from the microplastics. In the marine environment, the proportion of high-density plastics is relatively higher due to their greater density. Such plastics tend to sink more easily than lighter plastics.

k. Analysis of Stranded Marine Debris and Microplastics

All the debris observed were sorted into the following categories: plastics, polystyrene, metals, wood, and others. The data collected were entered into an Excel database for analysis. The quantity of marine debris was determined by taking the average mean value of each marine debris category. Analysis was done using the Statistical Package for the Social Sciences (SPSS) software.

IV. RESULTS AND DISCUSSIONS

A. Biodiversity

1. Fish and Fisheries[2]

In this study, we monitored fish species diversity and richness in Marudu Bay during the southwest monsoon in June–December 2015. A total of 188 species from 51 families were recorded, comprising 21 species from 7 families of elasmobranchs and 167 species from 44 families of teleosts (Tables 4.1.1a and 4.1.1b). This results to an additional 98 species compared with previous studies (Manjaji-Matsumoto et al., 2009; Mohd Azim et al., 2013,

[2] By B. Mabel Manjaji-Matsumoto, Jean-Chai Yee, Siti Nasihin Binti Mohammad Seth, Kai-Ching Cheong, and Keita Koeda.

2014; Amin et al., 2014; Arshad et al., 2014; Mohd Azim, 2014). Many of the additional species are small coral reef fishes observed from scuba diving. While these are normally not consumed as food by humans, some are popular as marine ornamental fish.

Table 4.1.1a: Summary of Fish Composition by Group Recorded During the Study

Fish Group	Family	Number of Species Recorded in the Study
Elasmobranch		
	Hemiscyllidae	2
	Carcharhinidae	5
	Pristidae	1
	Rhinidae	1
	Rhinobatidae	1
	Dasyatidae	10
	Myliobatidae	1
Teleost*		
	Carangidae	14
	Serranidae	14
	Apogonidae	13
	Leiognathidae	12
	Pomacentridae	12
	Gobiidae	12

Note: Only families of teleosts with more than 10 species are listed.

Table 4.1.1b: List of Fish Species

Fish Group	Family	Species
Elasmobranch		
	Hemiscyllidae	*Chiloscyllium plagiosum*
		Chiloscyllium punctatum
	Carcharhinidae	*Carcharhinus dussumieri*
		Carcharhinus limbatus
		Carcharhinus melanopterus
		Carcharhinus sorrah
		Rhizoprionodon acutus
	Pristidae	*Pristis zijsron*
	Rhinidae	*Rhynchobatus australiae*
	Rhinobatidae	*Glaucostegus typus*
	Dasyatidae	*Brevitrygon walga*
		Himantura uarnak
		Maculabatis gerrardi
		Maculabatis pastinacoides
		Neotrygon kuhlii
		Pastinachus gracilicaudus
		Pateobatis jenkinsii
		Pateobatis uarnacoides
		Telatrygon zugei
		Urogymnus asperrimus
	Myliobatidae	*Aetobatus ocellatus*
Teleost		
	Engraulidae	*Encrasicholina devisi*

Fish Group	Family	Species
		Encrasicholina heteroloba
		Stolephorus baganensis
		Stolephorus indicus
		Thryssa baelama
		Thryssa hamiltonii
		Thryssa mystax
	Clupeidae	*Amblygaster sirm*
		Dussumieria elopsoides
		Escualosa thoracata
		Herklotsichthys dispilonotus
		Sardinella gibbosa
		Sardinella melanura
		Sardinella zunasi
	Plotosidae	*Plotosus lineatus*
	Ariidae	*Arius maculatus*
	Synodontidae	*Saurida tumbil*
	Mugilidae	*Chelon subviridis*
		Liza tade [*Chelon planiceps*]
		Moolgarda perusii
	Phallostethidae	*Neostethus* sp.
	Atherinidae	*Atherinomorus pinguis*
		Atherinomurus duodecimalis
		Hypoatherina temminckii
	Zenarchopteridae	*Zenarchopterus buffonis*
	Belonidae	*Strongylura timucu*
		Tylosurus acus melanotus
	Holocentridae	*Myripristis hexagona*
	Ambassidae	*Ambassis interrupta*
		Ambassis nalua
		Ambassis urotaenia
	Serranidae	*Anyperodon leucogrammicus*
		Cephalopholis cyanostigma
		Cephalopholis formosa
		Cephalopholis microprion
		Cromileptes altivelis
		Epinephelus bleekeri
		Epinephelus coiodes
		Epinephelus ongus
		Epinephelus sexfasciatus
		Plectropomus areolatus
		Plectropomus laevis
		Plectropomus leopardus
		Plectropomus maculatus
		Plectropomus oligacanthus
	Pseudochromidae	*Labracinus cyclophthalmus*
		Pictichromis diadema
		Pseudochromis fuscus
		Pseudochromis perspicillatus
	Plesiopidae	*Calloplesiops altivelis*
	Priacanthidae	*Priacanthus* spp.
	Apogonidae	*Apogon seminigracaudus*
		Apogon trimaculatus
		Archamia bleekeri
		Ostorhinchus compressus
		Ostorhinchus cookii

Fish Group	Family	Species
		Ostorhinchus endekataenia
		Ostorhinchus fasciatus
		Ostorhinchus griffini
		Ostorhinchus lateralis
		Ostorhinchus margaritophorus
		Ostorhinchus multilineatus
		Ostorhinchus nigrofasciatus
		Ostorhinchus properuptus
	Sillaginidae	*Sillago sihama*
	Carangidae	*Alectis cilliaris*
		Alectis indicus
		Alepes djedaba
		Atule mate
		Carangoides coeruleopinnatus
		Carangoides malabaricus
		Carangoides spp.
		Decapterus macrosoma
		Decapterus spp.
		Parastromateus niger
		Scomberoides commersonnianus
		Scomberoides tol
		Selar boops
		Ulua mentalis
	Leiognathidae	*Equulites elongatus*
		Equulites leuciscus
		Eubleekeria jonesi
		Eubleekeria splendens
		Gazza achlamys
		Gazza minuta
		Leiognathus brevirostris
		Leiognathus equulus
		Photopectoralis bindus
		Secutor hanedai
		Secutor insidiator
		Secutor ruconius
	Lutjanidae	*Lutjanus carponotatus*
		Lutjanus lemniscatus
		Lutjanus rivulatus
		Lutjanus russellii
		Lutjanus sebae
	Caesionidae	*Caesio cuning*
		Pterocaesio marri
	Gerreidae	*Gerres filamentosus*
		Gerres limbatus
		Gerres macracanthus
		Gerres oyena
	Haemulidae	*Diagramma pictum*
		Diagramma melanacrum
		Plectorhinchus lessonii
		Plectorhinchus vittatus
		Pomadasys argenteus
		Pomadasys maculatus
	Nemipteridae	*Nemipterus nemurus*
		Pentapodus bifasciatus
		Scolopsis sp.

Fish Group	Family	Species
	Lethrinidae	*Lethrinus erythropterus*
		Lethrinus olivaceus
		Lethrinus ornatus
	Polynemidae	*Filimanus similis*
	Sciaenidae	*Dendrophysa russelii*
		Johnius belangerii
		Otolithes ruber
		Pterotolithus lateoides
	Mullidae	*Parupeneus barberinus*
		Parupeneus forsskali
	Chaetodontidae	*Chaetodon lunulatus*
		Chelmon rostratus
		Coradion chrysozonus
	Pomacanthidae	*Pygoplites diacanthus*
	Terapontidae	*Pelates quadrilineatus*
		Rhyncopelates oxyrhynchus
		Terapon theraps
	Pomacentridae	*Amblyglyphidodon aureus*
		Amphiprion clarkii
		Amphiprion sandaracinos
		Cheiloprion labiatus
		Chrysiptera cyanea
		Dischistodus melanotus
		Neopomacentrus cyanomos
		Pomacentrus nagasakiensis
		Pomacentrus nigromanus
		Pomacentrus smithi
		Premnas biaculeatus
		Stegastes punctatus
	Labridae	*Coris pictoides*
		Cheilinus fasciatus
		Cheilinus undulatus
		Choerodon oligacanthus
		Hemigymnus melapterus
	Pinguipedidae	*Parapercis xanthozona*
	Tripterygiidae	*Enneapterygius* sp.
	Blenniidae	*Petroscirtes breviceps*
	Gobiidae	*Amblygobius decussatus*
		Amblygobius hectori
		Bryaninops sp.
		Callogobius hasseltii
		Cryptocentrus cinctus
		Cryptocentrus singapurensis
		Fusigobius signipinnis
		Gobiodon erythrospilus
		Trimma hayashii
		Trimma milta
		Trimma naudei
		Trimma striatum
	Siganidae	*Siganus unimaculatus*
		Siganus vulpinus
	Sphyraenidae	*Sphyraena forsteri*
	Scombridae	*Rastrelliger kanagurta*
	Istiophoridae	*Istiophorus platypterus*
	Monacanthidae	*Stephanolepis* sp.

Fish Group	Family	Species
	Tetraodontidae	*Canthigaster solandri*

Notes: Families are listed in systematic order following Nelson, 2006. Dasyatid species names follow Last et al., 2016.

Our findings agree with the fish landing trends of the annual fisheries statistics (**Figure 4.1.1a**), which recorded a high number of pelagic fish species in Marudu Bay, corresponding to the high number of drift nets in Kota Marudu and Pitas districts (**Figure 4.1.1b**). The pelagic fishes comprise mainly of small pelagic species: engraulids (anchovies), clupeids (sardines and shads), and carangids (mackerel scads). Most of the fish caught are important as a protein source for the locals, although many other fish end up for the fish meal industry. Additionally, small pelagics, especially anchovies and shads, are processed into dried and/or salted products for sale.

The results of the analysis of the Department of Fisheries (DOF) Annual Fisheries Statistics (2009–2013) of the three districts are somewhat surprising, as fish landings are on the decline elsewhere in Malaysia and in the world. For Kudat, a 52% increase in fish catch was recorded during the five-year period: from 16,000 metric tons (MT) in 2009 to 33,000 MT in 2013 (Figure 4.1.1a.i). For Kota Marudu, the increase was almost 100%: from 11 MT in 2009 to 550 MT in 2013 (**Figure 4.1.1a.i**i). For Pitas, the total fish catch increased from 2,700 MT in 2009 to 4,800 MT in 2012, after which it decreased to 2,800 MT in 2013. This indicated a 4% increase in the five-year period (Fig. 4.1.1a.iii). In general, pelagic fish landings in Marudu Bay are higher than demersal fish landings, ranging between 50% and 80% of the total landings in each of the three districts.

Figure 4.1.1a.: Annual Demersal and Pelagic Fisheries Landing in (i) Kudat, (ii) Kota Marudu, and (iii) Pitas (2009-2013)

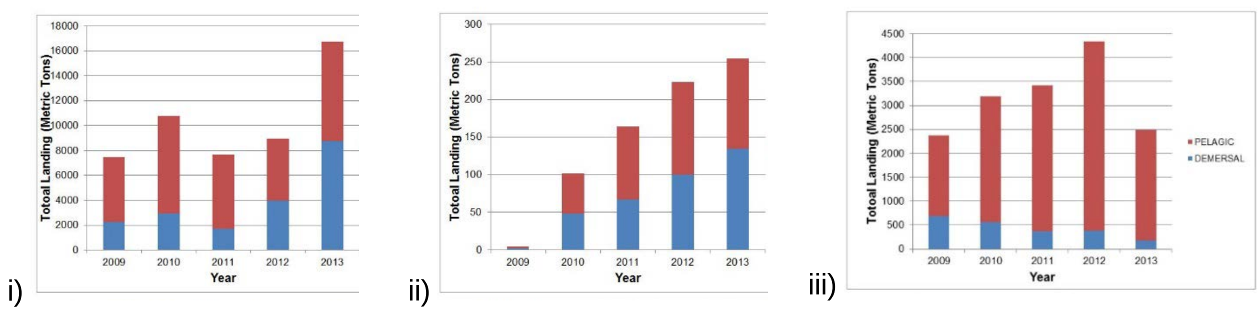
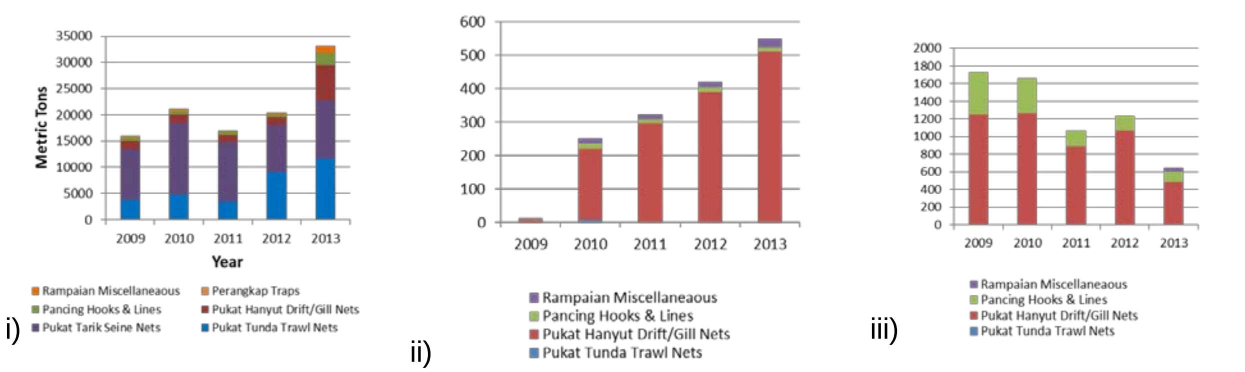


Figure 4.1.1b.: Annual Demersal and Pelagic Fisheries Landing Trend by Gear Type in (i) Kudat, (ii) Kota Marudu, and (iii) Pitas (2009-2013)



2. Marine Invertebrates[3]

The results presented here are preliminary, as no statistical strategy of sampling and analysis was applied. The results were recorded based on samples collected from various coastal marine habitats in Marudu Bay, including mixed habitats comprised of sandy beaches, seagrass beds, and corals in adjacent waters along the coast of Simpang Mengayau to Kudat, Tanjung Limau-limauan, and Berungus.

Two of the sampling sites in the southern part of Marudu Bay (Sungai Matunggung and Sungai Bandau) are major rivers in the bay area and have a complex river system covered with mangrove forests. There are large areas of shallow mudflats at the mouth of Sungai Bandau. The mudflats are exposed during low tide, when villagers harvest clams buried in the mudflats using homemade rakes.

3. Marine Invertebrates in the Coastal Area of Marudu Bay

From six sampling sites, a total of 755 invertebrate specimens were collected, comprising 35 species from 19 families of molluscs and eight species from six families of crustacea (**Table 4.1.2a** for species list and Photo 4.1.2a for the common species found during the study). Species composition in the mangrove forests of Sungai Matunggung and Sungai Bandau were similar, with a total of 24 species from 12 families of marine invertebrates recorded. The common species recorded, totalling to 80% of abundance, were cerith snail (*Cerithidea quoyii),* nerite snail *(Nerita balteata),* mangrove helmet snail (*Cassidula nucleus* and *Cassidula aurisfelis),* mangrove murex (*Chicoreus capucinus),* and red berry snail (*Assiminea brevicula)*.

Species found at Simpang Mengayau were different from the mangrove habitat, where 15 species from 14 families were recorded. The area was dominated by channeled cerith (*Clypeomorus batillariaeformis),* true limpet (*Patelloida saccharina),* hermit crab (*Clibanarius striolatus*), and lighting dove shell (*Pictocolumbella ocellata*), totalling to 80% of abundance.

At the exposed mudflat of Sungai Bandau, only eight species from seven families were recorded, with acorn barnacles (*Balanus* sp.) and cerith snail (*Cerithideopsilla cingulata*) being highly dominant. During low tide, villagers were seen towing homemade rakes across the exposed mudflat to harvest clams locally known as *dalus* and *remis* (*Meretrix* spp.) (**Photo 4.1.2b**). The rakes are equipped with long metal plates that are dragged just below the sandy surface.

Table 4.1.2a: Invertebrate Species Composition Recorded During the Study

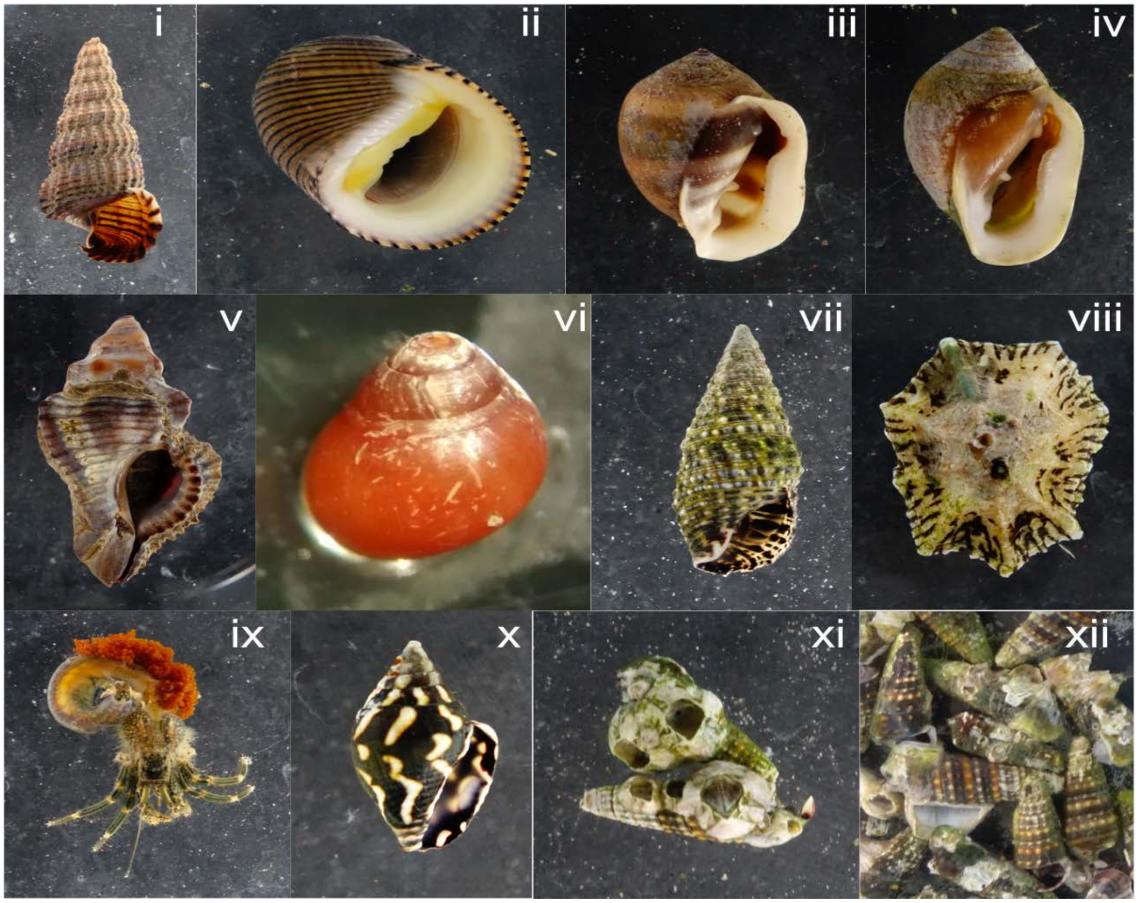
Transect	Site	Category	Family	Species
1	Simpang Mengayau			
		Bivalve	Chamidae	*Chama* sp.
			Ostreidae	*Saccostrea scyphophilla*
		Crustacea	Diogenidae	*Clibanarius striolatus*
			Tetraclitidae	*Tetraclita* sp.
		Gastropod	Cerithidae	*Clypeomorus batillariaeformis*
			Columbellidae	*Pictocolumbella ocellata*
			Conidae	*Conus magus*
			Lottiidae	*Patelloida saccharina*

[3] By John Madin, Kai-Ching Cheong, and B. Mabel Manjaji-Matsumoto.

Transect	Site	Category	Family	Species
			Muricidae	*Orania* sp.
			Muricidae	*Semiricinula* sp.
			Neritidae	*Nerita albicilla*
			Neritidae	*Nerita chamaeleon*
			Planaxidae	*Planaxis sulcatus*
			Siphonariidae	*Siphonaria laciniosa*
			Strombidae	*Canarium urceus*
2	Sungai Matunggung			
		Bivalve	Pteriidae	*Isonomon nucleus*
		Crustacea	Sesarmidae	*Episesarma singaporense*
		Gastropod	Assimineidae	*Assiminea brevicula*
			Ellobiidae	*Cassidula nucleus*
			Ellobiidae	*Laemodonta* sp.
			Littorinidae	*Littoraria carinifera*
			Muricidae	*Chicoreus capucinus*
			Neritidae	*Nerita balteata*
			Potamididae	*Cerithidea quoyii*
3	Sungai Matunggung			
		Bivalve	Pteriidae	*Isonomon* sp.2
		Crustacea	Diogenidae	*Clibanarius striolatus*
			Sesarmidae	*Episesarma singaporense*
		Gastropod	Assimineidae	*Assiminea brevicula*
			Ellobiidae	*Cassidula aurisfelis*
			Ellobiidae	*Cassidula nucleus*
			Ellobiidae	*Cassidula* sp.1
			Ellobiidae	*Cassidula* sp.2
			Littorinidae	*Littoraria carinifera*
			Muricidae	*Chicoreus capucinus*
			Muricidae	*Thais* sp.
			Neritidae	*Nerita albicilla*
			Neritidae	*Nerita balteata*
			Neritidae	*Nerita planospira*
			Neritidae	*Neritina cornucopia*
			Potamididae	*Cerithidea quoyii*
4	Sungai Bandau			
		Crustacea	Sesarmidae	*Episesarma singaporense*
			Varunidae	*Metaplax elegans*
			Varunidae	*Metaplax* sp.1
		Gastropod	Assimineidae	*Assiminea brevicula*

Transect	Site	Category	Family	Species
			Ellobiidae	*Cassidula aurisfelis*
			Ellobiidae	*Cassidula nucleus*
			Littorinidae	*Littoraria carinifera*
			Lottiidae	*Patelloida saccharina*
			Muricidae	*Chicoreus capucinus*
			Neritidae	*Nerita balteata*
			Neritidae	*Neritina violacea*
			Planaxidae	*Planaxis sulcatus*
			Potamididae	*Cerithidea quoyii*
5	Sungai Bandau			
		Crustacea	Varunidae	*Metaplax* sp.2
		Gastropod	Ellobiidae	*Cassidula nucleus*
			Ellobiidae	*Pythia* sp.
			Neritidae	*Clithon* sp.
			Potamididae	*Cerithidea quoyii*
6	Sungai Bandau			
		Bivalve	Cyrenidae	*Polymesoda* sp.
			Psammobiidae	*Gari* sp.
			Veneridae	*Meretrix* sp.
		Crustacea	Balanidae	*Balanus* sp.
			Diogenidae	*Clibanarius striolatus*
			Macrophthalmidae	*Macrophthalmus abbreviatus*
			Macrophthalmidae	*Macrophthalmus brevis*
		Gastropod	Potamididae	*Cerithideopsilla cingulata*

Photo 4.1.2a: Common marine invertebrate species found in Marudu Bay: (i) *Cerithidea quoyii,* (ii) *Nerita balteata,* (iii) *Cassidula nucleus,* (iv) *Cassidula aurisfelis,* (v) *Chicoreus capucinus,* (vi) *Assiminea brevicula,* (vii) *Clypeomorus batillariaeformis,* (viii) *Patelloida saccharina,* (ix) *Clibanarius striolatus,* (x) *Pictocolumbella ocellata,* (xi) *Balanus* sp., and (xii) *Cerithideopsilla cingulata*



Notes:
- Species are under three categories: bivalve, crustacea, and gastropod.
- Six transects were deployed: one at Simpang Mengayau, two at Sungai Matunggung, and three at Sungai Bandau.

Photo 4.1.2b: Mudflat scenes in Sungai Bandau: (i) villagers harvesting clams (*remis*) at the mudflat; (ii) fishers towing their handmade rake across the mudflat in search of clams; (iii) clam (*Meretrix* sp.) that villagers harvest and (background) harvesting equipment; and (iv) rake with wheels to facilitate clam harvesting

Fisheries and aquaculture activities based on marine invertebrate species are scattered throughout Marudu Bay. Marine invertebrates are also cultured in pens, floating rafts, or ponds, depending on the species. Aquacultured marine invertebrates are mainly species of shrimps, green mussels, and sea cucumbers. Shrimp farms are located inland, near river systems, with shrimps being cultured in earthen ponds, while green mussels and sea cucumbers are cultured in coastal waters (**Table 4.1.2b**).

The Pitas Shrimp Park, which is the largest shrimp aquaculture project in Malaysia, was established at Kampung Kuyuh, Pitas District, in 2014. Based on Google Maps (2017), the current aquaculture farm area is estimated to be approximately 1,000 hectares and largely located within a virgin mangrove forest. The aquaculture farm is being developed by Yayasan Sabah's Inno-Fisheries Sdn. Bhd. and Sunlight Seafood (Sabah) Sdn. Bhd (The Star Online, 2014), with the main cultured species being Pacific white shrimp (*Litopenaeus vannamei*). Although the project is touted by the government as a boon for the local communities, the mega project has been mired in controversy from the beginning (see Chapter 4.1.5; Daily Express Sabah, 2015; Borneo Post Online, 2017).

Other commercial shrimp farms were observed near Kampung Masangkung and Toporoi (Enriched Wise Sdn. Bhd.) in Kudat district, all of which were relatively smaller in scale.

Green mussels (*Perna viridis*), locally known as *kupang*, were cultured in floating rafts at offshore waters of Tanjung Batu, Pitas District. The species was apparently introduced into Marudu Bay in 2000 with broodstock from Johor, Peninsular Malaysia, as an aquaculture species (Taib, Madin & Ransangan, 2016; Tan & Ransangan, 2015). However, the industry had collapsed by 2010 due to an unusual mass mortality event that had wiped out the green mussel stock (Tan & Ransangan, 2015). Recent studies by Universiti Malaysia Sabah (UMS) researchers on the population status of green mussels in Marudu Bay suggest the high relative abundance of phytoplankton *Chaetocerotaceae* as the main limiting factor to their growth (Tan & Ransangan, 2016; Tan, Denil, & Ransangan, 2016).

Small-scale sea cucumber pens were observed in shallow water areas in Berungus and Tanjung Limau-limauan. According to villagers, wild sea cucumbers are collected and transferred into grow-out enclosures until they reach commercial size. A more advanced sea cucumber pond culture farm was also observed in Tanjung Limau-limauan.

Table 4.1.2b: Types and Locations of Invertebrate Cultures in Marudu Bay

Type and Location	Cultured Species	Latitude (N)	Longitude (E)
Pitas Shrimp Park, Kg. Kuyuh	Pacific white shrimp	06° 47.197’	117° 5.164’
Green mussel raft, Tg. Batu	Green mussel *Perna viridis*	06° 36.012’	116° 51.053’
Sea cucumber pen, Berungus	Sea cucumber (various species)	06° 57.109’	117° 1.982’
Sea cucumber pen, Berungus	Sea cucumber (various species)	06° 56.999’	117° 1.803’
Sea cucumber farm, Tg. Limau-limauan	Sea cucumber (various species)	06° 49.201’	116° 51.633’
Sea cucumber pen, Tg. Limau-limauan	Sea cucumber (various species)	06° 49.474’	116° 51.741’
Shrimp farm, Kg. Dampirit, Sg. Karang	Shrimp (species unknown)	06° 52.559’	116° 46.094’
Enrich Wise Sdn. Bhd., Kg. Toporoi	Shrimp (species unknown)	06° 40.778’	116° 45.025’

4. Coral Reefs[4]

Hard coral composed 36% of the substrate in Marudu Bay, followed by rock (23%) and sand (16%) (**Figure 4.1.3a**). Non-living components (rock, rubble, and sand) accounted for almost 48% of the substrate, while the rest of the categories (soft coral, nutrient indicator algae, sponge, recently killed coral, and other substrate), excluding hard coral, accounted for approximately 16%. Site 10 had the most coral cover (53%), followed by site 9 (49%) and site 8 (48%), while site 5 had the least coral cover (3%) (**Figure 4.1.3b**). Soft coral (which includes zoanthids) was most dominant at site 5 (54%) and site 3 (44%). Nutrient indicator algae were most dominant at site 9 (15%). Sponge was most dominant at site 5 (14%).

[4] By Zarinah Waheed, Muhammad Ali Syed Hussein, Mohd Firdaus Akmal Bin Nooramli, and Mariyam Shidha Afzal.

Figure 4.1.3a: Average Percentage Cover of Substrate in Marudu Bay Based on 14 Sites

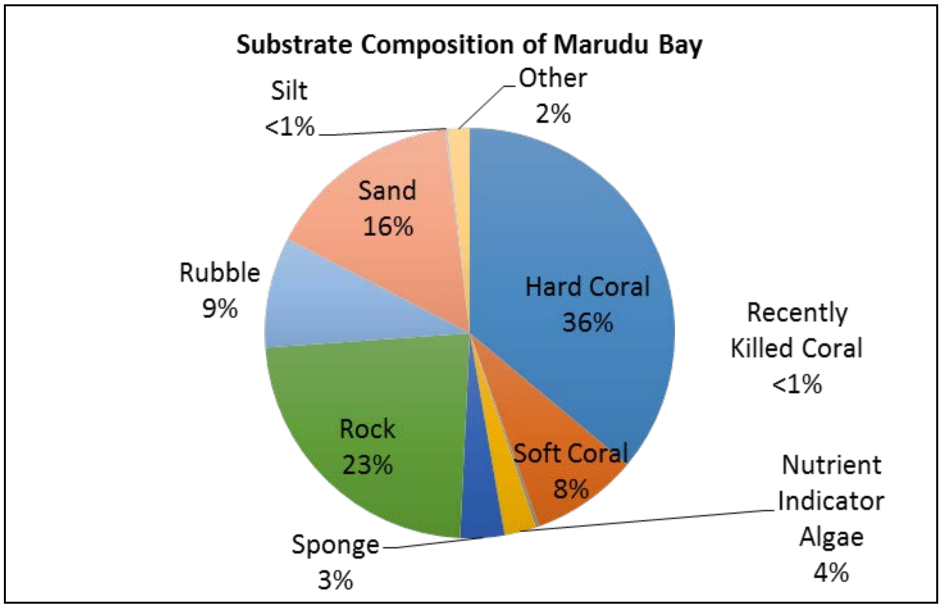
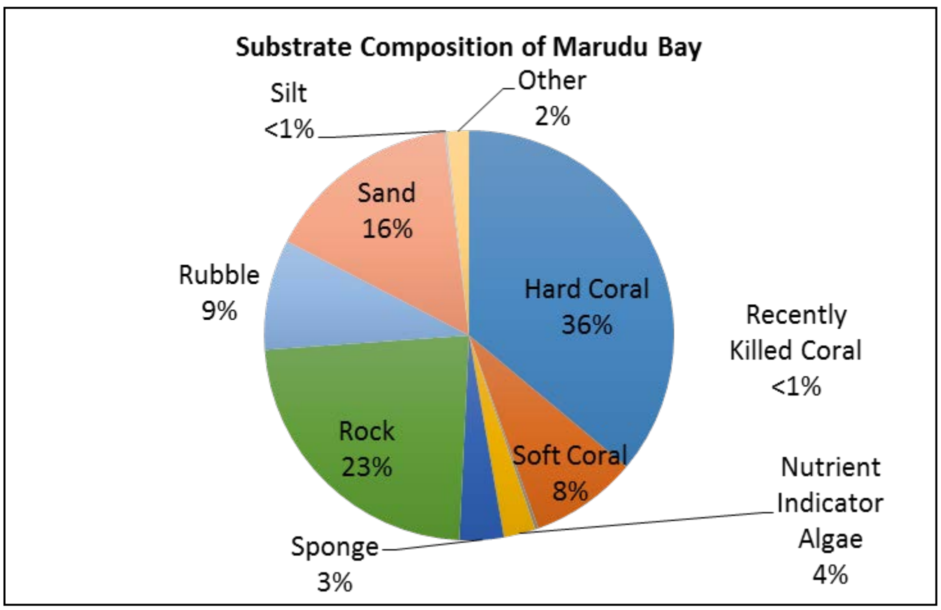


Figure 4.1.3b: Percentage Cover of Each Substrate Category in 14 Sites



In terms of hard coral cover, the sites in the inner area of the bay had lower percentage cover, with the exception of sites 4 and 6 (**Photos 4.1.3a** and **4.1.3b**). Water visibility was slightly lower in the inner bay compared to the sites in the outer bay. Site 3 had a high percentage of the zoanthid *Palythoa tuberculosa* (**Photo 4.1.3c**), which was found overgrowing large colonies of the hard coral *Porites* sp. (**Photo 4.1.3d**). The presence of this zoanthid covering a large area of the reef could indicate high levels of nutrients at site 3. Site 5 also had a high percentage of zoanthids, such as *Zoanthus* spp. (**Photo 4.1.3e**). Large barrel sponges *Xestospongia* sp. were common at site 5 (**Photo 4.1.3f**).

Photo 4.1.3a: Coral cover at site 4

Photo 4.1.3b: Coral cover at site 6

Photo 4.1.3c: Colonial zoanthid *Palythoa tuberculosa*

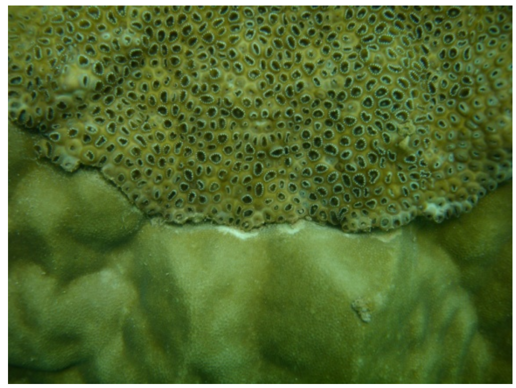


Photo 4.1.3d: *Palythoa tuberculosa* overgrowing hard coral *Porites* sp.

Photo 4.1.3e: Zoanthids *Zoanthus* spp.

Photo 4.1.3f: Barrel sponges *Xestospongia* sp.

Only four Reef Check invertebrate indicator species were present during the surveys: *Diadema* urchin, sea cucumber, lobster, and giant clam. The reef invertebrate indicators were dominated primarily by *Diadema* urchin, particularly at sites 4 and 13 (**Figure 4.1.3c** and **Photo 4.1.3g**). Sea cucumber and lobster were noted only at site 8. Giant clams were encountered at eight sites (1, 3, 4, 8, 11, 12, 13, and 14) (Photo 4.1.3h). Indicator species that were not encountered during the surveys were banded coral shrimp, pencil urchin, collector urchin, crown-of-thorns seastar, and triton shell.

Figure 4.1.3c: Number of *Diadema* Urchins at Each Site

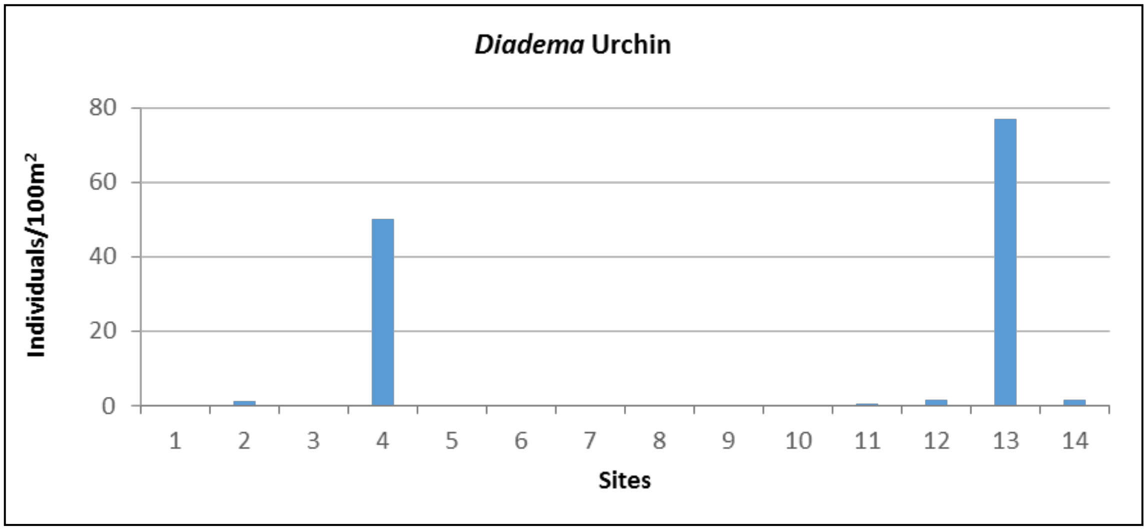
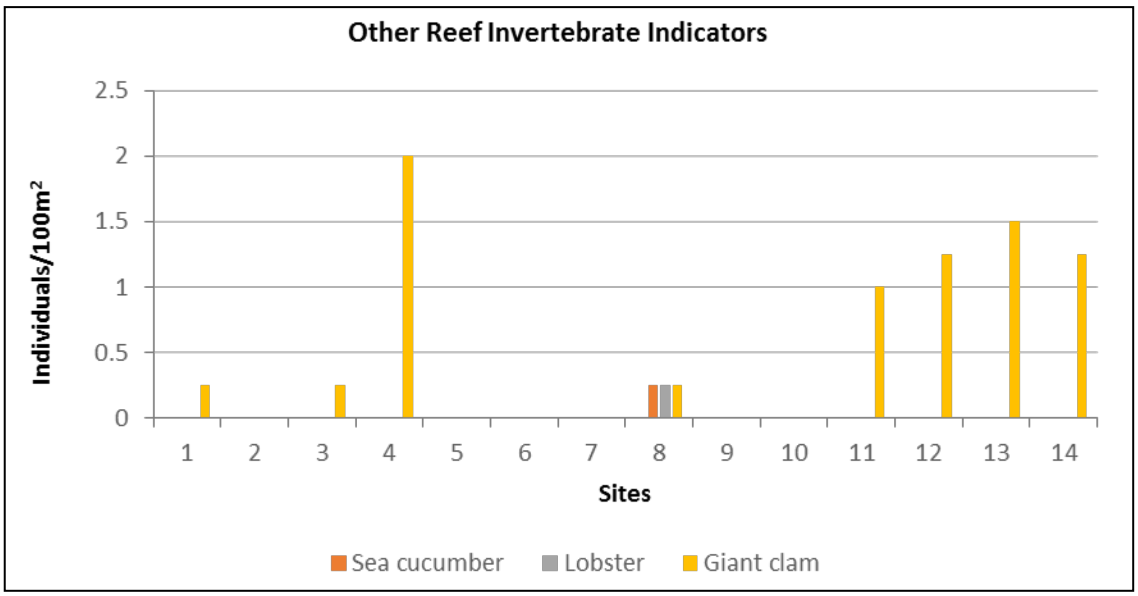


Figure 4.1.3d: Mean Abundance of Reef Invertebrate Indicators at Each Site



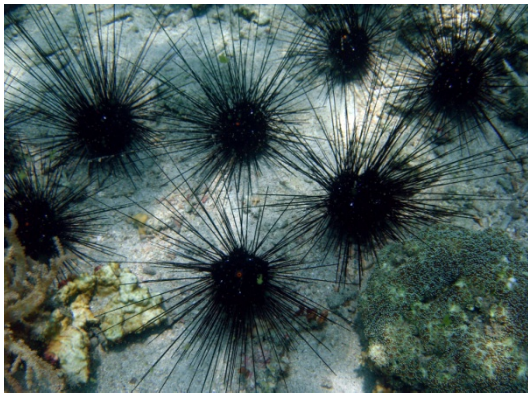


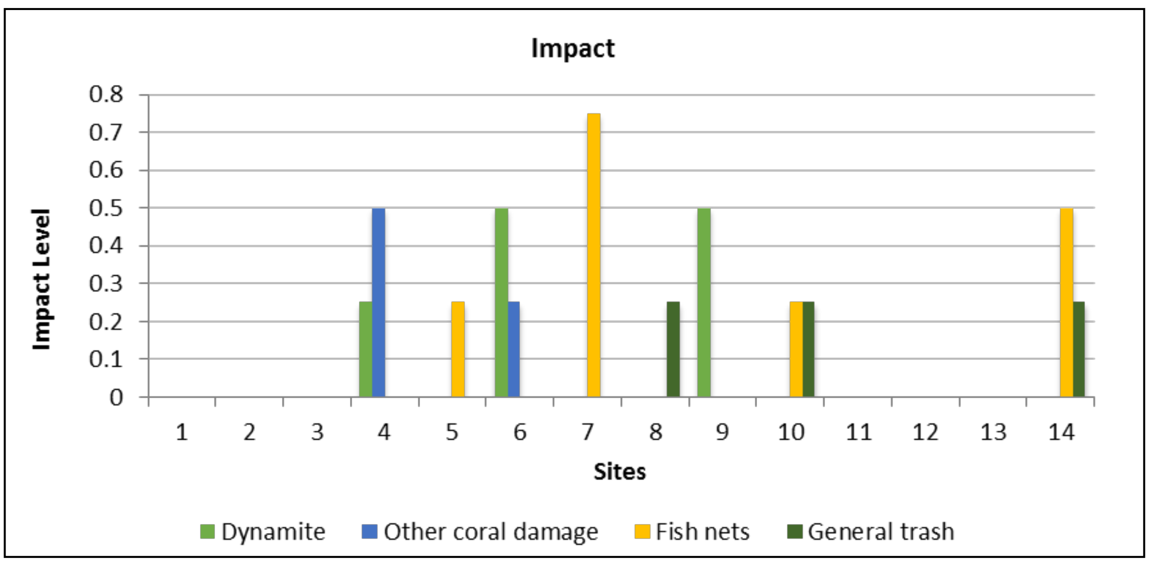
Photo 4.1.3g: Sea urchin *Diadema* sp. at site 13

Photo 4.1.3h: Giant clam *Tridacna squamosa*

The highest level of impact caused by blast (dynamite) fishing was noted at sites 6 and 9 (**Figure 4.1.3e**, and **Photos 4.1.3i and 4.1.3j**). Both reef sites had patches of coral rubble among intact reef, indicating previous blast events. The damage to the reef appeared old, and high algal cover was found near the rubble areas at site 9. Despite blast fishing activities, the hard coral cover was fair at both sites: 41% for site 6 and 49% for site 9.

Old, abandoned fish traps also caused coral damage. Several traps were encountered along the transect line at site 4 (Photo 4.1.3k). On the other hand, discarded fish nets were found at four sites (5, 7, 10, and 14). The highest impact due to these nets was seen at site 7, where a large ghost net laid across 40-50m^2 of reef (Photo 4.1.3l). Attempts were made to remove the nets from the four sites, but the net at site 7 was thoroughly wedged into the reef. In several parts of the reef, corals have started to overgrow the net, indicating that the net has been on the reef for at least a year. General trash such as plastic bags, plastic bottles, and fishing lines were seen at sites 8, 10, and 14.

Figure 4.1.3e: Impact to the Reef at Each Site



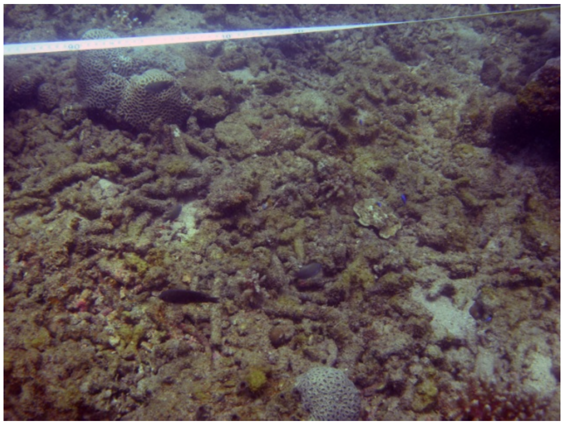


Photo 4.1.3i: Rubble patches at site 6, most likely caused by blast fishing

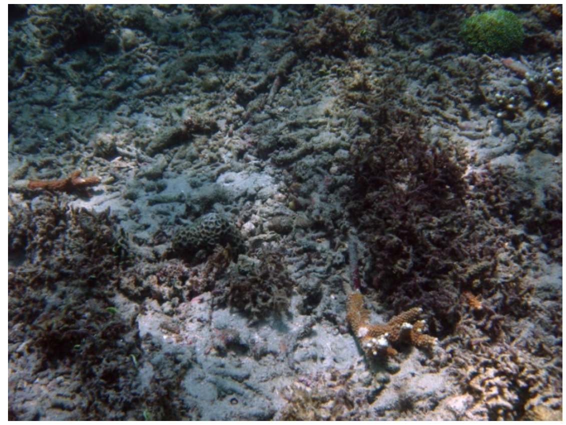


Photo 4.1.3j: Rubble patches at site 9, with *Acropora* sp. on the reef

Photo 4.1.3k: Abandoned fish trap at site 4

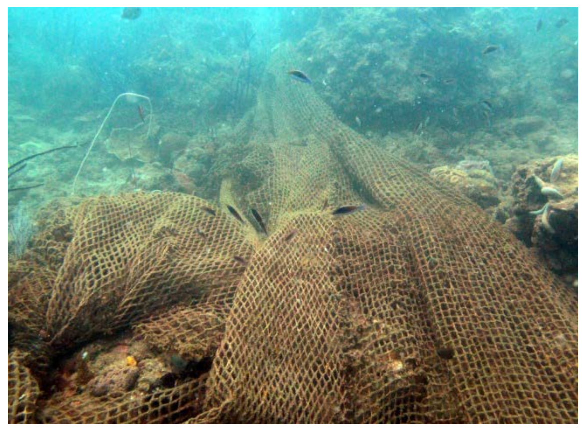


Photo 4.1.3l: Large ghost net on the reef at site 7

Coral bleaching was encountered at eight sites, with the highest percentage of population bleaching at site 2 (12.5%), followed by site 3 (12.3%) and site 1 (5.25%) (**Figure 4.1.3f**). Maximum coral colony bleaching occurred at site 3 with an average of 40% colony bleaching. In a few instances, 100% colony bleaching was observed (**Photos 4.1.3m** and **4.1.3n**).

Figure 4.1.3f: Bleaching Occurrence of Coral Population and Coral Colony at Each Site

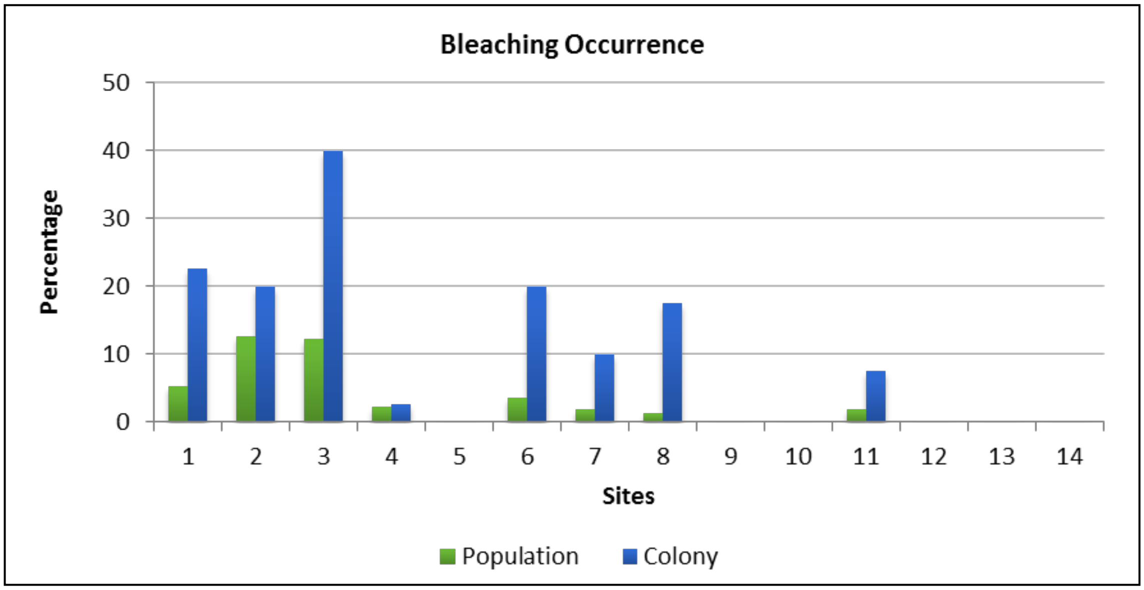


Photo 4.1.3m: Fully bleached colony of hard coral *Pectinia* sp. at site 3

Photo 4.1.3n: Partially bleached hard coral *Favites* sp. along the transect at site 3

This study identified 168 species of hard corals from coral families Fungiidae, Agariciidae, and Euphylliidae in Marudu Bay, compared with 45 species identified in previous studies. Of the 168 species, 138 were not identified in previous studies, bringing the total to 183 species in Marudu Bay. Hard corals found in the bay are common shallow water and nearshore species, or have adapted to the slightly turbid conditions, particularly in the inner area of the bay due to its close proximity to land and its semi-enclosed geomorphology.

Several corals could not be identified from photographs. These corals need to be collected to examine the corallite structures. Some coral genera were extremely difficult to identify *in situ*, including species of *Acropora*, *Montipora*, *Dipsastraea*, *Favites*, *Pocillopora*, *Goniopora*, and *Porites*.

A total of 236 fish species (seven species identified to genus level only) and 57 invertebrate species (seven species up to genus level and one unidentified bivalve) were recorded in the 14 dive sites. Some of the invertebrates such as the feather stars of class Crinoidea, serpentine sea cucumbers *Eupta* spp. and *Opheodesoma* spp., feather duster worms *Sabellastarte* spp., and Christmas tree worms *Spirobranchus* spp. consisted of more than one species. Some of the species were only rarely encountered, with 77 species of fishes and 23 species of invertebrates observed only in one out of the 14 dive sites. In some cases, only a single individual was observed.

The sites were categorized based on the number of species and the Shannon Weiner and Evenness indices, which were calculated from the species and approximate number of individuals recorded during the survey (**Table 4.1.3**). Site 11 was the most diverse in terms of fish species but had a low Evenness Index value. This was due to the large number of schooling species found at the site. Low Evenness Index values were also recorded at sites 5, 6, and 7, where large schools of yellowtail fusilier *Caesio cuning* were observed. Sites 1 and 2 in inner Marudu Bay had the lowest fish diversity among the dive sites.

The most diverse families of fishes were represented by Pomacentridae (50 species), Labridae (38 species), Gobidae (17 species), and Apogonidae (17 species), contributing 51.7% of the total species observed during the survey. These species are mostly small-sized fishes that are often widely distributed in association with coral reefs. Meanwhile, commercially important species such as Lethrinidae, Haemulidae, Mullidae, Caesionidae, Carangidae, Lutjanidae, Serranidae, Scaridae, Siganidae, and Nemipteridae comprised 25% of the species diversity found in the dive sites around Marudu Bay. Several of these species, including *Selaroides leptolepis*, *Selar boops*, *Caesio cuning,* and *Pterocaesio chrysozona,* were observed to form large schools.

The most widely distributed invertebrates in Marudu Bay were the feather duster worm *Sabellastarte* spp., which was observed at site 8, and Christmas tree worms *Spirobranchus* spp., observed at site 10. The fluted giant clam *Tridacna squamosa* was recorded in eight of the 14 sites. Although the number of giant clams recorded was low, their presence in many of the surveyed sites indicated their wide distribution in the bay. The long-spined sea urchin *Diadema setosum* was recorded as the most abundant species, although it was recorded in only five sites. This could indicate habitat degradation in the sites, as *Diadema* is known to prefer areas dominated by rubble and algae. While lower species diversity of fishes was recorded in the inner bay, invertebrates were found to be diverse in the inner sites as well as the outer sites. Interestingly, the lowest diversity of invertebrates was found at the outer part of most stations.

Table 4.1.3: Species Diversity, Shannon Weiner Index, and Evenness Index Values for Fish and Invertebrates in Marudu Bay

FISH	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Site 13	Site 14
Taxa_S	27	14	46	74	74	63	74	86	66	51	99	67	54	75
Shannon_H	2.177	1.508	2.149	3.222	2.46	3.022	2.56	3.865	3.576	3.52	3.663	3.656	3.33	3.305
Evenness_e^H/S	0.3268	0.3227	0.1864	0.3388	0.1582	0.3261	0.1748	0.5544	0.5416	0.6625	0.3938	0.5779	0.5174	0.3632

INVERTEBRATES	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Site 13	Site 14
Taxa_S	11	16	11	18	11	15	10	9	8	7	13	4	16	11
Shannon_H	1.815	1.709	2.215	1.464	1.869	2.001	1.872	1.977	1.798	1.768	2.34	1.157	1.936	2.209
Evenness_e^H/S	0.5581	0.3453	0.8332	0.2402	0.5891	0.4931	0.65	0.8023	0.7551	0.8368	0.7985	0.7951	0.4334	0.8278

5. Seagrasses[5]

The estimation of the coverage of seagrass beds in Marudu Bay was done by *in situ* observation and aerial photographs from web sources. Field observations were taken mainly aboard a small boat, except in shallow waters, where observation by snorkelling was conducted from the shore. During field observations, photos were taken and samples of seagrass were collected for further identification (identification guides: Lanyon, 1986; McKenzie et al., 2001, 2013). The samples were placed in plastic bags with seawater and stored in polystyrene box with ice.

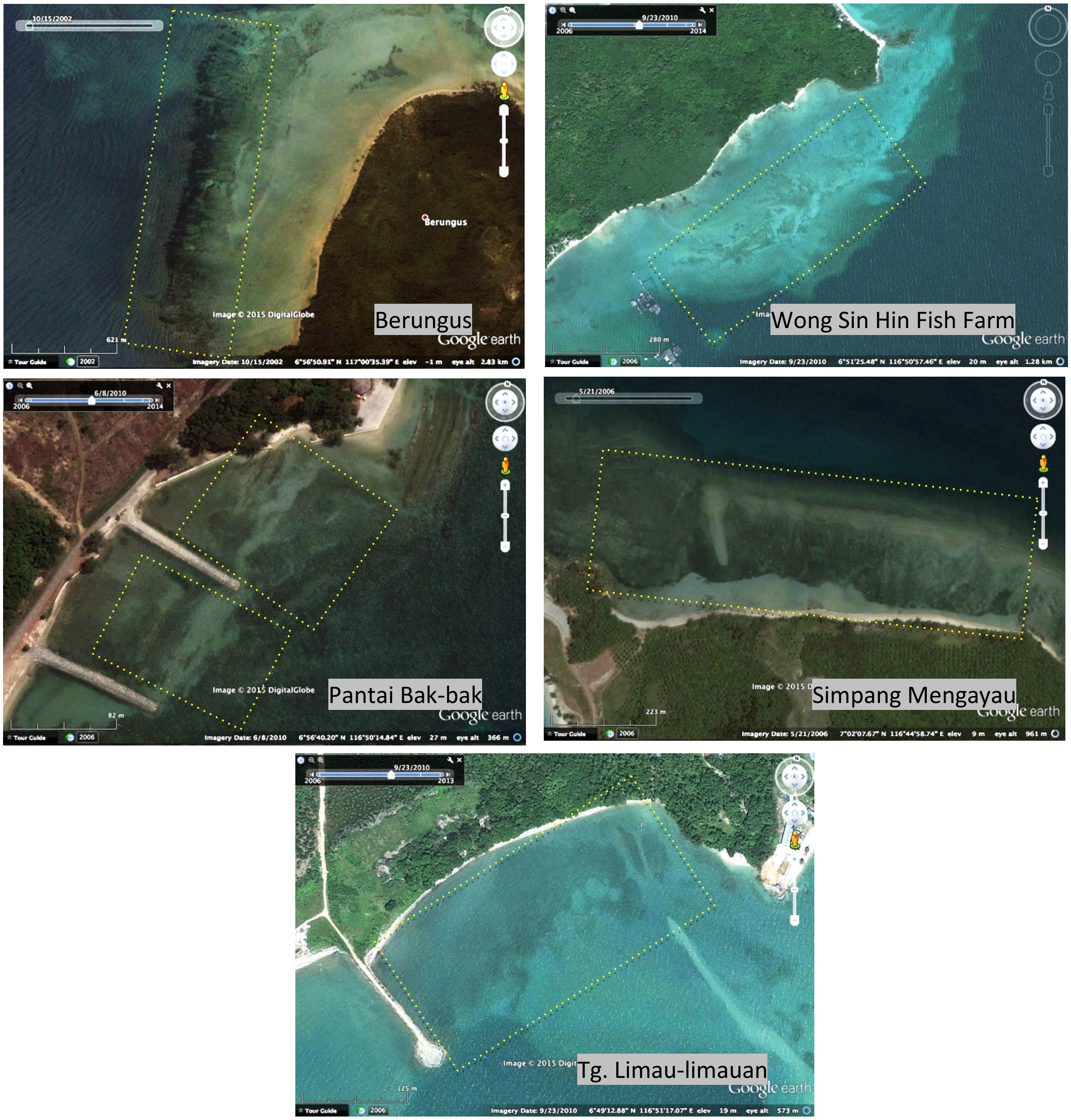
Estimation of seagrass coverage through aerial photographs was done by determining the color characteristics of seagrass beds on Google Earth satellite map. Ground truthing during field observations equipped with GPS, sites with patchy seagrass beds were recorded and then superimposed over the satellite map. The results showed an uneven shape and dark coloration (**Figure 4.1.4**). The located sites were used as color reference to estimate the coverage of seagrass beds in nearby areas.

Seagrass beds were spotted in five areas during the field surveys in June and August 2015. The location of each site is indicated in Tables 3.2.2a and 3.2.2b (Chapter 3: Materials and Methods). Estimation of coverage using Google Earth map near the five areas was carried out. The coverage of seagrass beds extended from the recorded eight sites to the nearby areas (**Figure 3.2.2a** in Chapter 3: Materials and Methods).

Except for coastal areas of Kampong Rosob, seagrasses were photographed and samples collected for identification. Four species from two families of seagrass species were identified: *Enhalus acoroides* (Hydrocharitaceae), *Thalassia hemprichii* (Hydrocharitaceae), *Holodule* sp. (Potamogetonaceae), and *Holodule uninervis* (Potamogetonaceae) (**Photo 4.1.4**). Three species of seagrasses were recorded in Pantai Bak-bak, two species in Tanjung Limau-limauan and Simpang Mengayau, and one species in Berungus (**Table 4.1.4**).

[5] By John Madin and Kai-Ching Cheong.

Figure 4.1.4: Seagrass Patches in Different Areas Indicated by Dark Coloration and Uneven Shape



Note: Actual seagrass patches are indicated within yellow boxes in the satellite map. Google Maps, 2015

Photo 4.1.4: Seagrass species found in Marudu Bay: (i) *Enhalus acoroides*, (ii) *Thalassia hemprichii*, (iii) *Halodule* sp., and (iv) *Halodule uninervis*

Table 4.1.4: Seagrass Species Composition in Different Areas of Marudu Bay

Family	Species	Simpang Mengayau	Pantai Bak-bak	Tanjung Limau-limauan	Berungus
Hydrocharitaceae	*Enhalus acoroides*	√	√	√	
Potamogetonaceae	*Halodule* sp.		√		√
Hydrocharitaceae	*Thalassia hemprichii*		√		
Potamogetonaceae	*Halodule uninervis*	√		√	

6. Mangroves[6]

We attempted to cover the highest astronomical tide level at all sampling sites that were pre-selected with the aid of GPS. The salinity of the furthest site reached (site 3 in Sg. Bandau) was 8.08 ppt. This site has brackish water inundated by normal high tide.

a. Physical Water Quality Parameters

The surface water temperatures in all sites were within the range of 28.11-31.50°C (**Table 4.1.5a**). Dissolved oxygen indicated a wide range, i.e. 31.90-62.90% in most sites, with only one exceptional high value of 89.30% at site 1 in Sg. Bandau. pH values ranged from 6.84 to 7.89 in all sites, indicating a slightly neutral water compared to an ordinary marine ecosystem.

b. Species Composition and Diversity

This study surveyed 825 adult (mature) mangrove trees belonging to 26 species in 20 genera from 19 families (excluding one unidentified species) (**Table 4.1.5b**). Of the 26 species, 13 are true mangrove species, while the other 13 are mangrove-associated species. In terms of true mangrove species, the largest family recorded was Rhizophoraceae with six species: *Bruguiera cylindrica* (Beus), *B. parviflora* (Lenggadai), *Ceriops decandra* (Tengar), *Rhizophora apiculata* (Bangkita), *R. mucronata* (Bakau Kurap), and *R. stylosa* (Bakau Putih). This resulted to an additional 10 species, an additional eight genera, and an additional 10 families compared to a previous study (Faridah-Hanum et al., 2012).

The mangrove species composition in Marudu Bay varies between the three surveyed areas: Kudat (five species), Marudu (11 species in Sg. Matunggong and 10 species in Bandau), and Pitas (18 species) (**Photo 4.1.5**). Using the Shannon species diversity index (H), the diversity value is highest for Sg. Telaga (1.98), followed by Sg. Matunggong (1.72), Sg. Bandau (1.58), and Sg. Dualog (1.19). This indicates that Sg. Telaga has higher species diversity compared with the other stations (**Tables 4.1.5c–f**).

[6] By Kai-Ching Cheong, Jean-Chai Yee, Ejria Saleh, and B. Mabel Manjaji-Matsumoto.

Table 4.1.5a: Physical Water Quality Parameters of Survey Stations (Landward from River Mouth)

Parameter	Sg. Dualog, Kudat					Sg. Matunggong, Marudu					Sg. Bandau, Marudu			Sg. Telaga, Pitas				
	Site No.					*Site No.*					*Site No.*			*Site No.*				
	1	2	3	4	5	1	2	3	4	5	1	2	3	1	2	3	4	5
Temperature (°C)	29.50	28.11	28.50	29.1	28.60	29.70	29.80	29.60	31.50	29.30	30.80	29.50	28.80	29.10	29.20	29.40	31.00	30.10
Conductivity (ms/cm)	N/A	42.66	41.36	35.78	N/A	48.23	46.75	41.21	40.72	41.78	23.17	18.13	15.08	48.58	46.87	48.09	49.98	46.74
Salinity (ppt)	26.89	25.68	24.56	20.66	17.21	28.44	27.38	23.92	22.70	24.70	12.38	9.70	**8.08**	29.02	27.85	28.56	28.78	27.28
DO (%)	42.20	31.90	36.90	42.40	41.0	34.80	34.10	37.20	46.20	34.00	**89.30**	48.90	52.60	62.90	58.60	48.10	44.00	32.20
DO (ppm)	2.71	2.13	2.48	2.92	N/A	2.25	2.15	2.47	3.42	2.28	6.31	3.54	3.86	4.10	3.88	3.21	2.79	2.09
pH	7.47	6.99	7.01	6.93	6.84	7.11	7.11	7.01	7.15	7.02	7.89	7.11	7.21	7.58	7.43	7.34	7.28	7.07

N/A: Data not available

Photo 4.1.5: Mangrove forest conditions in the four river stations

(i) Virgin mangrove forest at site 1, Sg. Dualog, Kudat

(ii) Stilt roots exposed at site 1, Sg. Matunggong, Marudu

(iii) *Avicennia alba* observed only in the outermost fringing mangrove forest, Sg. Bandau, Marudu

(iv) A cleared area for aquaculture pond. On the white signboard is written, "Riparian Reserves & Wildlife Corridor," Sg. Telaga, Pitas.

Table 4.1.5b: List of Mangrove Species Observed in This Study

No.	Family	Species	Local Name	Class	A	B	C	D
1.	Acanthaceae	*Acanthus ebracteatus**	Jeruju Hitam	MA			√	
2.	Acanthaceae	*Acanthus ilicifolius**	Jeruju Putih	MA			√	
3.	Arecaceae	*Metroxylon sagu**	Sago Palm	MA		√		
4.	Avicenniaceae	*Avicennia alba*	Api-api	TM			√	
5.	Avicenniaceae	*Avicennia marina*	Miapi	TM				√
6.	Bignoniaceae	*Dolichandrome spathacea**	Tui	MA				√
7.	Casuarinaceae	*Cassuarina equisetifolia**	Rhu	MA			√	
8.	Combretaceae	*Lumnitzera littorea*	Geriting Merah	TM				√
9.	Euphorbiaceae	*Excoecaria agallocha*	Buta-buta	MA		√		
10.	Leguminosae	*Caesalpinia crista**	Mata Kijang	MA				√
11.	Malvaceae	*Hibiscus tiliaceus*	Baru-baru	MA				√
12.	Meliaceae	*Xylocarpus granatum*	Nyireh	TM		√		√
13.	Palmae	*Nypa fructicans**	Nipa Palm	TM		√	√	
14.	Pteridaceae	*Acrostichum aureum**	Piai Raya	MA		√		√
15.	Rhizophoraceae	*Bruguiera cylindrica*	Beus	TM		√		√
16.	Rhizophoraceae	*Bruguiera parviflora*	Lenggadai	TM	√	√	√	√
17.	Rhizophoraceae	*Ceriops decandra*	Tengar	TM	√	√	√	√
18.	Rhizophoraceae	*Rhizophora apiculata*	Bangkita	TM	√	√	√	√
19.	Rhizophoraceae	*Rhizophora mucronata*	Bakau Kurap	TM	√	√		√
20.	Rhizophoraceae	*Rhizophora stylosa*	Bakau Putih	TM	√	√	√	√
21.	Rubiaceae	*Scyphiphora hydrophyllacea*	Landing-landing	MA				√
22.	Rutaceae	*Merope angulata**	Limau Buaya	MA				√
23.	Sapindaceae	*Allophylus cobbe*	Membuakat	MA				√
24.	Sapotaceae	*Pouteria obovata*	Nyatoh Laut	MA				√
25.	Sonneratiaceae	*Sonneratia alba*	Pedada	TM			√	
26.	Sonneratiaceae	*Sonneratia caseolaris*	Perepat	TM				√
			Total TM		**5**	**8**	**7**	**10**
			Total MA		**0**	**3**	**3**	**8**

MA = mangrove-associated species, TM = true mangrove species
A = Sg. Dualog, Kudat; B = Sg. Matunggong, Marudu; C = Sg. Bandau, Marudu; D = Sg. Telaga, Pitas
*Species not included in structural parameters and statistical analysis

Table 4.1.5c: Mangrove Species and Ecological Indices in Sg. Dualog, Kudat

Species	Importance Value Index, IVI	Species Diversity, H	Equitability, E_H
Rhizophora apiculata	166.07	0.33	0.20
Rhizophora mucronata	62.97	0.33	0.20
Rhizophora stylosa	49.18	0.30	0.18
Ceriops decandra	13.41	0.14	0.09
Bruguiera parviflora	8.37	0.10	0.06
Total	**300.00**	**1.20**	**0.73**

Table 4.1.5d: Mangrove Species and Ecological Indices in Sg. Matunggong, Marudu

Species	Importance Value Index, IVI	Species Diversity, H	Equitability, E_H
Rhizophora apiculata	122.44	0.37	0.17
Ceriops decandra	59.60	0.32	0.15
Rhizophora mucronata	44.11	0.28	0.13
Bruguiera parviflora	25.08	0.21	0.09
Xylocarpus granatum	15.63	0.15	0.07
Bruguiera cylindrica	10.75	0.12	0.05
Excoecaria agallocha	8.84	0.10	0.05
Rhizophora stylosa	8.54	0.10	0.05
Unknown sp.	4.99	0.07	0.03
Total	**300.00**	**1.72**	**0.79**

Table 4.1.5e: Mangrove Species and Ecological Indices in Sg. Bandau, Marudu

Species	Importance Value Index, IVI	Species Diversity, H	Equitability, E_H
Rhizophora apiculata	100.00	0.37	0.20
Avicennia alba	89.67	0.36	0.20
Bruguiera parviflora	38.83	0.26	0.15
Rhizophora stylosa	29.39	0.23	0.13
Sonneratia alba	29.33	0.23	0.13
Ceriops decandra	12.78	0.13	0.08
Total	**300.00**	**1.58**	**0.89**

Table 4.1.5f: Mangrove Species and Ecological Indices in Sg. Telaga, Pitas

Species	Importance Value Index, IVI	Species Diversity, H	Equitability, E_H
Rhizophora apiculata	104.68	0.37	0.14
Rhizophora mucronata	66.61	0.33	0.12
Ceriops decandra	46.89	0.29	0.11
Avicennia marina	14.84	0.15	0.05

Hibiscus tiliaceus	13.16	0.14	0.05
Bruguiera parviflora	9.64	0.11	0.04
Scyphiphora hydrophyllacea	8.57	0.10	0.04
Bruguiera cylindrica	7.78	0.09	0.03
Pouteria obovata	5.51	0.07	0.03
Rhizophora stylosa	4.14	0.06	0.02
Lumnitzera littorea	3.80	0.06	0.02
Xylocarpus granatum	3.75	0.05	0.02
Sonneratia caseolaris	3.57	0.05	0.02
Allophylus cobbe	3.52	0.05	0.02
Merope angulata	3.52	0.05	0.02
Total	**300.00**	**1.97**	**0.73**

As indicated by Shannon's equitability (E_H), among all the rivers, the value is highest for Sg. Bandau (0.88), followed by Sg. Matunggong (0.78), Sg. Dualog (0.74), and Sg. Telaga (0.73). This means that the mangrove species in Sg. Bandau are more evenly distributed compared with the other stations. In contrast, Sg. Telaga had the lowest equitability score because of its high species number, as equitability decreases with an increase in species number.

Throughout the survey areas, *Rhizophora apiculata* (Bangkita) is the dominant species, ranking first in the Importance Value Index (IVI) compared to the other recorded species in the four survey stations. This indicates that *R. apiculata* is the major mangrove species in Marudu Bay. It occupies a large portion of the mangrove community, with a high relative density in the surveyed areas (64% in Sg. Dualog, 39% in Sg. Matunggong, 37% in Sg. Bandau, and 45% in Sg. Telaga). The relative frequency of *R. apiculata* is 32% in Sg. Dualog, 21% in Sg. Matunggong, 33% in Sg. Bandau, and 45% in Sg. Telaga. Meanwhile, its relative dominancy is 70% in Sg. Dualog, 63% in Sg. Matunggong, 30% in Sg. Bandau, and 39% in Sg. Telaga.

The second highest contributor to the IVI values varies by station: *Avicennia alba* (90 in Sg. Bandau), *Ceriops decandra* (60 in Sg. Matunggong), and *R. mucronata* (63 in Sg. Dualog and 67 in Sg. Telaga). Most of the high IVI values are contributed by true mangrove species.
Only data for mean DBH of four mangrove species (*B. parviflora*, *C. decandra*, *R. apiculata*, and *R. stylosa*) were used for the statistical analysis. This is because only these four species were observed in the four river stations. All data were subjected to two-way ANOVA using Minitab version 17. The mean DBH of the four mangrove species suggests that the trees may experience different growth rates, resulting to larger DBH in certain areas for certain species. However, the result of two-way ANOVA indicates that this difference is not statistically significant ($p>0.05$).

B. Oceanographic Parameters[7]

For this study, we divided Marudu Bay into two parts: inner and outer. The inner part is located in the southern half of the bay, from the estuary to about 53 km north, while the outer part is located in the northern half, towards the opening of the bay. The outer part is exposed to strong winds and waves from the open sea. Field observations and samplings were conducted three times in June and August 2015.

[7] By Ejria Saleh and Muhammad Rashid Bin Abdul Rahim.

1. Tidal Pattern

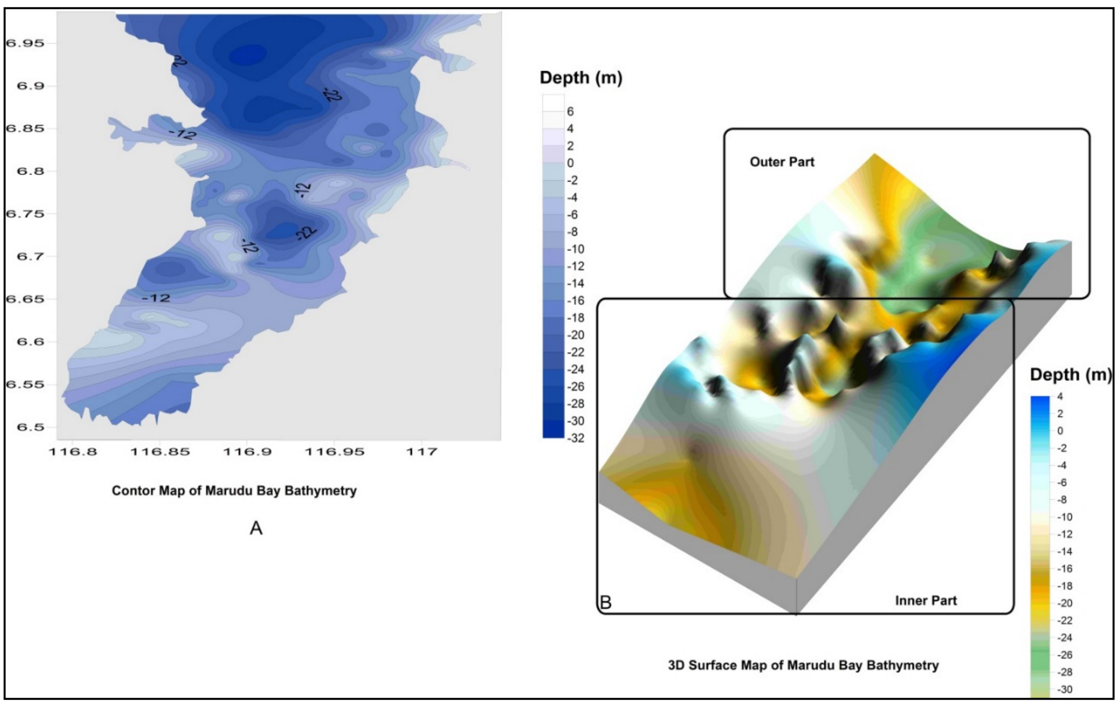
The tidal condition of Marudu Bay is similar to that of Kudat waters. According to the National Hydrographic Centre (NHC, 2015), the tidal range at Kudat district is between 0.2 m and 2.2 m. This increases the potential of inundated coastal areas during typhoon and storm surges, especially at high tide (Siringan et al., 2013).

2. Bathymetry

The inner part of Marudu Bay has a water depth of less than 10 m near the coastline and uneven bathymetry. Generally, the bathymetry of the inner part of the bay shows deeper water towards the middle, increasing from 0.5 m near the coastline to 21.5 m at mid-north of the bay (**Figure 4.2a**). The coastline is dominated by fringing mangroves, while other parts form sandy beaches. The inner part of the bay is also dominated by the intertidal zone and shallow water surrounding its coastline. Details of the seabed floor is presented as a 3D surface map generated using Surfer software version 8.0 (**Figure 4.2b**). Large areas of the intertidal zone/shallow water are mostly located in the inner part of Marudu Bay and along the bay's shoreline.

The outer part of the bay is formed by narrow intertidal areas along the coastline. The west and east coastlines of the outer bay are formed by sandy beaches and patchy mangroves. The bathymetry of the outer part of the bay shows an increase in the water depth towards the bay's opening **(Figure 4.2a**). The maximum water depth is 31 m in the middle of the outer part of Marudu Bay.

Figure 4.2a: (i) Contour Map and (ii) 3D Surface Map of Marudu Bay Bathymetry

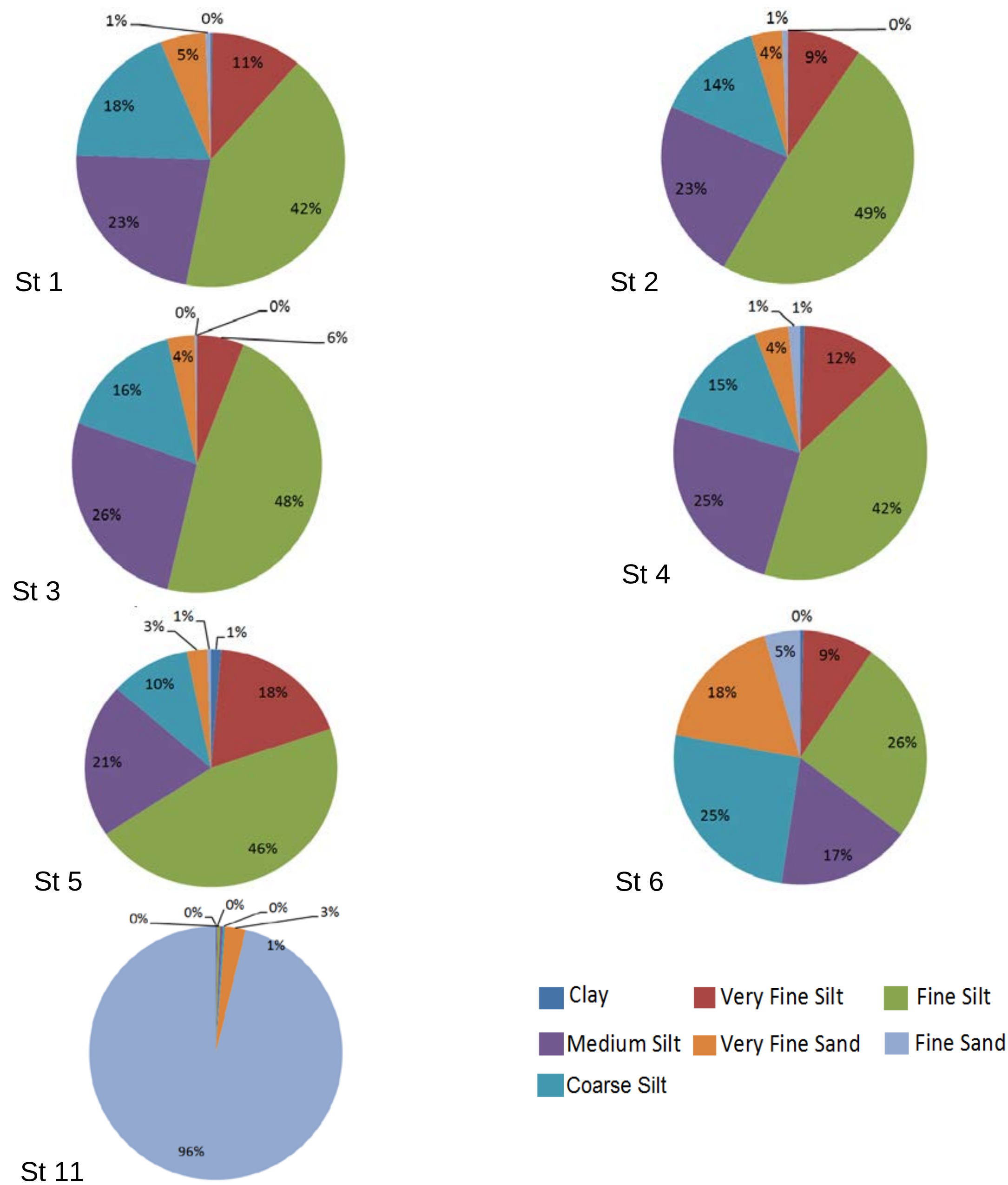


3. Seabed Substrate

The substrate of Marudu Bay is mainly sand and silt. Sand is distributed along the intertidal zone while mud settles in the middle of the bay. The grain size of the sea surface sediment is dominated by fine silt in almost all stations (St). Grain size ranges from 4.82 μm (fine silt) to

18.13 µm (medium silt), while sand size ranges from 63 µm (very fine sand) to 200 µm (fine sand). The percentage range of fine silt is 41-48%, followed by fine sand at 93.20% at the intertidal zone of the Senaja River estuary.

Figure 4.2b: Percentage of Seabed Substrate in Different Sampling Stations in Marudu Bay



Small portions of clay and very fine silt are also present in the samples. The percentage of fine silt sediment decreases towards the outer bay. As an example, St 10 has mixed composition size of fine (26%), medium (17%), and coarse silt (25%), while St 11 is almost completely dominated (96%) by fine sand (184.11 µm). The finest component of sediment is easily transported seaward due to the high energy in nearshore shallow water, mixing of fresh water and seawater, and the interaction between river and tidal flows (Chen et al., 2009).

The general trend of decreasing grain size with increasing distance away from shoreline to middle, and middle to seaward is supported by the fact that particles are advected by the flow or fraction. Thus, larger grain sizes remain in the area with a strong current, while smaller grain sizes are distributed at a weaker current (Fiechter et al., 2006).

4. Physico-Chemical Characteristics

The water parameter values are shown in **Tables 4.2a** and **4.2b**. The salinity range of Marudu Bay during the southwest monsoon is between 20.7 psu and 31.86 psu. According to Jakobsen et al. (2007), the salinity in the middle of the bay during the northeast monsoon can be as low as 26 psu due to freshwater inflow from the surrounding areas. Another factor affecting the salinity range of Marudu Bay is the current generated from wind-driven forces during the monsoon seasons. On the other hand, the salinity range of the bay can increase due to limited river inflow and seawater mixing with the fresh water from Marudu Bay by strong current effect (Islam et al., 2011).

Table 4.2a: Sampling Localities for Water Parameter Survey on 25 June 2015, and Water Parameter Results

Station No.	Locality	GPS Coordinates	Depth (m)	Temperature (°C)	Salinity (psu)	DO (mg/L)	pH
1	Kg. Berungus	06° 57.164’ **N**; 117° 01.306’ **E**	1.6	29.87	30.99	4.43	7.88
2	Kg. Rosob	06° 44.300’ **N**; 116° 57.330’ **E**	22.3	30.54	31.52	5.78	8.71
3	Barraut Reef	06° 42.982’ **N**; 116° 54.263’ **E**	3.9	30.69	31.65	6.67	8.56
4	Parapat Laut	06° 46.110’ **N**; 116° 54.263’ **E**	0.6	30.60	31.63	8.34	8.37
5	Limau-limauan	06° 49.050’ **N**; 116° 51.449’ **E**	1.4	30.79	31.72	7.42	8.40

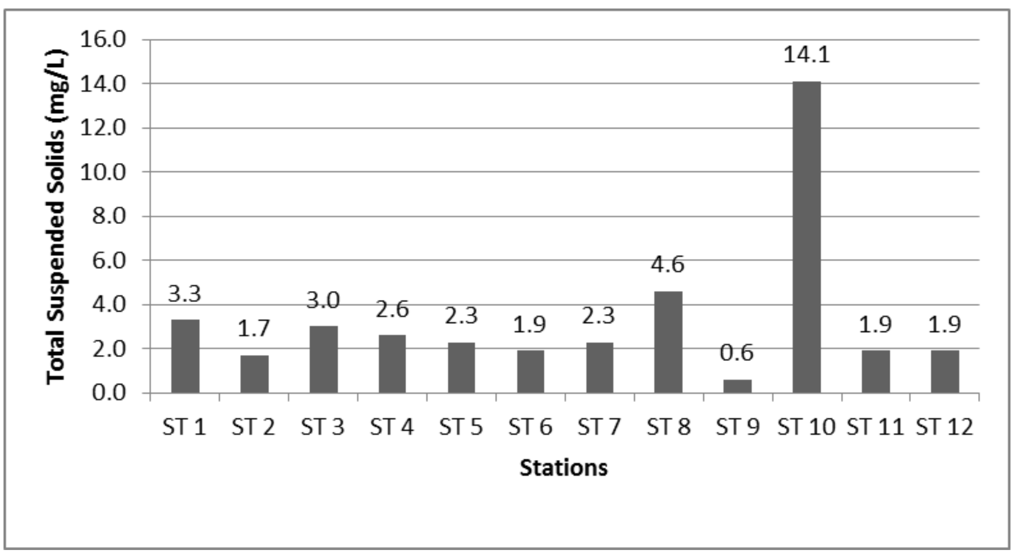
Table 4.2b: Sampling Localities for Water Parameter and Seabed* Surveys on 27-28 August 2015

Station No.	Locality	GPS Coordinates	Depth (m)	Temperature (°C)	Salinity (psu)	DO (mg/L)	pH
1	-	06° 51.7717’ **N**; 116° 52.2383’ **E**	20	29.41	30.82	5.92	8.50
2	-	06° 52.865’ **N**; 116° 47.0933’ **E**	15	29.56	30.74	5.16	8.35
3	-	06° 44.595’ **N**; 116° 50.9167’ **E**	14	29.69	30.60	6.10	8.38
4	-	06° 39.445’ **N**; 116° 50.4117’ **E**	16	29.72	30.78	4.81	8.30
5	-	06° 38.2767’ **N**; 116° 52.1317’	10	30.07	30.60	5.26	8.41

		E					
6*	-	06° 44.675’ **N**; 116° 56.3233’ **E**	23	29.38	30.81	5.40	8.34
7*	-	06° 49.075’ **N**; 116° 57.8433’ **E**	22	29.40	30.87	4.92	8.25
8*	-	06° 52.0867’ **N**; 116° 55.965’ **E**	28	29.36	30.67	6.38	8.31
9*	-	06° 52.6317’ **N**; 116° 59.4483’ **E**	10	29.88	30.56	6.39	8.34
10	-	06° 50.9683’ **N**; 117° 0.49’ **E**	10	30.55	30.26	6.65	7.63
11	-	06° 45.48’ **N**; 116° 57.8367’ **E**	20	30.20	30.64	6.62	8.37
12*	-	06° 54.9183’ **N**; 116° 54.1367’ **E**	23	29.41	30.89	6.32	8.54

The total suspended solids (TSS) measured in September 2015 ranged from 0.6mg/L to 14.1 mg/L. The highest TSS value was recorded at St 10, which is located close to the Telaga River estuary, while the lowest TSS value was at St 9 (**Figure 4.2c**). In general, the TSS of Marudu Bay is categorized under Class I of the National Water Quality Standard for Malaysia (DOE, 2006).

Figure 4.2c: Total Suspended Solids at 12 Sampling Stations in Marudu Bay



C. Quality of Coastal and Marine Waters, and Marine Pollutants[8]

1. Total Suspended Solids, Temperature, pH, Dissolved Oxygen, and Salinity

The means (± S.D) and range of total suspended solids (TSS) concentrations in the three surveyed areas of Marudu Bay are shown in Table 4.3a. The highest TSS concentration was recorded in the inner area of the bay with 20.93 ± 11.70 mg/L, followed by the middle area with 12.90 ± 6.54 mg/L. The lowest TSS concentration was 4.98 ± 6.83 mg/L in the bay's outer area. ANOVA analysis proved that the means of TSS concentrations were significantly different ($p<0.05$) between the three areas of Marudu Bay.

Table 4.3a: Mean (± S.D) and Range of Total Suspended Solids in Inner, Middle, and Outer Areas of Marudu Bay

	N	Inner Area	Middle Area	Outer Area
Total Suspended Solids, TSS (mg/L)	26	20.93 ± 11.70 [a] (8.40 – 48.80)	12.90 ± 6.54 [a,b] (3.00 – 18.80)	4.98 ± 6.83 [c] (0.20 – 15.80)

Note: Values with same alphabetical superscripts in a row are not significantly different ($p<0.05$). Values in brackets are the range.

Four sampling stations in the inner area are located near river mouths (**Figure 3.2.7a** in Chapter 3: Materials and Methods). Rivers carry sediments and solids from upriver down to the estuaries. The presence of sediments and solids in the water prevents sunlight from penetrating the water column. Primary productivity of marine plants and phytoplankton are thus reduced due to low light penetration. Filter feeding marine invertebrates such as clams and mussels are at risk of being smothered by suspended solids. Other aquatic animals are affected directly by suspended solids. According to Deocadiz and Montaño (1999), TSS levels in coastal or marine waters are highly inconsistent depending on a number of factors such as season, turbulence due to wave and current action, as well as the proximity to the source of suspended solids. They also stated that additional data are needed to support derivation of the TSS for protection of marine aquatic life and recreational activities. As suggested by MMWQS (2015), the TSS level is not more than 50 mg/L for the Malaysian Interim Marine Water Quality Standard.

The range concentrations of TSS during the survey were 8.40-48.80 mg/L in the inner area, 3.00-18.80 mg/L in the middle area, and 0.20-15.80 mg/L in the outer area of Marudu Bay.

Table 4.3b shows the means (± S.D) and range of seawater temperature, pH, dissolved oxygen (DO), and salinity levels in the three areas of the bay. The means of seawater temperature was 30.60 ± 1.17 ^{o}C in the bay's inner area, 30.00 ± 0.50 ^{o}C in the middle area, and 29.37 ± 0.92 ^{o}C in the outer area. For pH, DO, and salinity, the readings were 7.96 ± 0.24, 5.87 ± 0.89 mg/L, and 27.61 ± 3.08 psu, respectively, in the inner area; 8.21 ± 0.28, 7.42 ± 1.37 mg/L, and 30.08 ± 2.12 psu, respectively, in the middle area; and 8.11 ± 0.23, 6.38 ± 0.32 mg/L, and 31.07 ± 0.48 psu, respectively, in the outer area. One-way ANOVA analysis proved that the three areas had significant differences ($p<0.05$) in temperature, DO, and salinity (**Table 4.3b**).

[8] By Abentin Estim, Mohd Ruzaini Bin Jumadi, Mohd Amir Syaifuddin Mohd Usop, and Nurul Najwa Abd Rahman.

Table 4.3b: Mean (± S.D) and Range of Temperature, pH, Dissolved Oxygen, and Salinity in Inner, Middle, and Outer Areas of Marudu Bay

	N	Inner Area	Middle Area	Outer Area
Temperature (^{o}C)	27	30.60 ± 1.17 [b] (29.00 – 32.00)	30.00 ± 0.50 [a,b] (29.00 – 31.00)	29.37 ± 0.92 [a] (28.00 – 31.00)
pH	27	7.96 ± 0.24 (7.49 – 8.30)	8.21 ± 0.28 (7.83 – 8.91)	8.11 ± 0.23 (7.54 – 8.21)
Dissolved Oxygen, DO (mg/L)	27	5.87 ± 0.89 [a] (3.89 – 6.99)	7.42 ± 1.37 [a,b] (6.11 – 9.71)	6.38 ± 0.32 [b] (5.77 – 6.91)
Salinity (psu)	27	27.61 ± 3.08 [a] (20.69 – 31.61)	30.08 ± 2.12 [a,b] (24.67 – 31.93)	31.07 ± 0.48 [b] (30.13 – 31.68)

Values with same alphabetical superscripts in a row are not significantly different (p<0.05). Values in brackets are the range.

Boyd (2000) explained that the temperature of surface waters varies during the year, with seasonal changes in the air temperature, day length, and solar radiation. Low air temperature at night influences the seawater temperature, and a large volume of water provides a buffer against changes in temperature. Zweig et al. (1999) stated that each organism has an optimum temperature for best growth rate and living condition. Growth can still occur at very close to the upper and lower lethal temperature limits. Sub-optimal temperatures, however, cause stress, which affects behavior, feeding, metabolism, growth, and immunity to disease.

Changes in water temperature affect fish metabolism and activity, oxygen consumption, ammonia, and carbon dioxide. High temperature recorded in the inner area of Marudu Bay was due to the fact that the sampling was conducted during a cloudless day, when sunlight was not obstructed. It should be noted that cloud cover reduces the amount of sunlight reaching the water.

Total suspended solids (TSS) were higher in the inner area compared to the middle and outer areas. Water temperature is also influenced by the presence of suspended solids. Heat transferred to the water body is retained more effectively by suspended solids, which act as insulators. Seawater temperature recorded during the survey ranged from 29.00 ^{o}C to 32.00^{o}C in the inner area, 29.00 ^{o}C to 31.00^{o}C in the middle area, and 28.00 ^{o}C to 31.00^{o}C in the outer area (**Table 4.3b**).

Dissolved Oxygen (DO) is a basic but complex parameter and depends upon many factors. Several studies have reported details of the effects of DO concentrations in the aquatic environment (UNDP/FAO, 1989; Boyd, 2000; Estim, 2010). DO concentration ranging from 1 mg/L to 5 mg/L can ensure fish survival for a short period. But in a long exposure, oxygen deficit would cause slow growth. There are reports that DO concentration of about 4 mg/L could cause adverse effects. High DO concentration can cause gas bubble trauma at times when water temperature increases rapidly.

Boyd (2000) described five major processes of addition and removal of oxygen: air-water gas transfer, sediment oxygen uptake, animal respiration, plankton respiration, and photosynthesis. Zweig et al. (1999) mentioned that fish can survive at DO 1–5 mg/L, but a long exposure would cause slow growth and other health problems. DO concentrations recorded during the survey ranged from 3.89 mg/L to 6.99 mg/L in the inner area, 6.11 mg/L to 9.71 mg/L in the middle area, and 5.77 mg/L to 6.91 mg/L in the outer area (**Table 4.3b**).

Salinity regulates osmotic pressure, which greatly affects the fish ionic balance through the process of osmoregulation. Distinct species have their own optimal salinity for growth, and when out of the range, excess energy is expanded to maintain the desired salt concentration (Estim, 2010). Recorded seawater salinity ranged from 20.69 psu to 31.61 psu in the inner area, 24.67 psu to 31.93 psu in the middle area, and 30.13 psu to 31.68 psu in the outer area of Marudu Bay.

2. Nutrient Concentrations of NH3-N, NO2-N, NO3-N, and PO4-P

Table 4.3c shows the means (±S.D) and range of nutrient concentrations in the three surveyed areas of Marudu Bay. Nutrient concentrations were found to be in the range of the Malaysian Marine Water Quality Standard. The means (± S.D) concentrations of NH_3-N, NO_2-N, NO_3-N, and PO_4-P were 0.021 ± 0.003 mg/L, 0.508 ± 0.059 mg/L, 0.484 ± 0.264 mg/L, and 0.015 ± 0.001 mg/L, respectively, in the bay's inner area; 0.018 ± 0.006 mg/L, 0.349 ± 0.196 mg/L, 0.438 ± 0.412 mg/L, and 0.009 ± 0.005 mg/L, respectively, in the middle area; and 0.012 ± 0.005 mg/L, 0.355 ± 0.447 mg/L, 0.251 ± 0.464 mg/L, and 0.016 ± 0.011 mg/L, respectively, in the outer area. One-way ANOVA analysis proved that the three surveyed areas were significantly different (P<0.05) in NH3-N, but not for NO_2-N, NO_3-N, and PO_4-P concentrations. Details of the nutrient concentrations are shown in Table 4.3c.

Table 4.3c: Means (± S.D) and Range of Concentrations of NH_3-N, NO_2-N, NO_3-N, and PO_4-P in Inner, Middle, and Outer Areas of Marudu Bay

	N	Inner Area	Middle Area	Outer Area
NH_3-N (mg/L)	27	0.021 ± 0.003 ^{b} (0.02 – 0.03)	0.018 ± 0.006 ^{b} (0.01 – 0.03)	0.012 ± 0.005 ^{a} (0.01 – 0.02)
NO_2-N (mg/L)	27	0.508 ± 0.059 (0.39 – 0.60)	0.349 ± 0.196 (0.01 – 0.51)	0.355 ± 0.447 (0.04 – 1.26)
NO_3-N (mg/L)	27	0.484 ± 0.264 (* – 0.93)	0.438 ± 0.412 (* – 1.37)	0.251 ± 0.464 (* – 1.39)
PO_4-P (mg/L)	27	0.015 ± 0.001 (0.01 – 0.02)	0.009 ± 0.005 (* – 0.005)	0.016 ± 0.011 (* – 0.0)

Note: Values with different alphabetical superscripts in a row are significantly different (p<0.05). Values in brackets are the range. Values with an asterisk (*) are below the detection limit.

3. Fecal Coliform and Oil and Grease Concentrations

Table 4.3d shows the means (± S.D) and range concentrations of fecal coliform and oil and grease in the inner, middle, and outer areas of Marudu Bay. The means concentrations of fecal coliform were 13.96 ± 8.97 CFU/100 mL in the bay's inner area, 22.89 ± 25.92 CFU/100 mL in the middle area, and 37.69 ± 39.02 CFU/100 mL in the outer area. For oil and grease concentrations, the means recorded were 0.06 ± 0.09 mg/L in the inner area, 00.11 ± 0.09 mg/L in the middle area, and 0.05 ± 0.03 mg/L in the outer area of Marudu Bay. One-way ANOVA analysis proved that the three surveyed areas were not significantly different (P<0.05) in fecal coliform and oil and grease concentrations.

Table 4.3d: Mean (± S.D) and Range of Fecal Coliform and Oil and Grease in Inner, Middle, and Outer Areas of Marudu Bay

	N	Inner Area	Middle Area	Outer Area
Fecal coliform (mg/L)	27	13.96 ± 8.97 [b] (4.00 – 31.00)	22.89 ± 25.92 [b] (0.00 – 85.00)	37.69 ± 39.02 [a] (3.00 – 114.00)
Oil and grease (mg/L)	27	0.06 ± 0.09 (* – 0.33)	00.11 ± 0.09 (* – 0.28)	0.05 ± 0.03 (0.02 – 0.10)

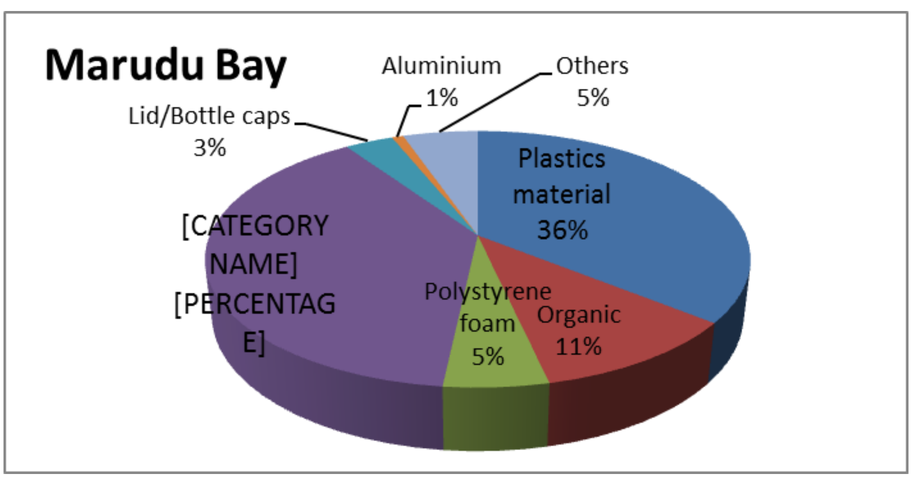
Note: Values with different alphabetical superscripts in a row are significantly different (P<0.05). Values in brackets are the range. Values with an asterisk (*) are below the detection limit.

4. Stranded Marine Debris and Microplastics

Table 3.2.7b and **Figure 3.2.7a** (Chapter 3: Materials and Methods) show the six surveyed beaches of Marudu Bay with their coordinates and estimated lengths. The longest beach was estimated at St 2 with a length of 2.71 km, followed by St 1 (1.05 km), St 3 (0.72 km), St 4 (0.46 km), and St 5 (0.21 km). The shortest beach was recorded at St 6 with a length of 0.13 km. The beach lengths were all recorded in the Bengkoka Peninsula, while none was recorded at the Kudat side. This was due to time constraints and safety purposes as the low tide occurred quicker than expected, thus presenting a hazardous condition to the boat and crew. Furthermore, areas surrounding Kudat consist of mangroves, which are known habitats of aggressive marine reptile such as crocodiles. Taking precaution, the beaches covered were all located in the Bengkoka Peninsula, as shown in **Table 3.2.7b** and **Figure 3.2.7a**.

Results revealed seven major types of marine debris at the surveyed beaches of Marudu Bay: (i) wood, (ii) plastic materials such as wrappers and bags, (iii) polystyrene foam, (iv) organic materials such as coconut husk and dead fish, (v) lids/bottle caps, (vi) aluminum, and (vii) other debris such as toothbrushes, lighters, shoes and other footwear, clothes, glass, paper, and metal. Wood was the most prevalent type of marine debris recorded at the beaches of Marudu Bay, comprising 39% of the debris. It was followed by plastic materials (36%), organic materials (11%), polystyrene foam (5%), other debris (5%), lids/bottle caps (3%), and aluminum (1%) (**Figure 4.3a**).

Figure 4.3a: Types and Percentage of Surveyed Marine Debris at Marudu Bay Beaches



The types and quantities of marine debris in the inner, middle, and outer areas of Marudu Bay are shown in **Table 4.3e** and **Figure 4.3b**. The most prevalent type of marine debris in the outer area was wood with 220 items, followed by plastic materials (90 items), other debris (35 items), organic materials (33 items), polystyrene foam (18 items), lids/bottle caps (22 items), and aluminum (11 items). In the middle area, plastic debris was most prevalent with 77 items, followed by wood (36 items), organic materials (33 items), lids/bottle caps (25 items), polystyrene foam (11 items), other debris (4 items), shoes/footwear (3 items), and clothes (3 items). In the inner area, the most prevalent type of marine debris was wood with 61 items, followed by plastic materials (32 items), organic materials (31 items), other debris (6 items), polystyrene foam (5 items), lids/bottle caps (5 items), aluminum (5 items), clothes (4 items), and glass (3 items).

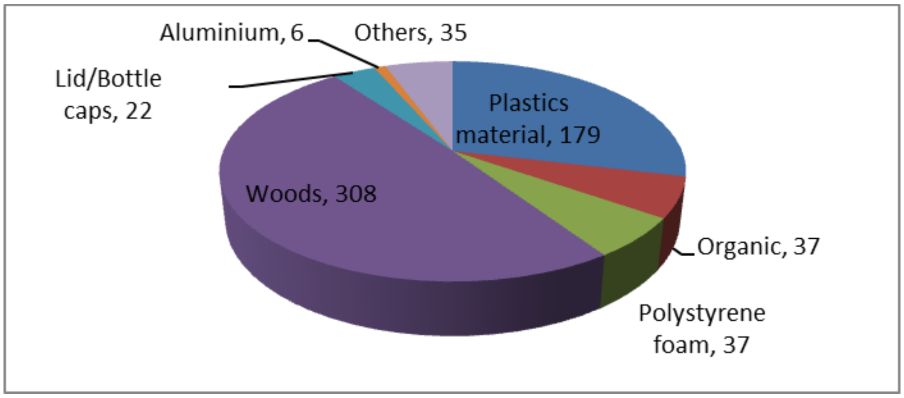
In the outer area of Marudu Bay, the surveyed area of St 2 was located near Lok Denkan village, which had about 40 people. The daily activities in the village may have contributed to the discarding of plastic materials on the beach. On the other hand, there were no people at the surveyed area of St 1. Thus, the wood debris may have come from the vegetation growing nearby, while the aluminum debris may have originated from the surrounding inhabited areas.

In the middle area of the bay, the surveyed areas of St 3 and St 4 only had a few people. In the inner area, the surveyed area of St 5 was near Kampung Pantai Marasimsim village, which had a small population. Meanwhile, the surveyed area of St 6 was near Kampung Garip village, which had about 50 people. The daily activities of Kampung Garip villagers may have resulted to the dumping of plastic materials on the beach. The least prevalent types of debris in this area were lids/bottle caps and other debris (polystyrene foam and glasses). The glass debris were a big concern because they could be contaminated with heavy metals and may affect the health of people if stepped on.

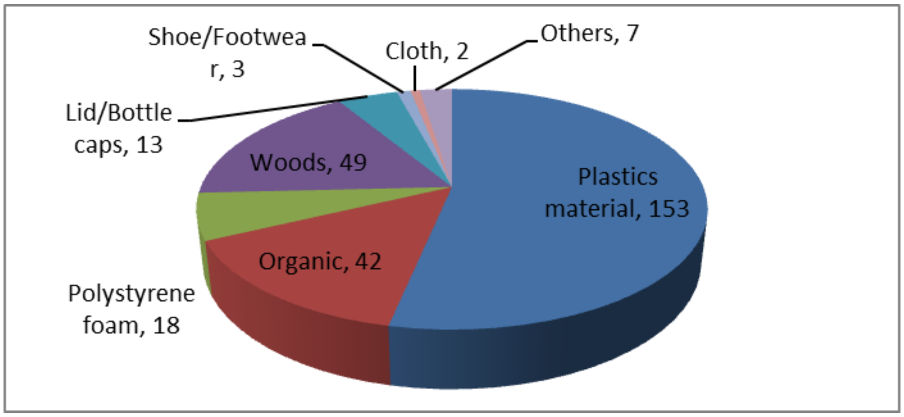
Table 4.3e: Six Surveyed Beaches of Marudu Bay with Their Coordinates, Estimated Lengths, and Quantities of Debris

Station No.	1	2	3	4	5	6
GPS Coordinates	6° 55.670' **N** 117° 2.040' **E**	6° 50.670' **N** 117° 2.188' **E**	6° 45.395' **N** 116° 59.553' **E**	6° 40.580' **N** 116° 56.633' **E**	6° 38.308' **N** 116° 53.390' **E**	6° 36.037' **N** 116° 51.262'**E**
Length of coastline (km)	1.51	2.71	0.72	0.46	0.21	0.13
Length of vegetation line (m)	5	6	10	6	5.5	6
Plastics materials	170	9	32.5	120.5	16	48.5
Organic materials	58	7.5	16.5	50	45	17.5
Polystyrene foam	26.5	10	9	13	5	-
Wood	265	175	45	26	96	25
Lids/bottle caps	21.5	-	-	25	-	5
Aluminum	-	11	-	-	5	-
Shoes/footwear	-	-	3	2	-	-
Clothes	-	-	3	-	2	5
Glass	-	-	-	-	-	3
Other debris	35	-	1	6	3	9

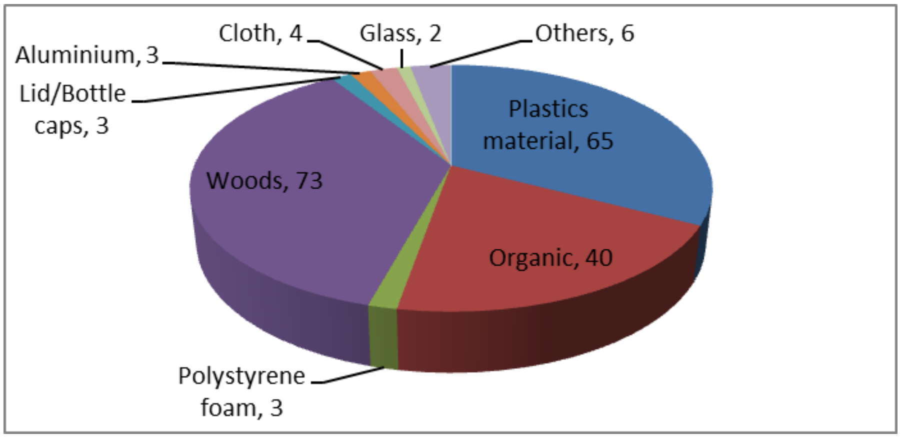
Figure 4.3b: Types and Percentage of Marine Debris in Three Survey Areas of Marudu Bay



Outer Area



Middle Area



Inner Area

V. conclusion

The coastal marine ecosystems of Marudu Bay are varied, ranging from virgin mangrove forests, pristine sandy beaches, and rocky shores with unique geological formations, to vast seagrass meadows. Coral cover is patchy, mostly with evidence of human-induced damage due to blast fishing, abandoned fishing gear (nets and traps), trash, and coral bleaching. In many parts of the bay, the coastal areas are uninhabited by humans, although not entirely free of marine debris and pollutants. However, in areas with human settlements, especially where houses are built directly over the seawater, there is no sewage or waste management system. Additionally, various types of pollution from agricultural activities and the seemingly uncontrolled clearance of large tracts of mangrove forests for agricultural purposes (in the northeastern Pitas Peninsula) contribute to the problem of negative human impacts in the bay.

The rich biodiversity of marine flora and fauna indicates that the mangrove ecosystems of Marudu Bay provide valuable habitats, nurseries, and spawning grounds for various commercially important species of fish and invertebrates. Moreover, mangroves serve as effective natural filter for land-based pollution (Faridah-Hanum et al., 2012). Complex mangrove vegetation structures, sheltered beaches, and tidal mudflats that are rich food resources also offer safe foraging and breeding grounds for marine life.

A. Biotic Component

1. Fish and Fisheries

A total of 188 species from 51 families were recorded, comprising 21 species from seven families of elasmobranchs and 167 species from 44 families of teleosts. As for fish landing trends, pelagic fish landings in Marudu Bay are higher than demersal fish landings.

2. Marine Invertebrates and Aquaculture Activities

A total of 755 invertebrate specimens were collected, comprising 35 species from 19 families of molluscs and eight species from six families of crustaceans. Species found in Simpang Mengayau are different from the mangrove habitat, where 15 species from 14 families were recorded. At the exposed mudflat of Sungai Bandau, only eight species from seven families were recorded. Fisheries and aquaculture activities based on marine invertebrate species are scattered throughout Marudu Bay. These include pen cultures and floating cages and rafts, depending on the species. The aquacultured marine invertebrates are mainly species of shrimps, sea cucumbers, and green mussels.

3. Coral Reefs

Based on the hard coral cover of 14 reefs surveyed in this study, Marudu Bay has a relatively fair coral cover (20-49% coverage), with site 10 having more than 50% coral cover, although site 5 had very poor coral cover of less than 3%. Invertebrate indicators were represented by *Diadema* urchins, sea cucumbers, lobsters, and giant clams, with the latter three in very low numbers. A diversity of fishes and invertebrates were recorded in Marudu Bay, which is a fair representation of the coral reefs in Sabah. While diversity of fishes was lower in the inner bay, diversity of invertebrates did not show a similar pattern. No direct correlation between diversity of fishes and invertebrates could be made to coral cover as the presence or preference of habitat is a multifactorial interaction.

Activities such as blast fishing and fisheries were evident from small areas of rubble, fish traps, and discarded nets and lines. Fish abundance was not particularly high and many of the fishes were relatively small in size. This could indicate the high fishing pressure taking place in the bay. Nevertheless, the diversity and presence of juvenile fish indicate that under proper fisheries regulations and guidelines, the coral reefs in the area could recover.

4. Seagrasses

Four species from two families of seagrass species were identified. This report shows the preliminary results based on sampling during the southwest monsoon. Baseline data of species composition of marine invertebrates in Marudu Bay were established, although further sampling needs to be conducted. Further sampling of marine invertebrates should include other habitats such as seagrass beds, sandy beaches, and rocky shores for a more comprehensive study.

5. Mangroves

A total of 26 species in 20 genera from 19 families, excluding one unidentified species, were recorded in Marudu Bay. These comprise 13 true mangrove species and 13 mangrove-associated species. The mangrove species composition in the bay varies between the three surveyed areas: Kudat (five species), Marudu (11 species in Sg. Matunggong and 10 species in Bandau), and Pitas (18 species).

B. Abiotic Component

1. Oceanographic Parameters

The tidal condition of Marudu Bay is similar to that of Kudat waters. Generally, the bathymetry of the inner part of the bay shows deeper water towards the middle, increasing from 0.5 m near the coastline to 21.5 m at the bay's mid-north. The bathymetry of the outer part of Marudu Bay shows an increase in the water depth towards the bay's opening, with a maximum depth of 31 m at the middle outer part of the bay. The substrate of Marudu Bay is mainly sand and silt. The salinity range of the bay during the southwest monsoon is between 20.7 psu and 31.86 psu. In general, the TSS of Marudu Bay is categorized under Class I of the National Water Quality Standard for Malaysia.

2. Quality of Coastal and Marine Waters, and Marine Pollutants

The highest TSS concentration was recorded in the inner area of Marudu Bay, while the lowest was in the outer bay. The nutrient concentrations were still within the range of the Malaysian Marine Water Quality Standard.

Wood was the most prevalent type of marine debris recorded on the beaches of Marudu Bay, with 39%, followed by plastic materials (36%), organic materials (11%), polystyrene foam (5%), other debris (5%), lids/bottle caps (3%), and aluminum (1%).

C. Suggestions and Recommendations

The findings of this study show that the mangrove forests in Marudu Bay are relatively intact, except for the mangroves in Pitas, where large-scale clearing of mangroves was observed. Otherwise, the mangrove communities are massive and diverse, and provide various ecosystem services to the local people. Any change to the mangrove forests, especially destructive and indiscriminate clearing of mangroves, will definitely affect the hydrology, pedology, biodiversity, and ecology of the mangrove ecosystem.

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