MAPPING THE DISTRIBUTION OF DIGITATE AND TABULATE *Acropora* CORALS IN SELECTED REEFS OF ZANZIBAR

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MAPPING THE DISTRIBUTION OF DIGITATE AND TABULATE *Acropora* CORALS IN SELECTED REEFS OF ZANZIBAR

By

Eliezer Brown Mwakalapa

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science (Marine Sciences) of the University of Dar es Salaam

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CERTIFICATION

The undersigned certifies that he has read and hereby recommend for acceptance by the University of Dar es Salaam a dissertation entitled: ***Mapping the distribution of tabulate and digitate Acropora corals in selected reefs of Zanzibar***, in partial fulfilment of the requirements for the degree of Master of Science (Marine Sciences) of the University of Dar es Salaam.

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Dr. Christopher A. Muhando

(Supervisor)

Date: -----------------------------

DECLARATION

AND

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I, **Eliezer B. Mwakalapa**, declare that this dissertation is my own original work and that it has not been presented and will not be presented to any other University for a similar or any other degree award.

Signature --

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I acknowledge the love and support shown by my family, especially my parents Mr and Mrs Brown Mwakalapa.

Lastly, I thank God almighty for his guidance and protection.

DEDICATION

This dissertation is dedicated to my dad **Brown Mwakalapa** and my mom **Felistas Mwakalapa**.

ABSTRACT

Mapping the boundaries and distribution of reef corals, especially at growth form level, is an important coastal zone management step. Digitate and tabulate *Acropora* are growth forms of stone corals associated with abundance of reef fishes and are important in building reef framework. In this study boundaries of coral reefs and the distribution of digitate and tabulate *Acropora* around Bawe and Mnemba Islets, Zanzibar Island were mapped and results compared with environmental parameters. Data were collected by manta tow technique, line intercept transect, belt intersect transect, GPS unit and an underwater camera. Geo-referenced data was processed using ArcMap 9.3 software. The border line was set where live coral cover was above 5%. At the boundaries reef corals are intermixed with seagrasses, sand, rock and algal mats. The estimated area of coral reef was 1.9 km^2 at Bawe Island and 20 km^2 at Mnemba Island. Tabulate *Acropora* were aggregated on Bawe and Mnemba coral reefs, while digitate *Acropora* were aggregated on the reef flats, randomly distributed on Bawe and dispersed on Mnemba reef slopes. Small sized colonies of 11 to 40 cm and 21 to 60 cm diameters dominated the distributions of digitate and tabulate *Acropora* respectively. Higher contribution of digitate *Acropora* (2.07 cm) were observed in terms of coral cover as compared to tabulate *Acropora* (0.03 cm). The study also revealed that the distribution of tabulate and digitate *Acropora* is influenced by depth, turbidity and habitat type. This study provides useful information on the location and distribution of digitate and tabulate *Acropora* and provides recommendations for management and future studies on ecosystem changes and vulnerability.

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CHAPTER ONE

INTRODUCTION

1.1 General introduction

Coral reefs provide some of the most spectacular underwater scenery and marine life biodiversity in the world (Veron, 2000). Reef corals appear in different morphology which are genetically determined but also environmentally regulated (Williams, 2000). Coral growth forms somehow reflect environmental condition of where they occur (Reigl *et al.,* 1996). Various coral morphologies provide physical complexity of the reef thereby increasing habitat diversity niches which are the key driver to high biodiversity of coral reef ecosystems (Williams, 2000). Due to difficulties in species identification, scientists have conventionally grouped reef corals according to their dominant growth forms. Such growth forms include massive, branching, sub-massive, foliose, tabulate, digitate and encrusting corals (Williams, 2000).

The diversity and abundance of reef corals are affected by various factors including temperature, light, depth and exposure to waves and currents (Huston, 1985), sedimentation (Hubbard *et al.,* 1987; Dudley, 2003) and turbidity (Obura *et al.,* 2000). Coral diversity and abundance increase with increasing depth reaching maximum in between 15 to 30m of depth and then decrease further with increasing depth (Huston, 1985; IUCN Conservation Monitoring Centre, 1988). The extent of exposure to waves, currents and tides affects coral cover and diversity, coral growth form, size and species distribution (Huston, 1985). Sedimentation affects reef corals by impeding light penetration (Obura *et al.,* 2000), controlling their growth (Dudley, 2003) and affecting the structure, growth rate, size and colony morphology (Rogers, 1999; Muzuka *et al.,* 2010).

Reef corals' size frequency distribution in an ecosystem reflects past opportunities of coral recruitment, mortality, growth and development of each individual within a population (Elvira and Acosta, 2009). A whole range of sizes is expected for coral reef species in an ecosystem (Miller *et al.,* 2000). Size-frequency distribution in a particular habitat varies with species and the type, intensity, and frequency of disturbance to which the populations have been exposed (Gilmour, 2004). Coral size distribution can be used as an ecological indicator in evaluating the conditions and changes in the coral community (Bak and Meesters, 1998; Meesters *et al.,* 2001) and state of coral reef (Elvira and Acosta, 2009).

Genus *Acropora* (Oken, 1815) is the most successful of today's tropical reef-building corals found in all the three major oceans with greatest diversity in the Indo-Pacific region (White *et al.,* 2008). They have unique characteristics, such as fast growth (Bruckner, 2002), sensitivity to environmental changes especially temperature (Hoegh-Guldberg, 1999), vulnerability to predation by crown-of-thorns (COT) (Wilkinson, 2002; Ussi, 2009) while they act as pioneer species (Mergner, 1985; Muhando, 2003). *Acropora* corals exhibit different growth forms which are branching, sub-massive, digitate and tabulate (Boulon *et al.,* 2005). Digitate and tabulate *Acropora* are among the reef corals which are associated with abundant coral reef fishes (Aktani, 2003) and are important reef building corals (Wallace, 1978). Mapping of these reef corals is therefore important for management of fisheries resources.

Mapping of coral reef and essential fish habitats has been a major fisheries concern (Walker *et al.,* 2008). Many academic and government initiatives focus in mapping different marine resources such as coral reef, sea grasses and mangroves to produce distribution maps of organisms (Walker *et al.,* 2008). Several methods have been used in ecosystem mapping including remote sensing (Mumby *et al.,* 1995) and side scan sonar (Masson *et al.,* 1998). Both of these methods are able to discriminate major reef substrates but are not able to classify them as separate coral morphological groups or species (Chennal, 2000). Mapping of submerged features such as seagrass beds, algal beds and coral reefs is still challenging in Tanzania. In the existing maps of Tanzania, coral reef distribution is represented only as lines (Johnstone *et al.,* 1998; Muhando and Rumisha, 2008), hence not effective for management purposes. Therefore, detailed mapping including boundaries of coral reefs and distribution area of reef corals' growth forms is still needed.

Geographic information system (GIS) is a growing technology that represents features of earth on a computer and used to capture, visualize, question, analyze, manipulate and present geo-referenced data for understanding the world and human activities (Rolf *et al.,* 2001). Using GIS and a Global Positioning System (GPS) unit, the distribution pattern of the different coral growth forms can be mapped and correlated with various environmental factors (Reigl *et al.,* 1996), such interactive mapping has not been done before in Tanzania

In this study boundaries of coral reef, location and distribution of digitate and tabulate *Acropora* corals were mapped, the contribution and size frequency distribution of digitate and tabulate *Acropora* corals were quantified and the link between reef corals' growth form and environmental parameters was established.

1.2 Literature review

1.2.1 *Acropora* corals

The coral genus *Acropora* belongs to the family Acroporidae in the order Scleractinia (true stony coral). They grow fast and are one of the major reef framework builders (Wallace, 1978). *Acropora* corals form a dense thicket and contribute significantly to Island formation, coastal protection and fish habitat (Johnson *et al.,* 2011). Bruckner (2002) points out that the open structure of the dense populated *Acropora* corals thicket provides refuge and essential habitat for fishes, gastropods, turtles, lobster, crabs and echinoids. *Acropora* coral population has declined significantly throughout the Caribbean and western Atlantic since 1980s (Bruckner, 2002) and some species specifically *Acropora cervicornis* (Lamarck, 1816) (staghorn coral) and *Acropora palmata* (Lamarck, 1816) (elkhorn coral) have been listed as critically endangered species under the International Union for Conservation of Nature (IUCN) red-list in

2008 (Johnson *et al.,* 2011). The most severe threats to *Acropora* corals include but not limited to temperature-induced bleaching, crown-of-thorns predation and human induced threats (Muhando and Lanshammar, 2009; Johnson *et al.,* 2011).

1.2.2 Environmental factors affecting coral reef distribution

Coral reefs are distributed globally between 30° North and South of the equator. In a wider sense, global distribution of coral reefs is affected by temperature, of which their optimum levels range from 20°-30°C (Fang and Soong, 2004). At both regional and local scale, coral reef distribution is influenced by variety of environmental factors, including sedimentation, which affect coral reefs by impeding light penetration (Obura, 2000). Dudley (2003) and Muzuka *et al*., (2010) point out that sediments can actually control the growth and distribution of corals. For example, Williams (2000) speculates that high level of sedimentation combined with turbidity restrict the number of tabulate corals and increases relative abundance of massive, encrusting and branching corals. Additionally, Rogers (1999) points out that excessive sedimentation can adversely affect the structure and function of coral reef ecosystem by altering both physical and biological processes. Hubbard *et al.,* (1987) points out that coral reef growing in areas of lower sediments have more coral species, high coral cover and higher growth rates. Coral reefs distribution within 8 m of depth is also affected by the exposure to waves, currents and tides, whereby areas of high waves and swells have low coral cover and diversity (Huston, 1985).

1.2.3 Size frequency distribution of coral reefs

Size frequency distribution (SFD) has been used to assess the ecological status of population in a variety of ecosystems and recently has become extensively used to examine coral reefs (Zvuloni *et al.,* 2008). SFD may reflect the response of time-varying influences of the environment, including the intensity and frequency of disturbances and the degree of environmental degradation (Bak and Meesters, 1998). It may be used to infer growth potential and population responses upon environmental changes of reef corals (Barros and Pires, 2006). Its analysis may reveal important characteristics of population on the reef (Bak and Meesters, 1998). Several studies have shown positive skewness of the colony size distribution in many coral populations, with many small colonies and few large ones (Bak and Meesters, 1998; Meesters *et al.,* 2001). Positive skewness implies that a population is in a good state and growing since it includes abundance of juveniles. On the contrary, a negative skewness indicates lack of recent recruitment and therefore implies a risk of population decline (Meesters *et al.,* 2001). Victor *et al.,* (2009) used size frequency distribution to examine the development stage, recovery and environmental condition of corymbose *Acropora* colonies in Palau. Size is often linked with physiological performance and thus reflects many life processes including survival, maturation and fecundity (Meesters *et al.,* 2001) and therefore may provide predictive capacity to infer change in population (Bak and Meesters, 1998).

1.2.4 Coral reef mapping

Coral reef mapping using GIS approach is the technology of viewing the location, abundance and distribution of coral reefs with spatial geographic coordinates on a computer or other display units. There are different methods of mapping coral reef and other resources, including remote sensing using satellite data which produces images which are sometimes hard to interpret on biological and geomorphological basis (Mumby *et al.,*1995). Coral reef mapping has been used by managers and other stakeholders for assessing ecosystems at risk, developing mitigation strategies, decision making in management, monitoring and further research. GIS integrates data, hardware, software and GPS to assist in the analysis and display of geographically referenced information. It is a general term that refers to any scientific effort which integrates data to help researchers visualize, analyze, and explore geographically referenced information (Rolf *et al.,*2001). GIS is capable of producing maps that incorporate numerous layers of interdisciplinary data (Snow and Snow, 2008). GIS data presentation is often used as a tool for decision making concerning coral reefs at every level. us, GIS has a potential capability of reinforcing the process of coral reef protection and policy-making as well as long-term integrated resource management (US coral reef task force, 2000).

1.3 The statement of research problem

Digitate and tabulate *Acropora* have been associated with abundance of reef fishes and contribute substantially to coral reef framework. However, mapping of these growth forms and that of coral reef boundaries at local scale has not been well demonstrated in Tanzania. Furthermore, there is lack of knowledge regarding size or age structure and frequency of occurrence of digitate and tabulate *Acropora* and their linkage with the prevailing environmental factors, conservation and fisheries management.

1.4 Objectives

1.4.1 General objective

The main objective of this study was to map the distribution and relative contribution of tabulate and digitate *Acropora* corals in selected reefs of Zanzibar.

1.4.2 Specific objective

1. To map the boundaries of coral reefs in the selected areas.

2. To determine the locations, relative contribution and size frequency distribution of tabulate and digitate *Acropora* corals in the selected reefs.

3. To determine the relative extent of sedimentation, exposure to wave and current, water visibility (turbidity) and depth of the selected reefs.

1.5 Hypothesis

1. There is no significant difference in coral reef boundary or substrate characteristics between selected areas.

2. There is no significant difference in percentage cover and size frequency distribution of digitate and tabulate *Acropora* corals between reef flats and reefs slope between and within selected sites.

3. The distribution of tabulate and digitate *Acropora* corals in the selected sites is not significantly related to environmental parameters.

1.6 Significance of the study

This study delineates the boundaries of coral reef and provides information on size-frequency distribution of some *Acropora* coral groups. The study also determines the morphological diversity and abundance of *Acropora* corals. It also reveals the relationship between tabulate, digitate and other *Acropora* corals and how they are influenced by environmental factors such as depth, exposure to waves and currents and sedimentation. Findings from this study will therefore assist coastal resource managers in locating reef areas that are more susceptible to environmental stress and/or areas that require monitoring, research and decision making for management priorities. This study provides baseline information on the boundaries of coral reefs which will be useful in the future for assessment of change and for verification of image signals provided by satellite data.

CHAPTER TWO

METHODOLOGY

2.1 Description of the study sites

This study was conducted in Unguja Island in two representative areas on Bawe Island coral reefs and Mnemba Island coral reefs (Fig. 1). Bawe Island is located on the western part of Unguja Island off the Zanzibar Stone Town. The area is reported to be protected from the influence of ocean currents and waves (Mohamed *et al.,* 2002) and high sedimentation (Muzuka *et al* 2010). It is an open reef system with continuous reef flat and reef slope where fishing and tourism activities take place. Mnemba Island is a small Island located 2 km off the northeastern coast of Unguja Island. with the site is reported to be highly influenced with strong currents and waves (Ngoile, 1990). The reef flat on Mnemba Island is located on the northern side of the Island, it is shallow and is declared as a Marine Conservation Area (Bergman and Ohman, 2001) hence its coral reefs has no influence of human activities such as fishing except tourism. Mnemba Island reef slope is located on the southern part of the Island, it has steep slope and it is under the influence of fishing activities some of which are destructive ones (Bergman and Ohman, 2001).

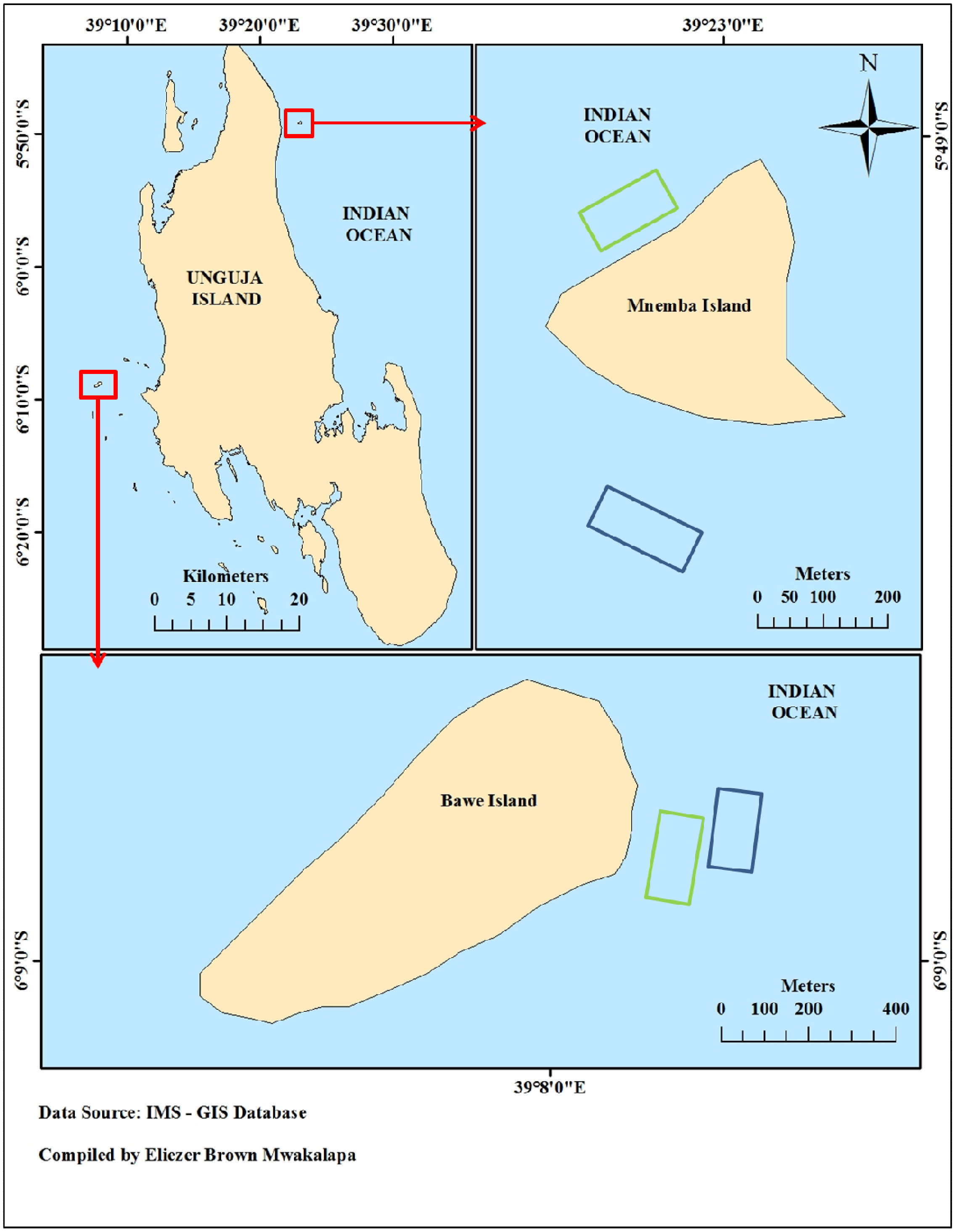

Figure 1: Map of Unguja Island showing locations of study areas. Green boxes are reef flat study areas and blue boxes are reef slope study areas.

2.2 Mapping of coral reef boundaries

Manta-tow technique and a GPS were used to map the boundaries of coral reef around Bawe and Mnemba Island. In each site two tows were made, one tow was made on the shallow water near the Island shoreline following the boundary of coral reefs and the adjacent habitat. The second tow was made following the boundary of the coral reefs at the end of a reef slope and the adjacent habitat. The observation was made from the surface where the swimmer with a GPS was towed by a boat at low speed following the boundary between coral reef and adjacent habitat. The GPS carried by the towed swimmer recorded the path taken by the swimmer, where the type of habitat and time interval between habitats bordering the coral reef was recorded by the swimmer. The adjacent habitat bordering the coral reefs on the upper and lower part of the coral reef were recorded. The demarcation between the coral reef and the adjacent habitat was identified to be area with less than 5% reef coral cover as a reasonable coral cover estimate used by Nadon and Stirling (2005).

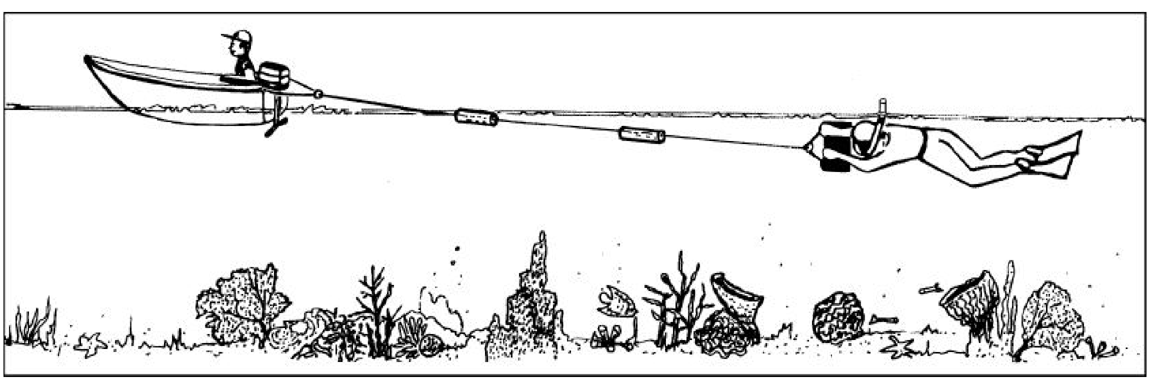

Figure 2: Manta tow technique. Adapted from English *et al*., (1994)

2.3 Identification and location of tabulate and digitate *Acropora*

Replicate belt transect of 2m x 50m long was used to determine the location and size of *Acropora* corals growth forms. Due to limited time, sampling was done on a single representative study area 50m x 100m on each of the selected reef habitats. A total number of eight belt transects 800 m^2 were conducted on the reef on each study site, four random belt transects on the reef flat and four random belt transect on the reef slope. On each belt transect an observer with a tape measure and a slate recorded the largest surface length of all *Acropora* corals encountered. An assistant holding a rope tied to a floating GPS took photos of the measured colonies, using a camera that was synchronized with GPS time. This was done in order to make sure that photos' time corresponded to the GPS location of the measured colonies.

2.4 Relative abundance of selected corals

On the selected representative study areas, Line Intercept Transect (LIT) method (English *et al.,* 1994) was employed to quantify relative abundance of the different benthos on coral reefs. On each site, 10m line transects were conducted with five random transect lines located on the reef flat habitat and five random transect lines located on the reef slope habitat. On each transect, the observer recorded the size of the coral colony and other substrate benthos which intersected the line. All coral colonies were identified to genus level while *Acropora* corals were further grouped into their growth forms. Other benthic substrate covers were grouped together in their functional groups, including algal turf, coralline algae, soft corals, sponges, calcareous algae, fleshy algae and sand. The observer also examined rugosity (reef complexity) by dividing total distance covered following the contour and the horizontal distance covered by the transect (Risk, 1972) in each sampled area for quantifying the complexity of the reef. At each site scuba diving equipments were used.

2.5 Environmental variables

Environmental variables including status of exposure of the reefs to ocean waves and currents, habitat type, turbidity and depth were determined at each study area on reef habitats of the selected sites. Status of exposure was evaluated visually by observing sand sediments on reef coral surface and also by taking photos of the reef coral surface for illustration of the presence or absence of sand particles on the reef coral corallite. Water current from strong oceanic currents help to keep sediment particles from settling on coral colony surfaces, and corals tend to spend less energy in sediment ejection (Rogers, 1990). The photos were used to determine whether the reef is exposed to strong water current and wave actions or not by visually differentiating the photos taken from each site (Dumas *et al.,* 2009).

The type of habitat was determined by physically examining the sediment size and visually assessing the associated organisms on the substrate. The observer physically examined the substrate sediments texture and taking photos of suspended sediments thrown by the observer in the water column. Visual assessment of the type of organisms on the substrate was done by taking photos of the substrate organism following Holt and Miller (2011). The photos were used to identify the organisms on the substrate and for qualifying the type of sediment of the reef as to whether the site had soft or hard substrate (Rogers, 1994; Dumas *et al.,* 2009). Photographs have become among the most popular method of coral reef monitoring (Hill and Wilkinson, 2004) and are sufficient to provide qualitative information to document the need for management actions (Rogers, 1994).

Turbidity or water visibility at each reef zone on selected reefs was measured by using Secchi disk, which was towed horizontally following Rushingisha (2012), whereby an observer held one end of the Secchi disk and an assistant held another end and then the distance between the observer and the assistant was recorded.

Depth ranges of the sampling areas (reef flat and reef slope) were measured using a handheld echo sounder and a scuba depth meter and the depth ranges were recorded during the surveying campaign.

2.6 Data analysis

The relative abundance data and environmental data were entered into a computer and organized into Microsoft Excel spread sheet files. Ecological data were first tested for normality using Shapiro-Wilk W Test. Benthic cover, turbidity and *Acropora* coral data did not meet the normality test requirement and therefore non-parametric Mann-Whitney tests were used to test for the differences between and within reef categories. Size frequency distribution parameters (mean size, standard deviation, mode, skewness and coefficient of variation) were calculated.

Mapsource software version 6.13.7 was used to download the recorded data from the GPS, where they were converted and exported as GPX files. The GPX files were uploaded in to the Quantum GIS software where they were converted to Arcmap compatible shape files. All spatial analysis of the collected data were carried out in GIS software ArcMap version 9.3. For each site, GIS derived maps showing the boundaries of coral reef, the distribution patterns and abundance of tabulate and digitate *Acropora* corals were produced.

STATISTICA 7 statistical software was used to analyze the relative abundance data collected where Mann-Whitney U test was employed to test if there were differences in reef communities' benthic cover and *Acropora* corals between and within reef. The Kolmogorov-Smirnov test (K-S test) was used to test for differences in size-frequency distributions.

CHAPTER THREE

RESULTS

3.1 Boundaries of coral reef in selected areas

Coral reefs on the Island side of Bawe were bordered by seagrasses covering 0.74 km on the northwest and 0.61 km on the southern parts of the Island, sand extending 0.37 km on the northern part of the Island. Rocky substrate covered 0.72 km on the eastern and 0.74 km of the southwestern part. Rocky and sand extended 0.24 km on the eastern part and erect algae covered 0.21 km and 0.69 km on the south eastern and southern part respectively (Fig. 3). Coral reefs at the end of Bawe reef slopes were boarded by sand (Fig. 3).

Mnemba coral reefs adjacent habitat features were different from those found on Bawe. Corals on Mnemba Island side were bordered by 2.22 km of sand and 1.40 km of seagrasses, while the boundary at the end of reef slope was bordered by 15.38 km of sand and 2.69 km of seagrasses (Fig. 4). In GIS the spatial analysis of boundaries of coral reefs revealed that Mnemba Island reefs covered an area of about 20 km^2 compared to 1.9 km^2 of Bawe Island reefs.

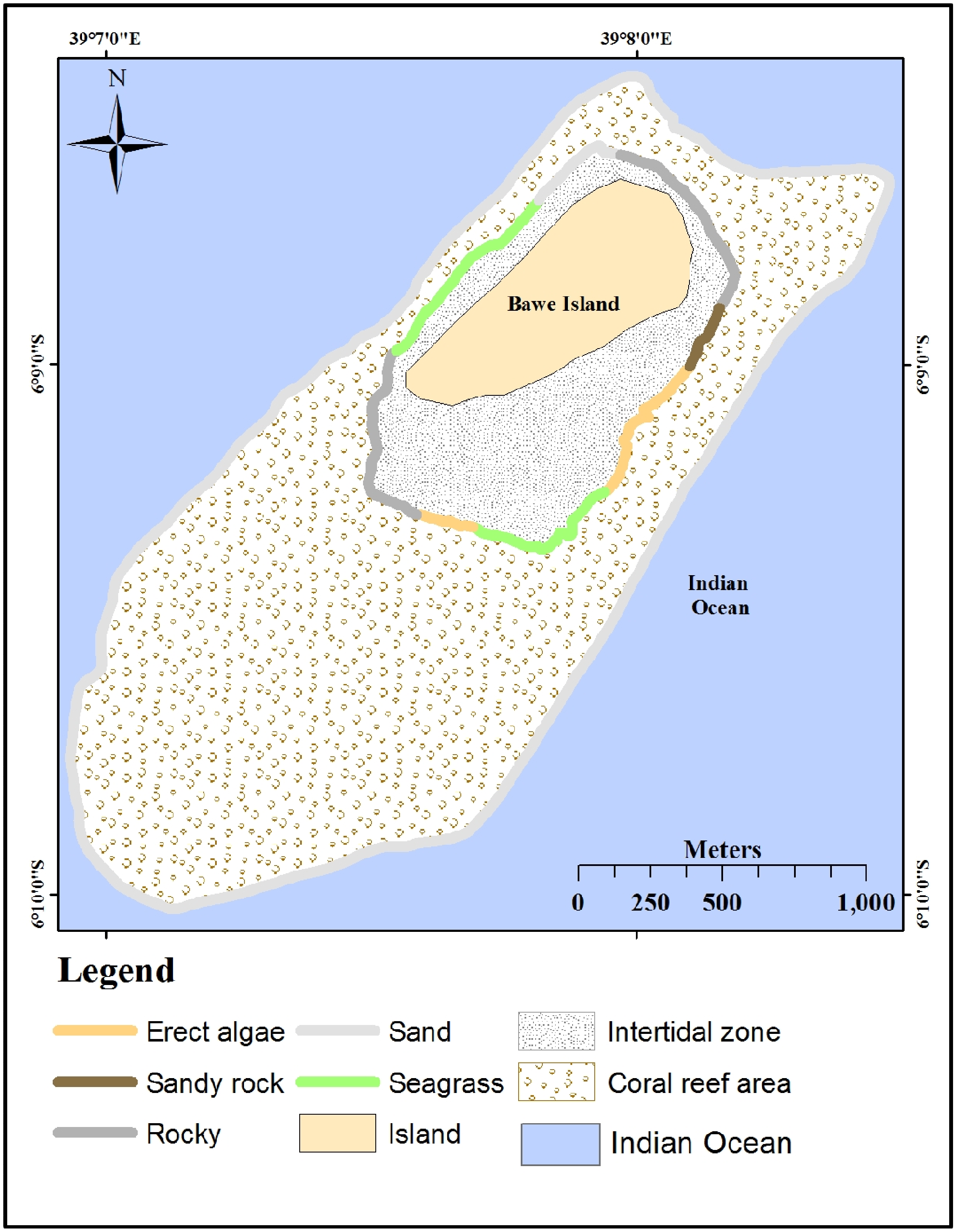

Figure 3: A map showing benthic features adjacent to inner and outer boundaries of coral reefs of Bawe Island.

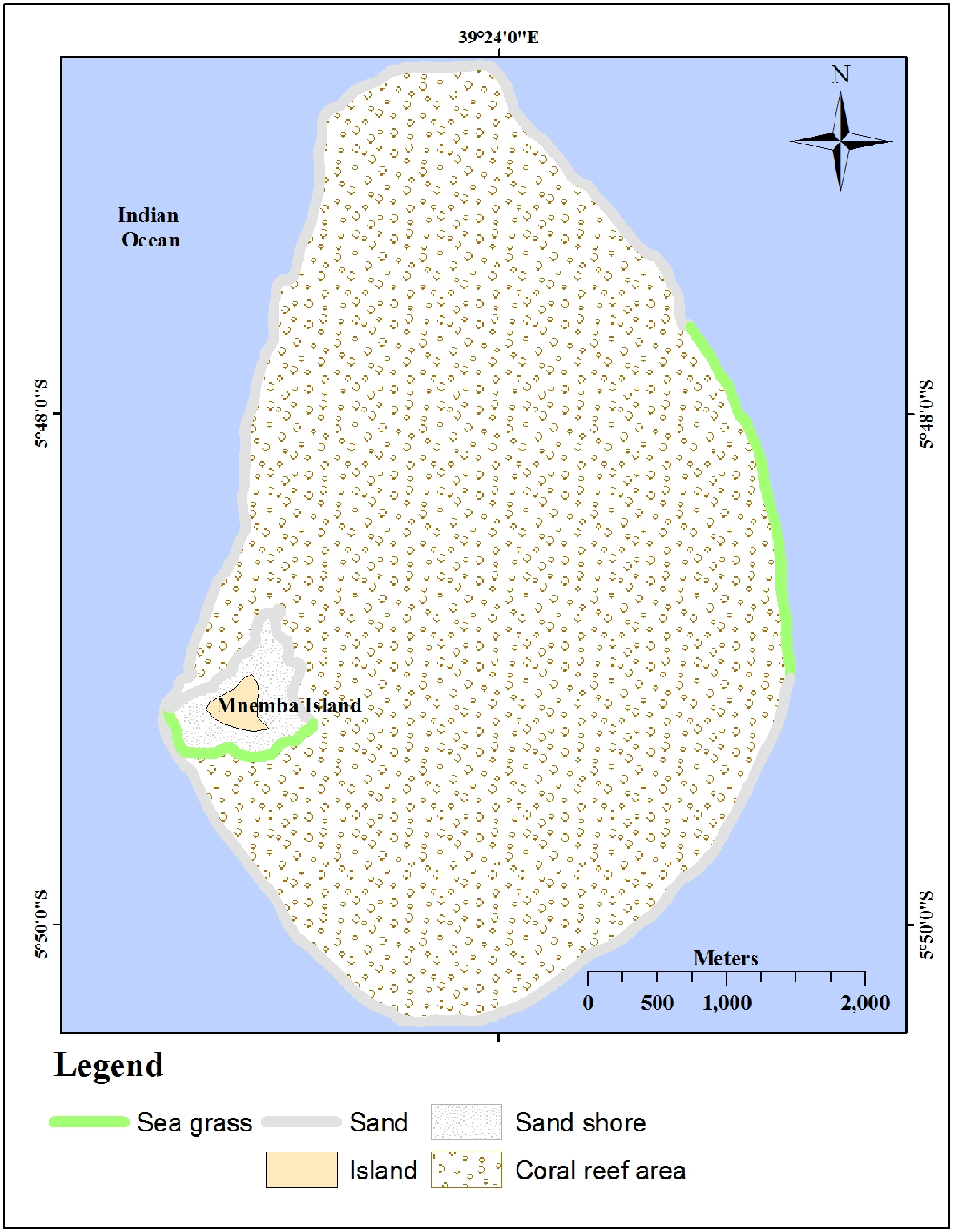

Figure 4: A map showing benthic features adjacent to the outer and inner boundaries of coral reefs of Mnemba Island

3.2 Reef benthic community

3.2.1 Reef benthic composition

Hard corals and algal turfs were the dominant features on Bawe reef and Mnemba reef flat, while soft coral and algal turf dominated Mnemba reef slope (Fig. 5). Mnemba reef slope had higher covers of calcareous algae, fleshy algae, soft corals, sand and sponges as compared to Mnemba reef flat which had higher covers of hard corals and algal turf (Fig. 5, Table 1). Mnemba reef slope had significantly higher covers of calcareous algae, fleshy algae, soft corals and sponges than Bawe reef slope which had higher cover of hard corals (Table 3). Hard corals and sand were significantly higher on Bawe reef flat as compared to Mnemba reef flat (Table 4). Reef complexity was more on Bawe reef slope as compared to Mnemba reef slope (Mann-U test: $U=0$, $p= 0.012$, Fig. 6). Mnemba reef flat complexity was significantly higher than Mnemba reef slope (Mann-U test: $U=0$, $p= 0.009$, Fig. 6). Other reef complexity comparison did not show significant differences (Tables 2 and 4).

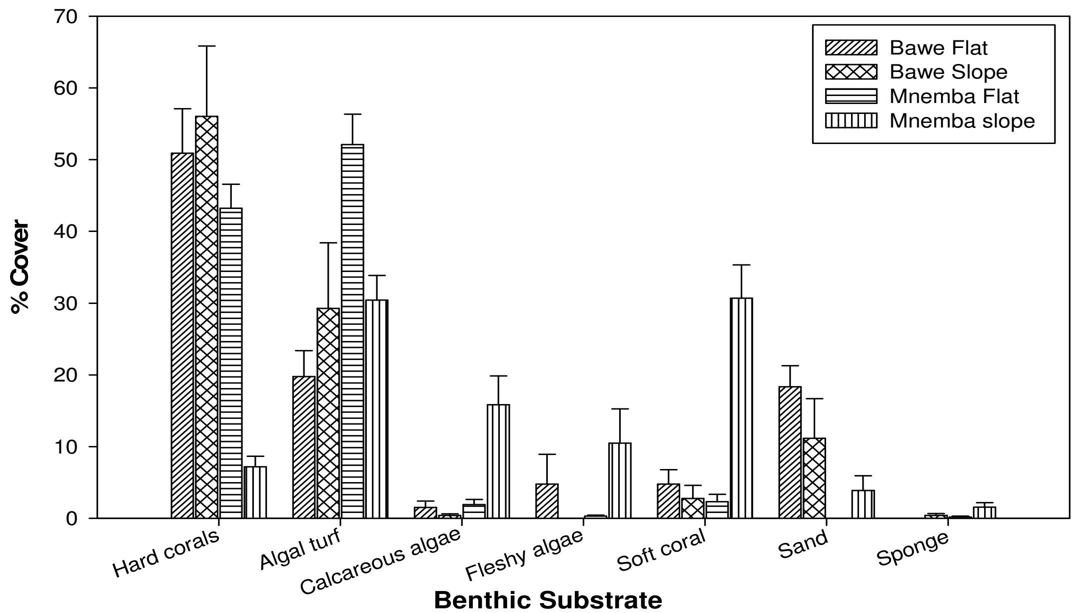

Figure 5: Mean percentage cover (±SE) of different substrate groups on Mnemba and Bawe reef habitats.

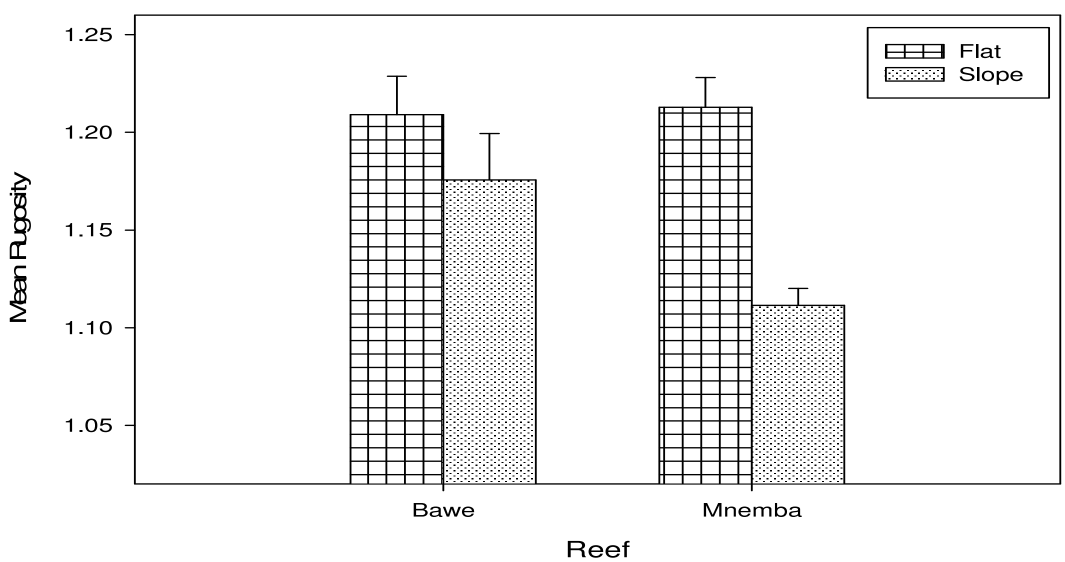

Figure 6: Mean (±SE) rugosity on Bawe and Mnemba reef habitats.

Table 1: Results of Mann-Whitney U test for differences in percentage cover of substrate categories between Mnemba reef flat and slope.

Substrate	Mnemba reef flat		Mnemba reef slope			
	Mean	SE	Mean	SE	U	P-value
Hard Coral	43.24	3.35	7.18	1.47	0	**0.009**
Algal Turf	52.09	4.25	30.42	3.44	1	**0.016**
Calcareous algae	1.92	0.69	15.82	4.02	0	**0.009**
Fleshy algae	0.29	0.13	10.47	4.77	0	**0.009**
Soft coral	2.30	1.04	30.69	4.64	0	**0.009**
Sand	0.00	0.00	3.86	2.09	0	**0.009**
Sponge	0.16	0.16	1.56	0.59	2	**0.028**
Rugosity	1.21	0.02	1.11	0.01	0	**0.009**

Table 2: Results of Mann-Whitney U test for differences in percentage cover of substrate categories between Bawe reef flat and slope.

Substrate	Bawe reef flat		Bawe reef slope			
	Mean	SE	Mean	SE	U	P-value
Hard Coral	50.88	6.21	52.28	8.82	11	0.754
Algal Turf	19.77	3.61	27.95	7.56	8	0.347
Calcareous algae	1.5	0.92	0.37	0.23	10	0.676
Fleshy algae	4.77	4.13	3.53	3.53	8	0.296
Soft coral	4.77	1.99	2.46	1.51	8	0.347
Sand	18.31	2.99	12.57	4.71	7	0.251
Sponge	0.00	0.00	0.33	0.22	5	0.117
Rugosity	1.18	0.02	1.22	0.02	8	0.347

Table 3: Results of Mann-Whitney U test for differences in percentage cover of substrate categories between Bawe and Mnemba reef slopes.

Substrate	Bawe reef slope		Mnemba reef slope			
	Mean	SE	Mean	SE	U	P-value
Hard Coral	52.28	8.82	7.18	1.47	0	**0.009**
Algal Turf	27.95	7.56	30.42	3.44	9	0.465
Calcareous algae	0.36	0.23	15.82	4.02	0	**0.009**
Fleshy algae	3.53	3.53	10.47	4.77	0	**0.009**
Soft coral	2.46	1.51	30.69	4.64	0	**0.009**
Sand	12.57	4.71	3.86	2.09	9	0.465
Sponge	0.33	0.22	1.56	0.59	3	**0.047**
Rugosity	1.22	0.02	1.11	0.01	1	**0.012**

Table 4: Results of Mann-Whitney U test for differences in percentage cover of substrate categories between Bawe and Mnemba reef flats.

Substrate	Bawe reef flat		Mnemba reef flat			
	Mean	SE	Mean	SE	U	P-value
Hard Coral	50.88	6.21	43.24	3.35	8	0.347
Algal Turf	19.77	3.61	52.09	4.25	0	**0.009**
Calcareous algae	1.5	0.92	1.92	0.69	9.5	0.531
Fleshy algae	4.77	4.13	0.29	0.13	12	0.917
Soft coral	4.77	1.99	2.30	1.04	9	0.465
Sand	18.31	2.99	0.00	0.00	0	**0.009**
Sponge	0.00	0.00	0.16	0.16	10	0.602
Rugosity	1.18	0.02	1.21	0.02	7	0.251

3.2.2 Coral genera richness

A total number of 28 coral genera were encountered in this study. The genera richness was highest on Bawe reef slope (18 genera) followed by Bawe reef flat (17 genera), Mnemba reef flat (15 genera) and was lowest on Mnemba reef slope (12 genera), (Figs. 7 - 10). *Synarea* (41%), *Acropora* 14.5%, *Hydnophora* (10.73%) and massive *Porites* (6.39%) dominated Bawe reef slope benthic cover (Fig. 7). Bawe reef flat was dominated by *Synarea* (23.53%) followed by *Galaxea fascicularis* (22.78%), *Porites branching* (21.87%) and *Acropora* contributing 9.6% (Fig. 8). Mnemba reef flat was dominated by *Acropora* (25.8%) followed by *Pocillopora* (17.37%) and *Porites massive* (10.27%), (Fig. 9). Mnemba reef slope was dominated by *Porites massive* (63.39%), followed by *Pocillopora* (10.72%) and *Pavona* (5.80%). *Acropora* showed the least dominance on Mnemba reef slope contributing only 0.89% of the benthic cover (Fig. 10).

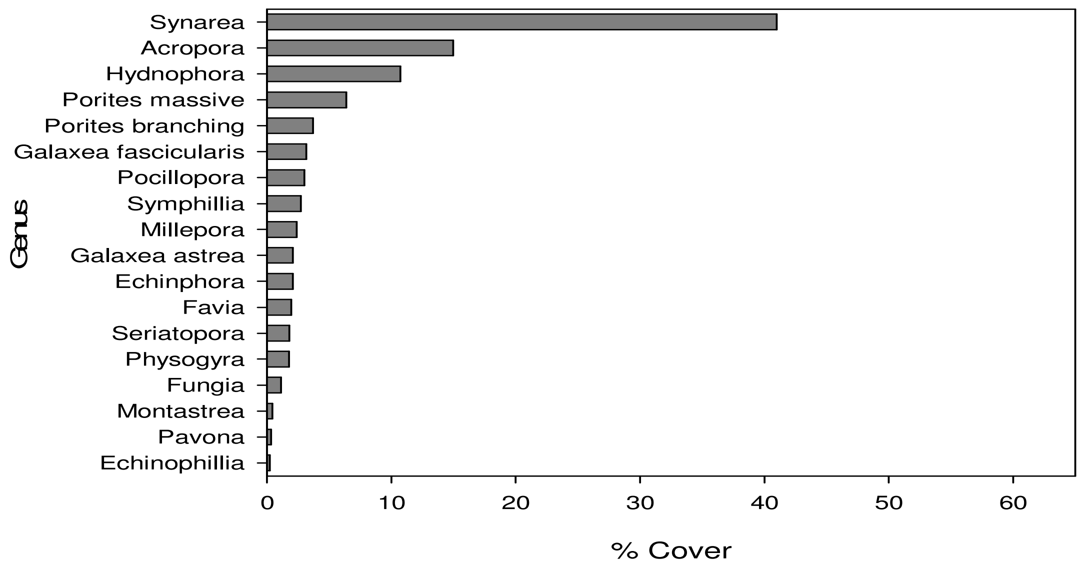

Figure 7: Percent coral genera cover on Bawe reef slope.

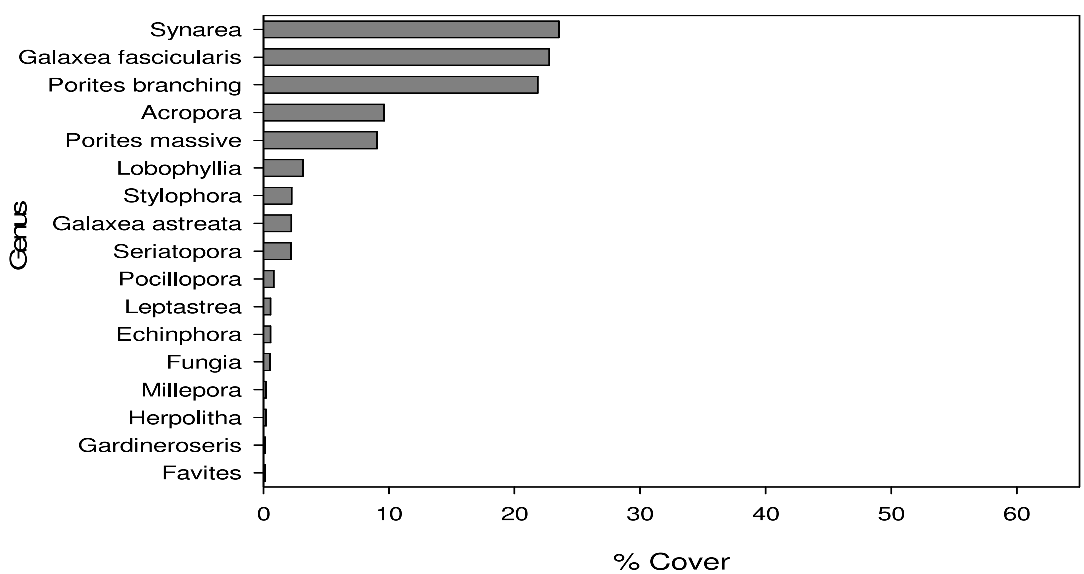

Figure 8: Percent coral genera cover on Bawe reef flat.

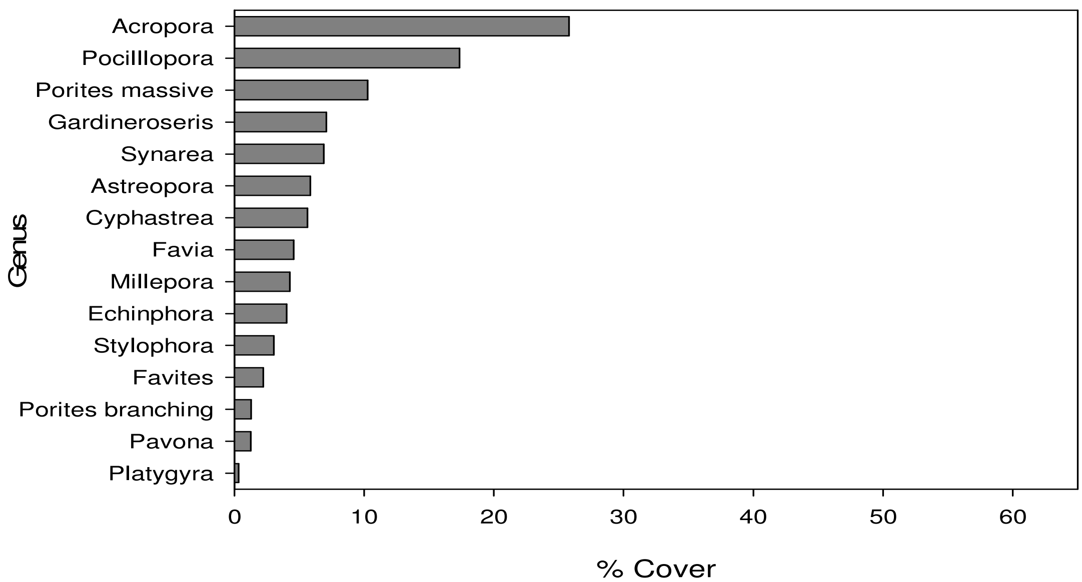

Figure 9: Percent coral genera cover on Mnemba reef flat.

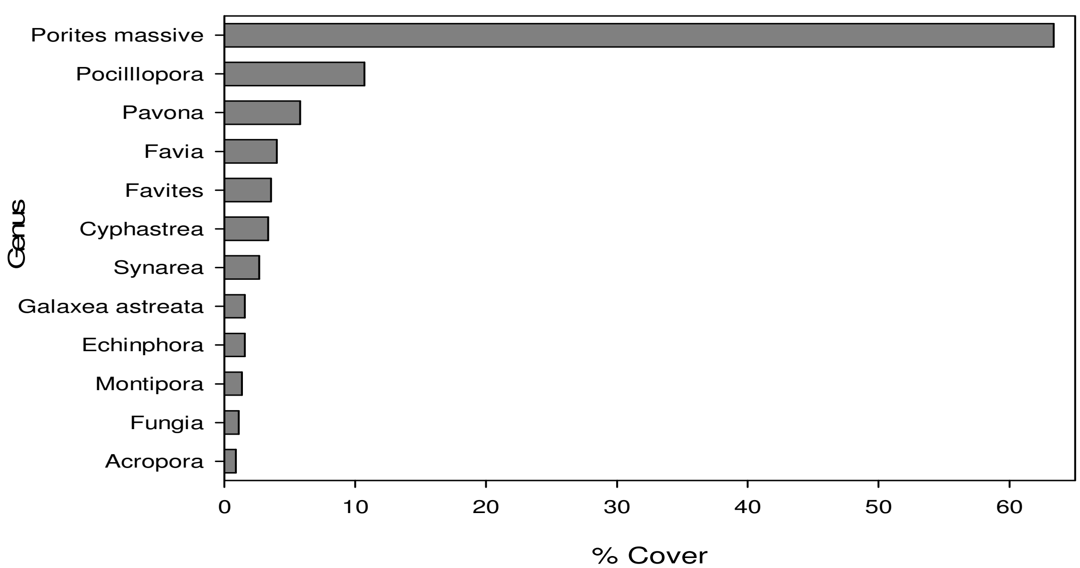

Figure 10: Percent coral genera cover on Mnemba reef slope.

3.3 Distribution of digitate and tabulate *Acropora* corals

Locations and distribution patterns of digitate and tabulate *Acropora* corals on the selected sampling plots on reef habitats of Bawe and Mnemba Islands are shown in Figs. 11 and 12. Spatial analysis (ArcMap Spatial Analyst) revealed an aggregated distribution pattern of digitate and tabulate *Acropora* with digitate *Acropora* being highly aggregated (Z-score= -4.14, p= <0.00001) than tabulate *Acropora* (Z-score= -2.26, p= 0.0235) on Bawe reef flat (Fig. 11A). On the reef slope, digitate *Acropora* were randomly distributed (Z-score= 1.7, p= 0.0892) and tabulate *Acropora* corals were aggregated (Z-score= -5.83, p= <0.00001, Fig. 11B). On Mnemba reef flat high aggregated digitate *Acropora* (Z-score= -2.96, p= 0.0031) and low aggregated tabulate *Acropora* corals (Z-score= -2.46, p= 0.0138) were observed (Figs. 12A). On Mnemba reef slope where tabulate *Acropora* were not encountered, digitate *Acropora* were highly dispersed (Z-score= 27.38, p= < 0.00001, Fig. 12B).

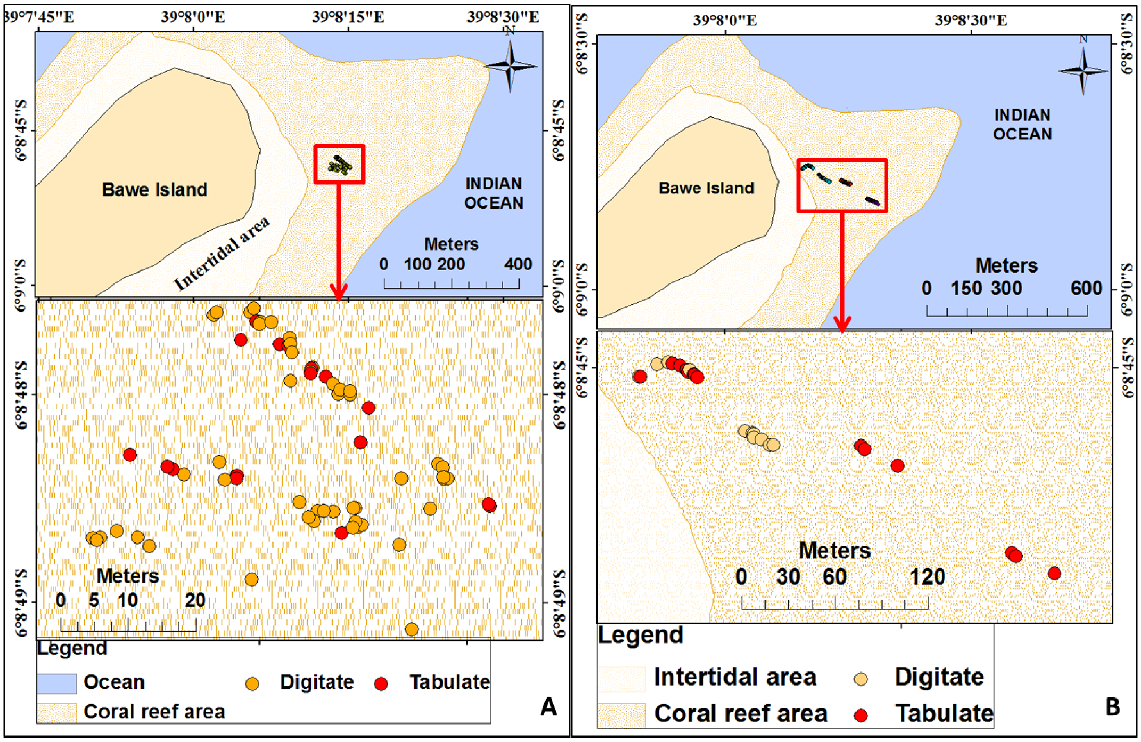

Figure 11: Location and distribution patterns of tabulate and digitate *Acropora* corals on Bawe reef flat (A) and Bawe ref slope (B).

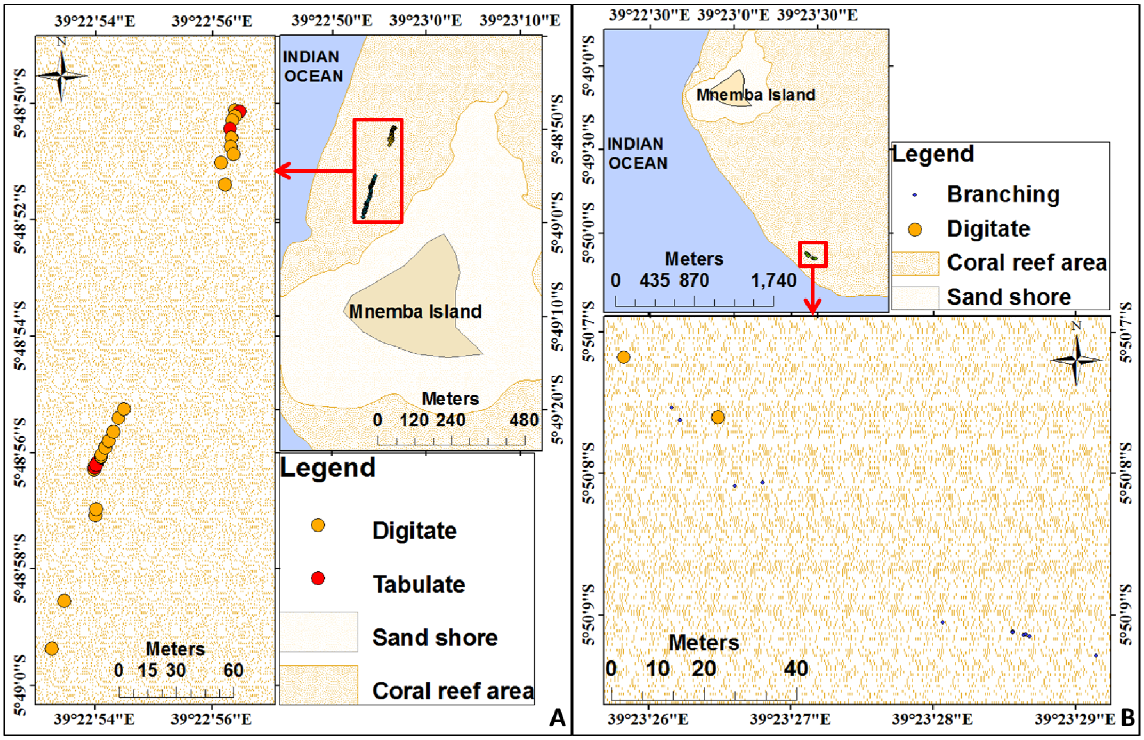

Figure 12: Location and distribution patterns of digitate and tabulate *Acropora* corals on Mnemba reef flat (A) and Mnemba reef slope (B).

3.4 Abundance and relative contribution of digitate and tabulate *Acropora*

3.4.1 Numerical contribution of *Acropora* corals, digitate and tabulate *Acropora*.

Total number of coral colonies encountered in this study was 330. Highest number of colonies were found on Bawe reef slope (104 colonies) followed by Mnemba reef flat (97 colonies), Bawe reef flat (88 colonies) and 41 colonies on Mnemba reef slope. The contribution of *Acropora,* in terms of number of colonies was highest on Mnemba reef flat (24.74%), followed by Bawe reef slope (21.15%), Bawe reef flat (11.36%) and was lowest on Mnemba reef slope (2.44%), (Fig. 13). The results also revealed that *Acropora* growth forms on Bawe reef flat were dominated by branching *Acropora* (56.10 %), followed by digitate *Acropora* (30.49%) and tabulate *Acropora* (10.98%), (Fig. 14A). On Bawe reef slope *Acropora* were dominated by branching *Acropora* (86.18%) followed by tabulate *Acropora* (7.37%) and digitate *Acropora* (5.53%, Fig. 14B). Sub-massive *Acropora* was the least dominant growth form on both Bawe reef flat (2.44%) and reef slope (0.92%), (Figs. 14A and B). Mnemba reef flat was dominated by sub-massive *Acropora* (54.82%) followed by branching *Acropora* (30.02%), digitate (10.96%) and tabulate *Acropora* (2.19%), (Fig. 14C). Mnemba reef slope was only dominated by two *Acropora* corals, branching *Acropora* with high percentage (84.62%) followed by digitate *Acropora* (15.38%), (Fig. 14D).

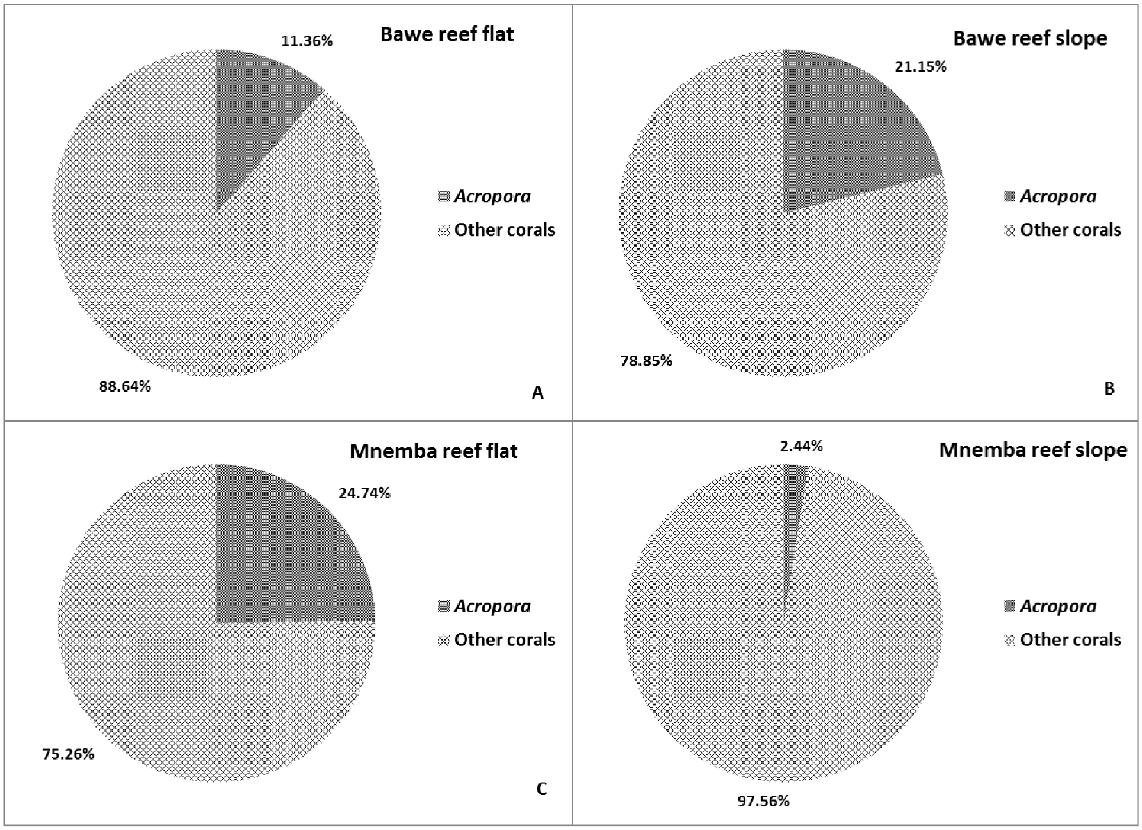

Figure 13: Numerical abundance of *Acropora* corals on reef habitats of Bawe and Mnemba reefs.

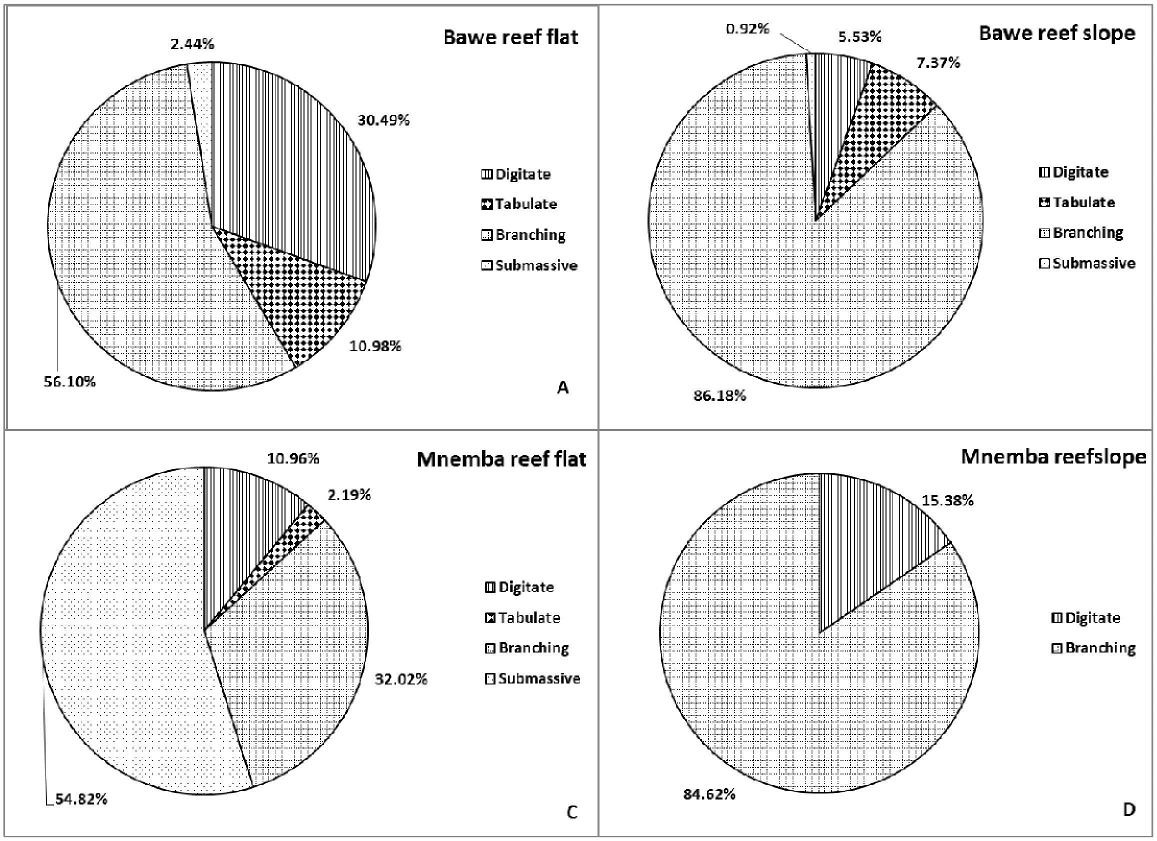

Figure 14: The numerical percentage dominance of *Acropora* growth form on Mnemba and Bawe reef habitats.

3.4.2 Percentage cover of *Acropora* corals, digitate and tabulate *Acropora* corals

Acropora cover was significantly higher on Bawe reef slope than on Mnemba reef slope (Man-U test; U=2, p= 0.028, Fig. 15). Whereas tabulate *Acropora* cover had no differences between reef slope habitats, digitate *Acropora* cover had higher cover on Bawe reef slope than Mnemba reef slope (Man-U test; U=0, p= 0.009, Fig. 15). There was no significant difference on reef flat habitats (Table 5).

Within reef comparison showed that *Acropora* corals, digitate and tabulate *Acropora* corals (Figs. 15 and 16) had higher covers on Mnemba reef flat compared to reef slope (Man-U test; U=3, p= 0.047), (Man-U test; U=3, p= 0.047) and (Man-U test; U=2.5, p= 0.037) respectively. No statistical difference was seen between reef flat and reef slope on Bawe reef (Table 6).

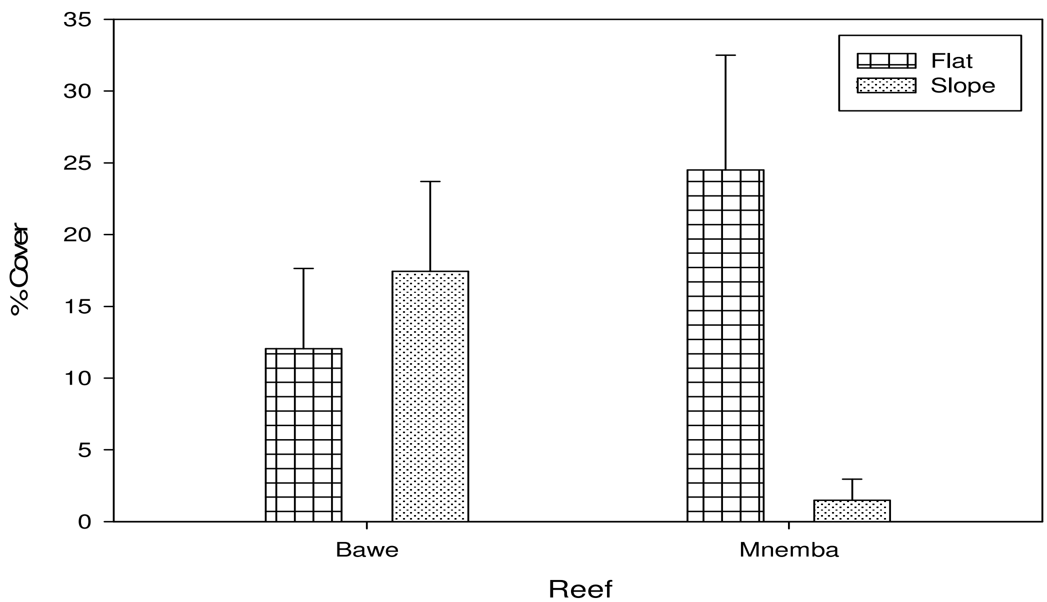

Figure 15: The percentage cover (±SE) of *Acropora* corals on Bawe and Mnemba reef habitats.

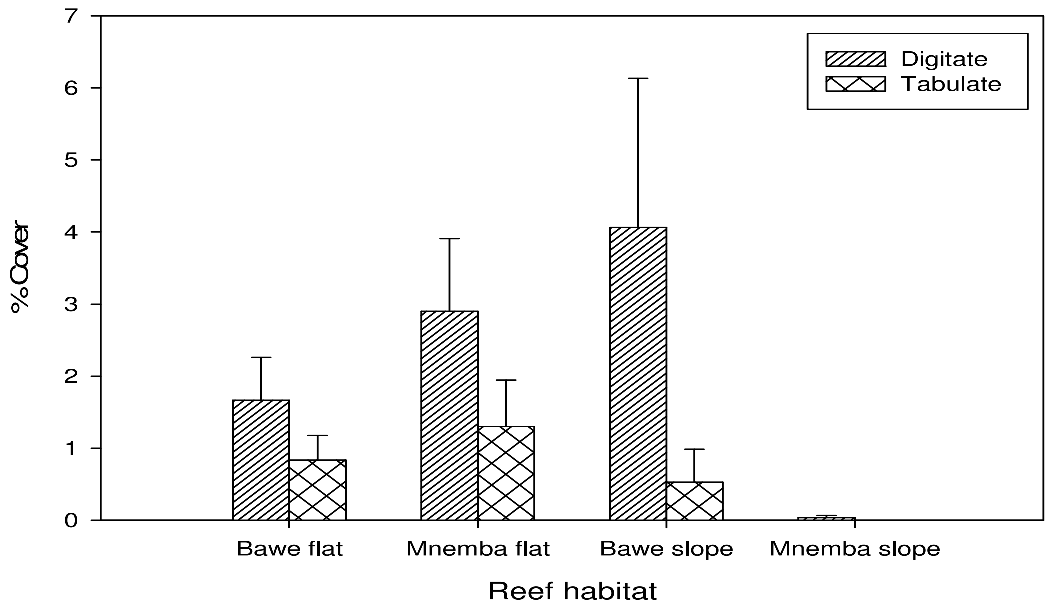

Figure 16: The Percentage (±SE) cover of digitate and tabulate *Acropora* corals on Mnemba and Bawe reef habitats.

Table 5: Results of Mann-Whitney U test for differences in percentage cover of hard coral and *Acropora* corals between Bawe and Mnemba reefs.

	Bawe		Mnemba		Mann-U test	
Reef flat	Mean	SE	Mean	SE	u	P-value
Acropora	12.04	5.60	24.51	7.98	7.5	0.296
Digitate	1.67	0.59	2.90	1.01	3	0.296
Tabulate	0.83	0.34	1.30	0.65	2.5	0.917
Reef slope						
Acropora	17.43	6.27	1.48	1.48	2	**0.028**
Digitate	4.06	2.07	0.03	0.03	0	**0.009**
Tabulate	0.53	0.46	0.00	0.00	7.5	0.296

Table 6: Results of Mann-Whitney U test for differences in percentage cover of hard corals and *Acropora* corals within Bawe and Mnemba reefs.

	Flat		Slope		Mann-U test	
Bawe	Mean	SE	Mean	SE	u	P-value
Acropora	12.04	5.60	17.43	6.27	11	0.754
Digitate	1.67	0.59	4.06	2.07	9	0.465
Tabulate	0.83	0.34	0.53	0.46	10	0.602
Mnemba						
Acropora	24.51	7.98	1.48	1.48	3	**0.047**
Digitate	2.90	1.01	0.03	0.03	3	**0.047**
Tabulate	1.30	0.65	0.00	0.00	7.5	**0.037**

3.5 Size frequency distribution of digitate and tabulate *Acropora* corals

3.5.1 Size frequency distribution

The size frequency distribution of digitate *Acropora* showed dominance of small colony sizes of (21-50 cm) on Bawe reef flat, (21-40 cm) on Bawe reef slope and (11-40 cm) on Mnemba reef flat as shown by the peaks on (Figs. 17 and 18). Mnemba reef slope had only small colonies of 10 and 30 cm (Fig. 18). Bawe reef slope had more distributions of small sized colonies of digitate *Acropora* with high positive skewness (2.66) compared to Mnemba reef slope (K-S test; p= 0.022, Fig. 18). Similar size frequency distribution of digitate *Acropora* with positive skewness was observed on other reef habitats (Figs. 17, 19 and 20). Size frequency distribution of tabulate *Acropora* corals showed dominance of small colony sizes of (21-60 cm) on both Bawe reef flat and slope (Fig. 21). On Mnemba reef flat same frequency of occurrence of medium sized (41-100 cm) of tabulate *Acropora* were observed (Fig. 22). Tabulate *Acropora* were not found on the reef slope. Small sized colonies of tabulate *Acropora* with positive skewness (1.4) on reef flat and (1.21) on reef slope were revealed on Bawe reef (Fig. 21). More small sized colonies of tabulate *Acropora* with positive skewness (1.40) were observed on Bawe reef flat than on Mnemba reef flat (K-S test; $p = 0.019$, Fig. 22).

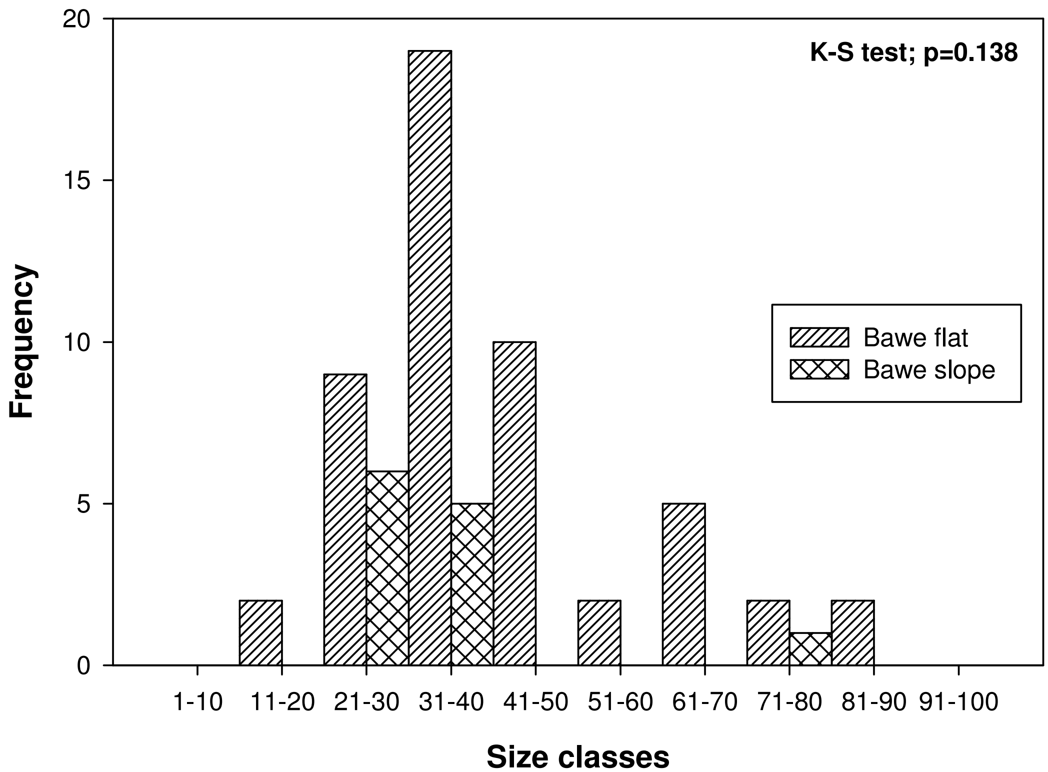

Figure 17: Size frequency distribution of digitate *Acropora* corals on Bawe reef flat and reef slope.

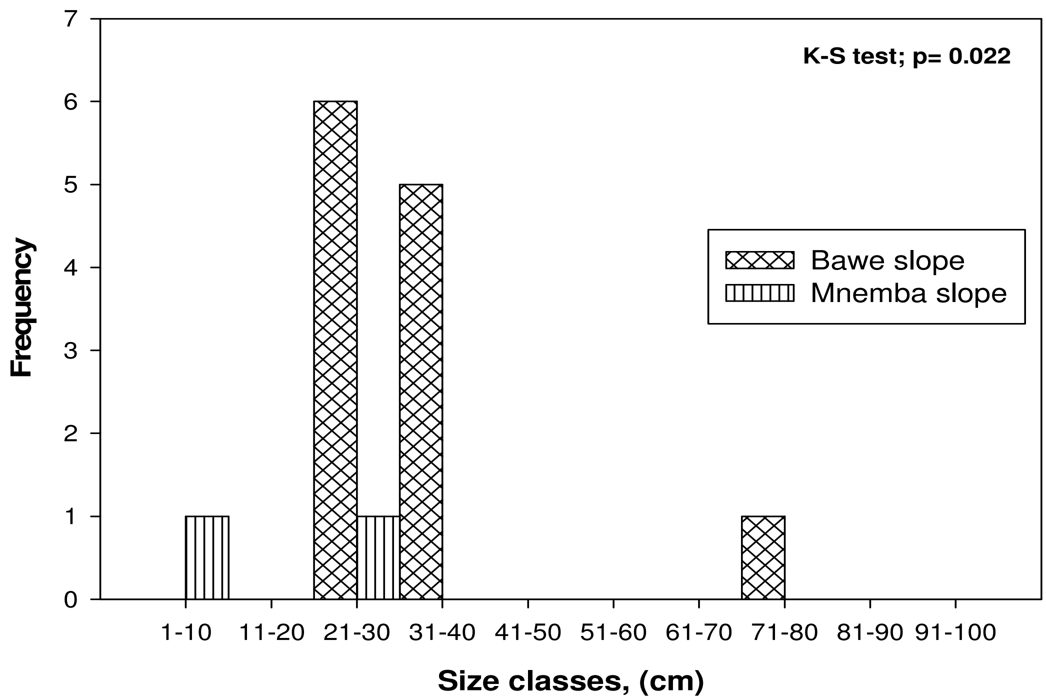

Figure 18: Size frequency distribution of digitate *Acropora* corals on Bawe reef slope and Mnemba reef slope.

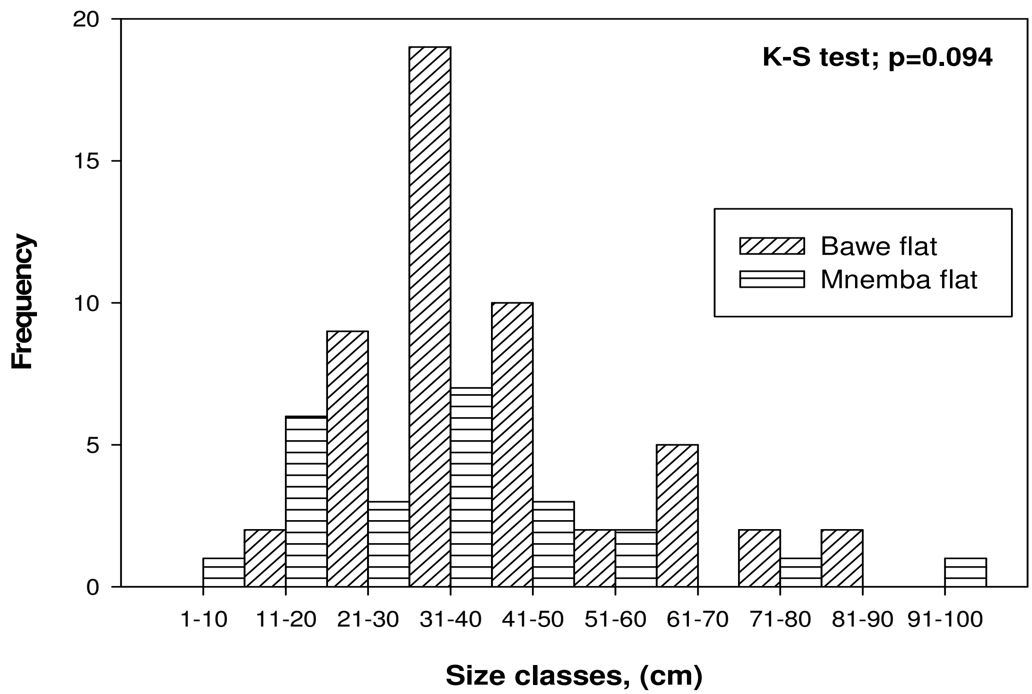

Figure 19: Size frequency distribution of digitate *Acropora* corals on Bawe reef flat and Mnemba reef flat.

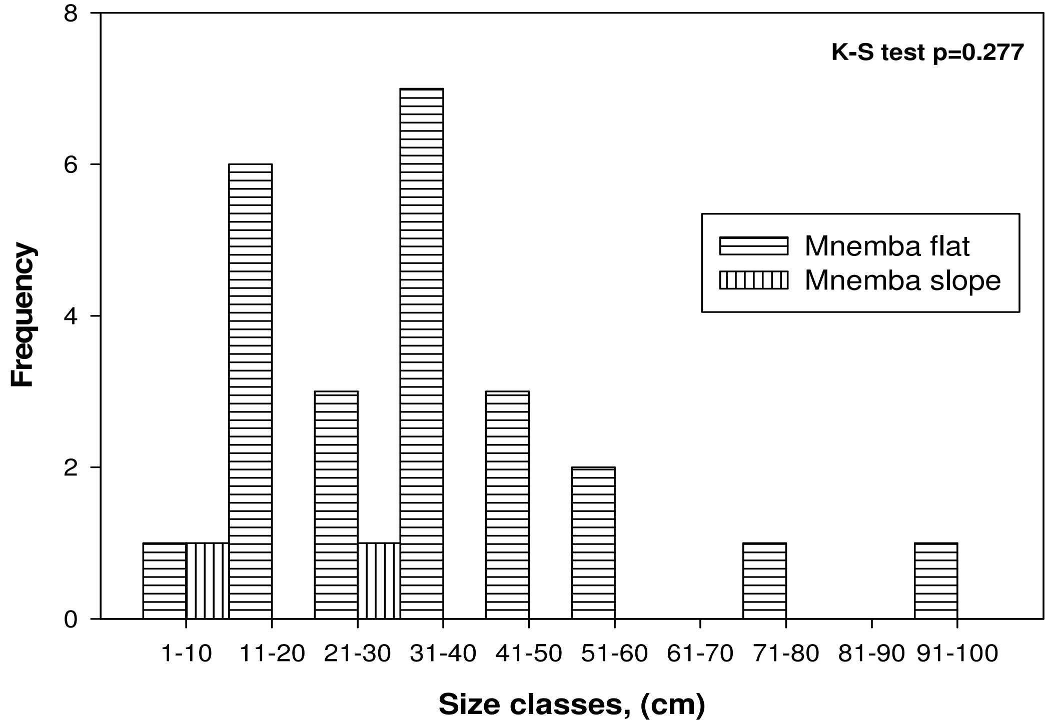

Figure 20: Size frequency distribution of digitate *Acropora* corals on Mnemba reef flat and reef slope.

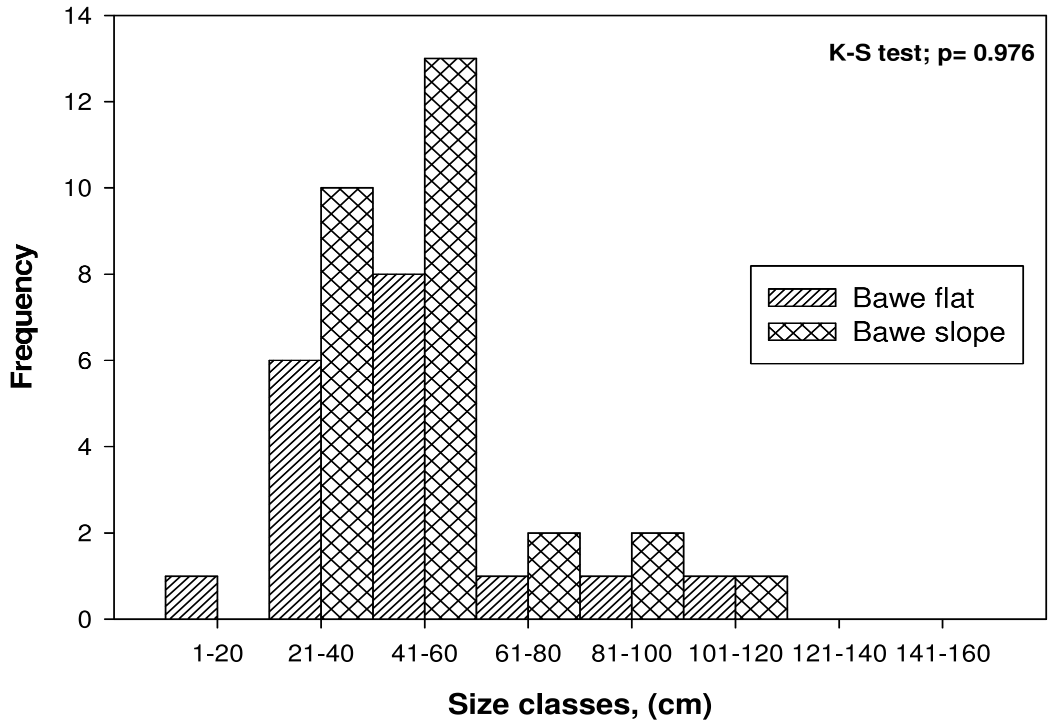

Figure 21: Size frequency distribution of tabulate *Acropora* corals on Bawe reef flat and Bawe reef slope.

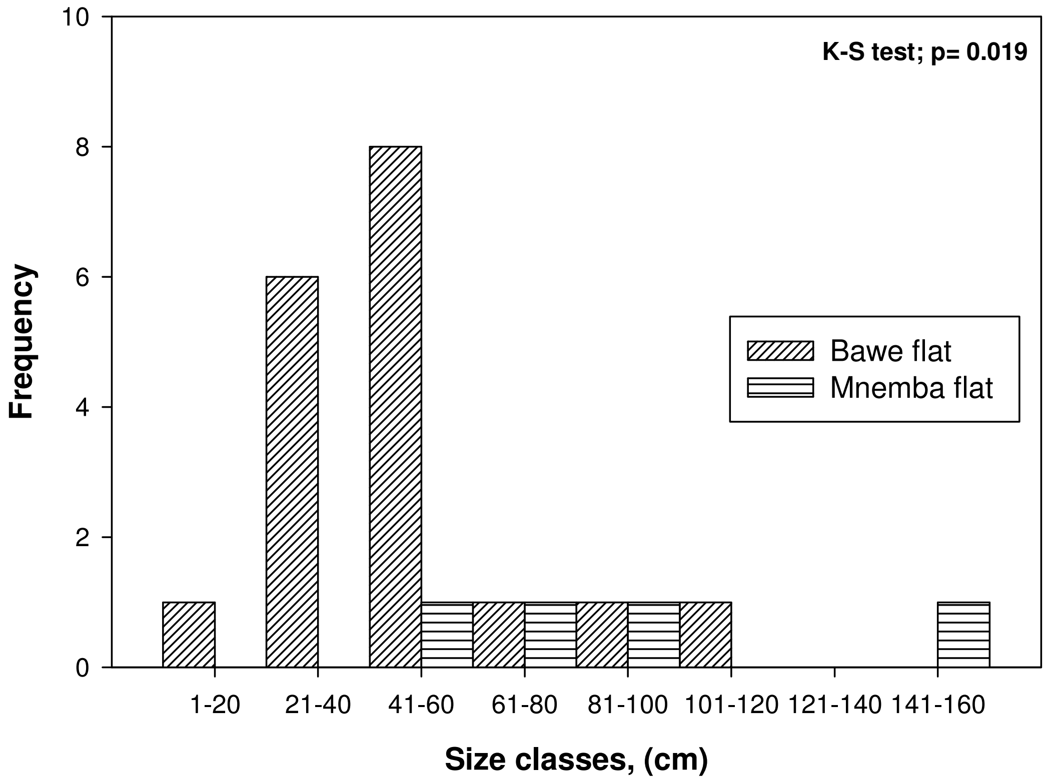

Figure 22: Size frequency distribution of tabulate *Acropora* corals on Bawe reef flat and Mnemba reef flat.

3.5.2 Mean and mode colony sizes

Digitate *Acropora* corals had a mean colony size of 41.84 cm on Bawe reef flat with commonest colony size of 31 cm corresponding to size classes 21-30 cm (Table 7, Fig 23). Bawe reef slope had mean colony size of 34.17 cm with commonest colony size of 30 cm corresponding to size class 31-40 cm. The mean colony size on Mnemba reef flat was 35.71 cm with commonest colony size of 39 cm corresponding to size class 31-40 cm. Mnemba reef slope had mean colony size of 14 cm with no commonest colony size (Table 7, Fig. 23). Differences in mean colony size was observed between Bawe reef slope and Mnemba reef slope (Man-U test; U=24, p= 0.022, Table 8) and between Bawe reef flat and slope (Man-U test; U=422, p= 0.041, Table 9).

Mean colony size of tabulate *Acropora* was 47.5 cm with commonest colony size of 43 cm on Bawe reef flat and 50.25 cm with commonest colony size of 44 on reef slope all corresponding to size class 41-60 cm. Mnemba reef flat had 92.25 cm mean colony size with no commonest colony size while reef slope had no tabulate *Acropora* (Table 7, Fig. 23). Tabulate *Acropora* mean colony size was significantly higher on Mnemba reef flat than on Bawe reef flat (Man-U test; U=7, p= 0.010, Table 8).

Table 7: Size frequency distribution of tabulate and digitate *Acropora* on Bawe and Mnemba reefs.

Site	Growth form	N	Mean size (cm)	SD	Mode (cm)	Skewness	Coeff. of variation
Bawe flat	Digitate	51	41.84	16.44	31	1.21	0.39
	Tabulate	18	47.5	20.85	43	1.4	0.44
Bawe slope	Digitate	12	34.17	12.83	30	2.66	0.38
	Tabulate	24	50.25	19.56	44	1.13	0.39
Mnemba flat	Digitate	24	35.71	20.28	39	1.03	0.57
	Tabulate	4	92.25	40.45	-	1.14	0.44
Mnemba slope	Digitate	2	14	9.9	-	-	0.71
	Tabulate	0	-	-	-	-	-

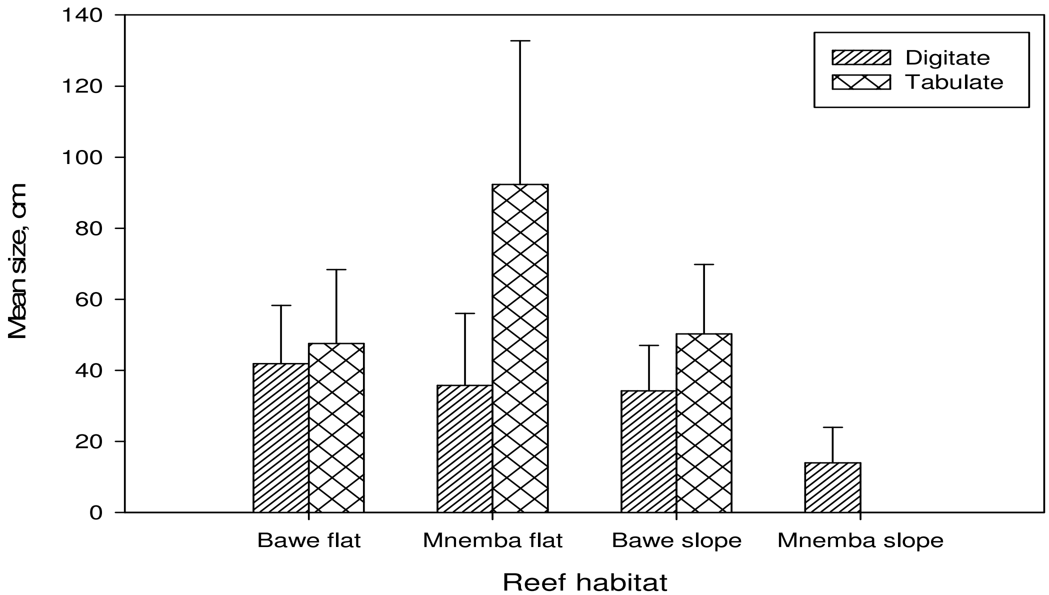

Figure 23: Mean size (±SD) of digitate and tabulate *Acropora* coral in selected sites.

Table 8: Results of Mann-Whitney U test for differences of mean size of digitate and tabulate *Acropora* between reefs.

		Bawe		Mnemba		Mann-U test	
		Mean	SD	Mean	SD	U	P-value
Flat	Digitate	41.84	16.44	35.71	20.28	739.5	0.149
	Tabulate	47.5	20.85	92.25	40.45	7	**0.010**
Slope	Digitate	34.17	12.83	14	9.9	24	**0.022**
	Tabulate	50.25	19.56	-	-	-	-

Table 9: Results of Mann-Whitney U test for differences of mean size of digitate and tabulate *Acropora* corals between habitats within reef.

		Reef flat		Reef slope		Mann-U test	
		Mean	SD	Mean	SD	U	P-value
Bawe	Digitate	41.84	16.44	34.17	12.83	422	**0.041**
	Tabulate	47.5	20.85	50.25	19.56	231.5	0.652
Mnemba	Digitate	35.71	20.28	14	9.9	40.5	0.135
	Tabulate	92.25	40.45	-	-	-	-

3.5.3 Variation of colony size

Variation of colony size, measured by coefficient of variation (as a ratio of standard deviation to mean colony size) of digitate *Acropora* was 0.39 (39%) on Bawe reef flat, 0.38 (38%) on Bawe reef slope, 0.71 (71%) and 0.57 (57%) on Mnemba reef flat and reef slope respectively. Colony size variation of tabulate *Acropora* was similar on Bawe reef flat (0.44 (44%)) and Mnemba reef flat (0.44 (44%)). Bawe reef slope had a colony variation of 0.39 (39%). On Mnemba reef slope, the colony variation was not calculated due to absence of tabulate corals.

The coefficient of variation was correlated with skewness and mean sizes of digitate and tabulate *Acropora* corals. The results showed that coefficient of variation was negatively correlated to mean size and skewness of digitate *Acropora* (Fig. 24) and positively correlated to mean size and skewness of tabulate *Acropora* (Fig. 24). This means that colony size variation is large and frequency of occurrence of small colonies is large in a population dominated by small sized digitate *Acropora* and in a population dominated by small tabulate *Acropora* corals, colony size variation is small and frequency of occurrence of small colonies is small.

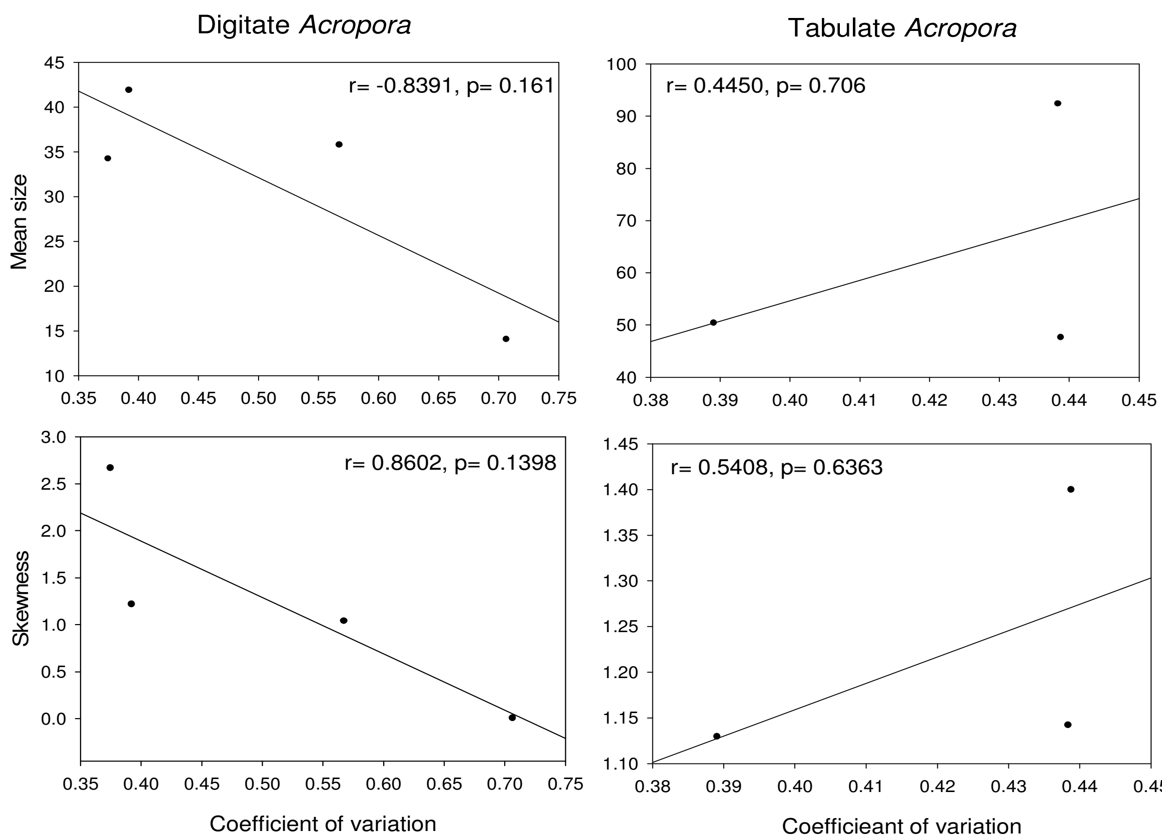

Figure 24: Relationship of coefficient of variation to mean size and skewness of digitate and tabulate *Acropora* corals.

3.6 Environmental variables

3.6.1 Habitat type

Visual analysis of various reef habitats as documented from photographs taken during the field survey revealed that Bawe reef flat had course sand patches with coral rubbles (Plate 1A) and hard substrate organisms (Plate 1B). Bawe reef slope had course sand patches (Plate 2A) and hard substrate organisms (Plates 2B and C). Mnemba reef flat had fine sand patches (Plates 3A and B) and hard substrate organisms (Plates 3C and D). Mnemba reef slope was observed to have few course sand patches (Plates 4A and B) and hard substrate organisms (Plates 4C, D, E and F).

Plate 1: Photographs showing coral rubble habitat (A) and fern plant organism (B) on Bawe reef flat.

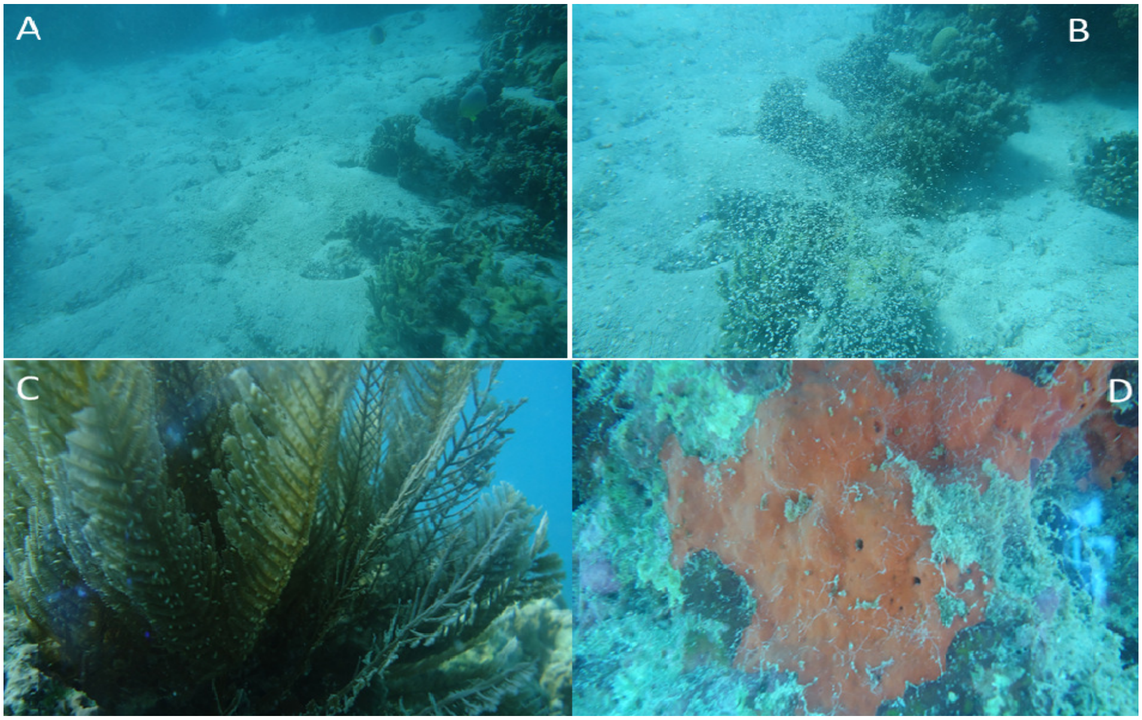

Plate 2: Photographs showing substrate type: Sand substrate (A) and sand particles (B) on water column, benthic organisms: fern plat organism (C) and sponge organism (D) at Bawe reef slope.

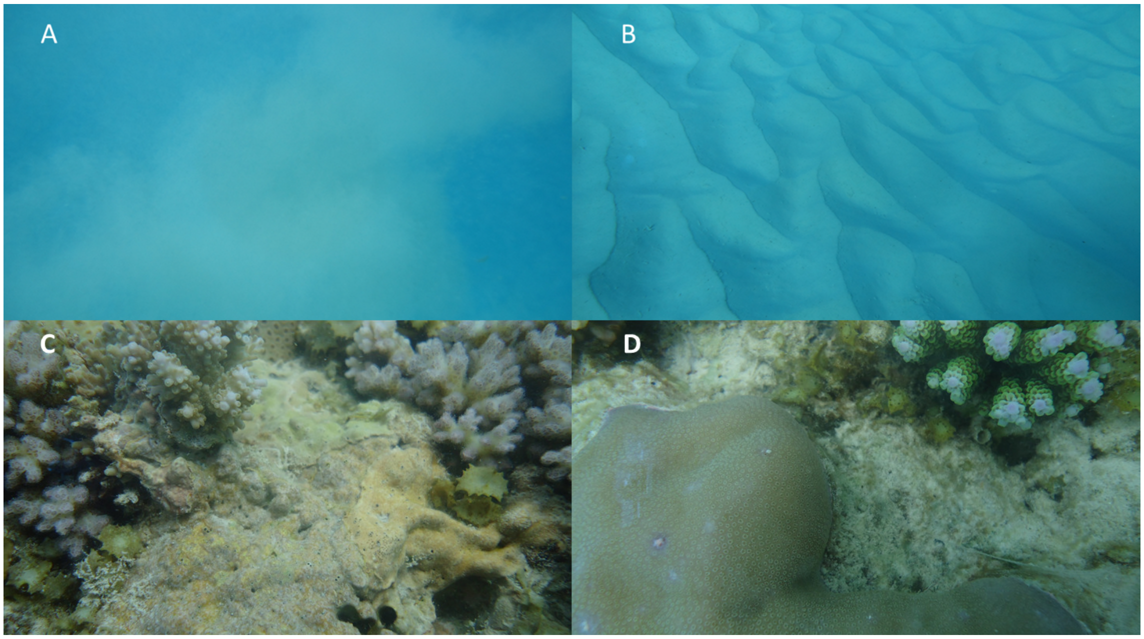

Plate 3: Photographs showing the substrate type: Sand particles on water column (A) and sand substrate (B), benthic organisms: Turbinaria (C and D) on Mnemba reef flat.

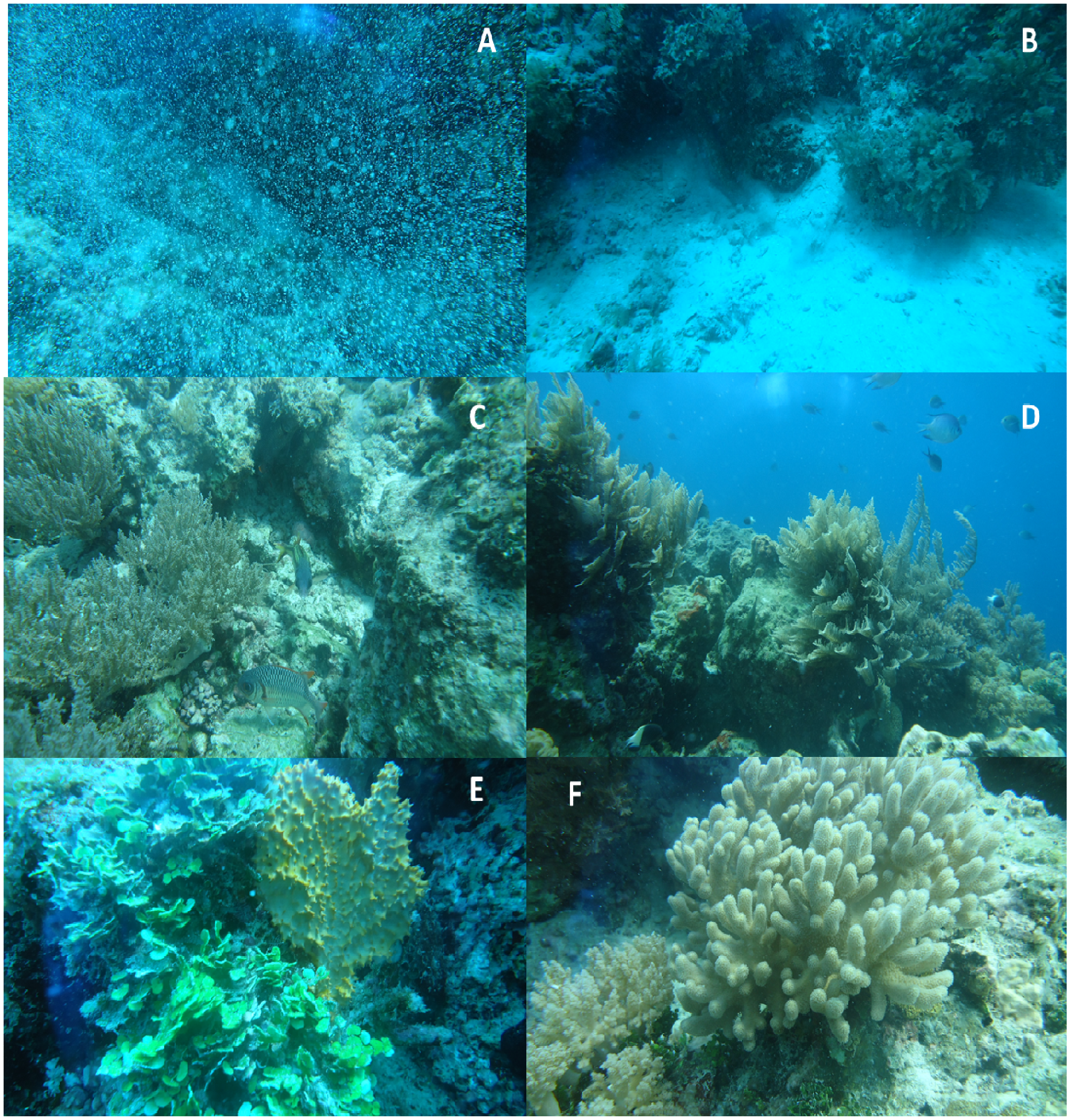

Plate 4: Photographs showing substrate type: sand particles on water column (A), sand substrate (B), rocky substrate (C) and benthic organism: Fern plants (D), halimeda and sponge (E), soft coral (F) on Mnemba reef slope.

3.6.2 Exposure to wave/current

Tidal currents and waves were stronger on Mnemba reef than Bawe reefs (pers. obs). Coral heads on Bawe reef flat (Plates 5A, B and C) as well as reef slope (Plates 5D, E and F) were observed to contain no sand particles on the corallites, meaning that the corals were well washed by current and wave energy. Despite strong currents and tidal waves on Mnemba reef, some of the coral heads on the reef flat (Plates 6A and B) had sand particles and others (Plates 6C and D) had no sand particles. On Mnemba reef slope similar observation was revealed, where some coral heads (Plates 7A, C and D) had no sand particles, while others (Plate7 B) contained sand particles. The results indicated that Mnemba reef is exposed to strong oceanic waves impact which stir the sediments and move sand particles on to the reef corals' surface.

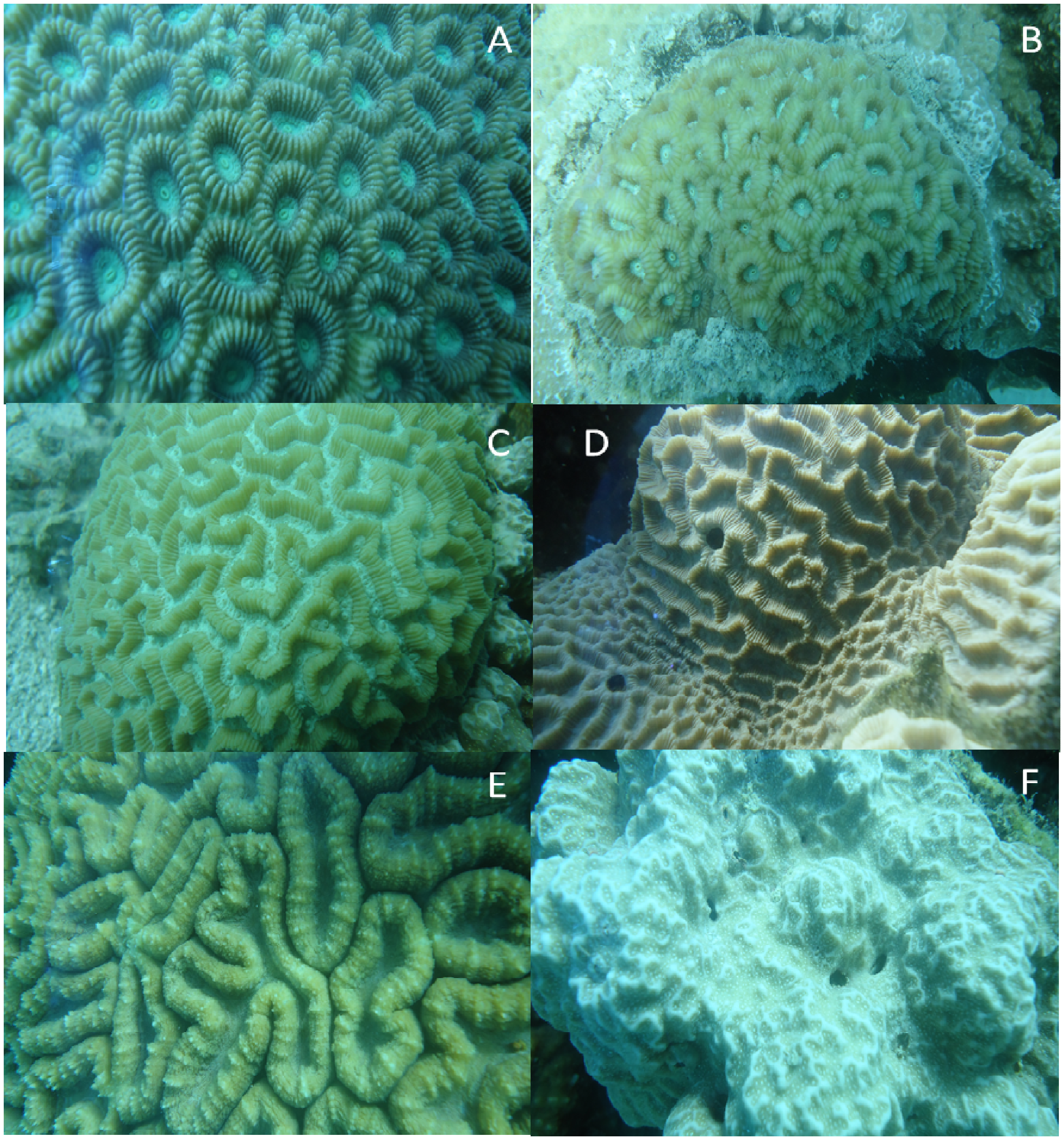

Plate 5: Photographs showing clean reef coral surface at Bawe reef flat (A, B and C) and Bawe reef slope (D, E and F).

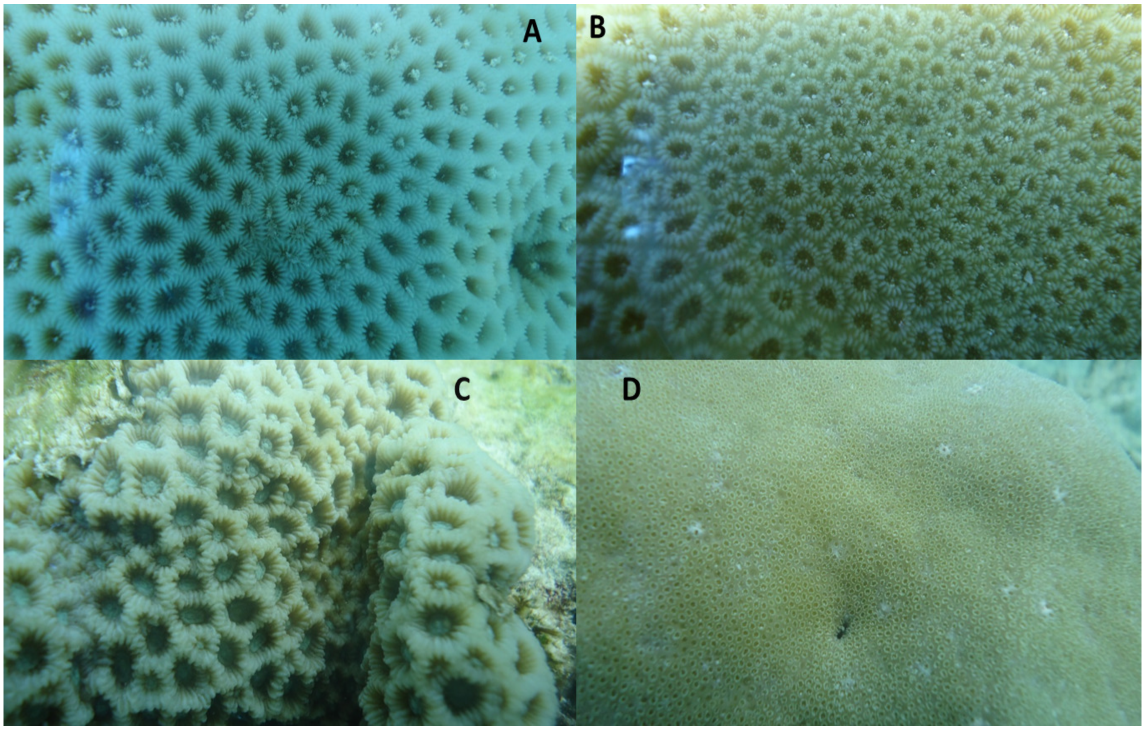

Plate 6: Photographs showing reef corals surface with sand particles (A and B) and without sand particles (C and D) on Mnemba reef flat.

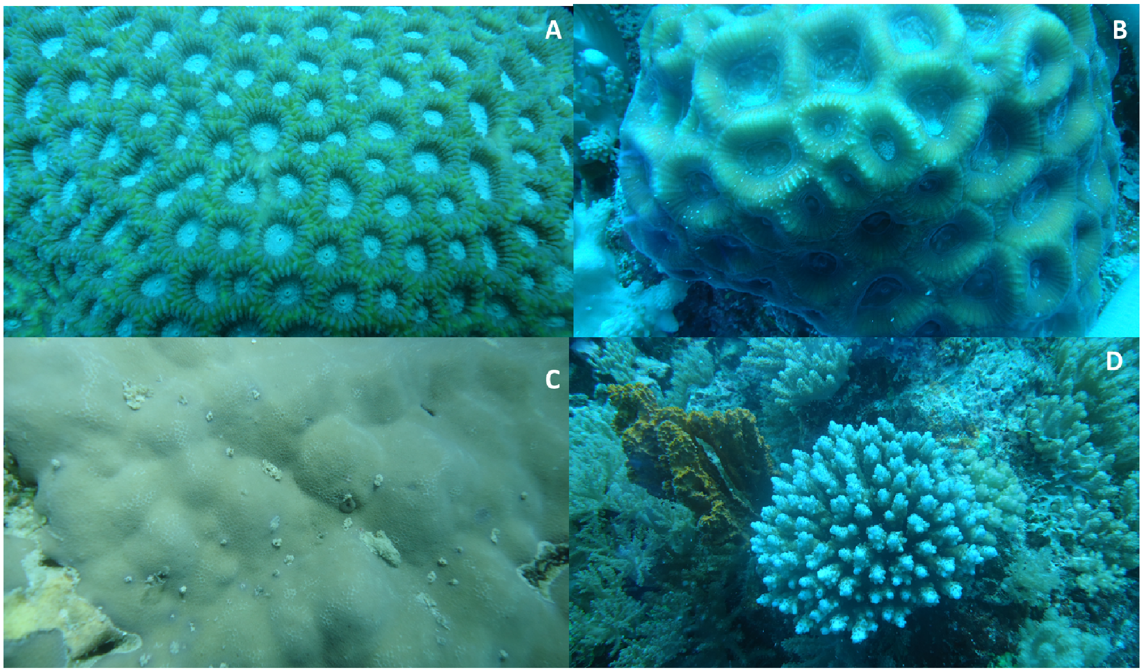

Plate 7: Photographs showing reef coral surface with sand particles (B) and without sand particles (A, C and D) on Mnemba reef slope.

3.6.3 Turbidity

Water visibility of Bawe and Mnemba reef habitats is shown in Fig. 25. The results showed that water visibility was significantly higher on Mnemba reef slope as compared to reef flat (Man-U test; $U=0$, $p=0.009$, Table 8) and Bawe reef slope (Man-U test; $U=0$, p=0.0.009, Table 8). Bawe reef flat had higher visibility than the reef slope (Man-U test; $U=0$, $p=0.009$, Table 8) but lower than Mnemba reef flat (Man-U test; $U=0$, $p=0.009$, Table 10).

Table 10: Results of Mann-Whitney U test for differences in visibility between and within reefs of Bawe and Mnemba Island.

	Bawe		Mnemba			
Between reef	Mean	SE	Mean	SE	U	P-value
Flat	1037.2	27.089	1290	81.24	3.000	**0.047**
Slope	629	46.163	2438	21.541	0.000	**0.009**
	Flat		Slope			
Within reef	Mean	SE	Mean	SE	U	P-value
Bawe	1037.2	27.089	629	46.163	0.000	**0.009**
Mnemba	1290	81.24	2438	21.541	0.000	**0.009**

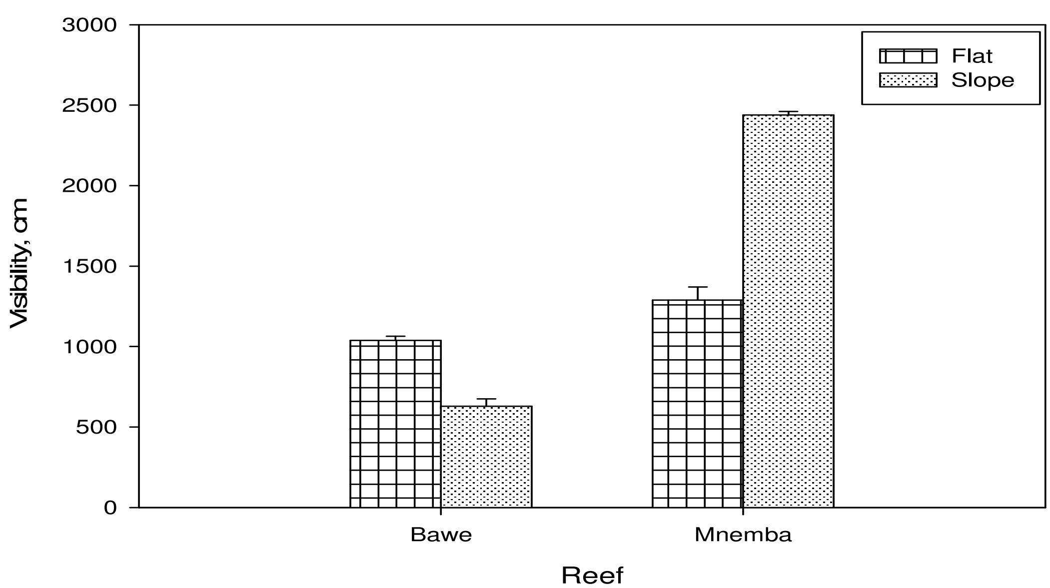

Figure 25: Visibility (±SE) of water in Bawe and Mnemba reef.

3.5.4 Depth variation

Bawe reef flat had a depth range varying from 0 to 3 meters and reef slope had a depth range varying from 4 to 10 meters. Mnemba reefs had a depth range varying from 0 to 4 meters on the reef flat and 5 to 15 meters on the reef slope.

Table 11: Depth ranges of reef habitats of Bawe and Mnemba reefs.

Reef habitat	Depth range (meters)
Bawe reef flat	0-3
Bawe reef slope	4-10
Mnemba reef flat	0-4
Mnemba reef slope	5-15

CHAPTER FOUR

DISCUSSION

4.1 Coral reef boundaries

This study delineated the boundaries of coral reefs and adjacent habitats on Bawe and Mnemba Islands. Spatial analysis revealed coral reef area of 1.9 km^2 on Bawe and 20 km^2 on Mnemba Islands. Coral reef and other adjacent habitats appeared to be fused or intermixed with one another, but boundary characterization which in this study was 5% coral cover enabled elucidating the border between coral reefs and other habitats. Bawe coral reef boundary appeared to be bordered with seagrasses, macroalgae, rocks and sand on the Island side and only sand at the end of the reef slope. On Mnemba Island coral reef boundaries were bordered with sand and seagrasses on both the Island side and end of reef slope. The apparent phyto-benthos (seagrasses and macroalgae), sand and rocky adjacent habitats observed bordering the boundary of coral reefs on Bawe Island could suggest that the reef has soft sandy and hard substrate present. Substrate type is an important factor in determining the distribution of phyto-benthos (Martin, 2000; Thomsen, 2004). Hard substrate with moderate exposure for instance is considered to be important for the growth of macroalgae (Kutser *et al.,* 2006). Sand habitat type bordering most part of the coral reefs on the Island side could be associated with erosion from the strong wave action on Mnemba reef. Bergman and Ohman (2001) explained the exposure of Mnemba coral reef to strong wave action and ocean currents.

In other studies mapping coral reefs and other marine habitats have been done by remote sensing using satellite and aerial photographs (Mumby *et al.,* 1997) in the Caribbean and side scan sonar survey (Masson *et al.,* 1998). Mumby *et al.,* (1995) in Belize and Muhando (1999) in Tanzania used GIS in mapping coral reef distribution. Moreover Walker *et al.,* (2008) in Southeast Florida used combined laser bathymetry, acoustic ground discrimination, sub-bottom profiling and aerial photography data in GIS to map coral reef habitat. Although these studies were capable of showing marine habitats and coral reef distribution, they could not clearly show the demarcation of coral reefs and other adjacent habitats. In the current study, GPS unit, manta-tow technique, boundary characterization and GIS technology were capable of showing the border between coral reef and adjacent habitat. In-situ observation always gives sharper boundaries compared to satellite image interpretation results, however spatial coverage is usually limited (Hill and Wilkinson, 2004).

Although marine habitats and ecosystem overlaps one another (Sunderland and Nichols, 2001), this study was the first case study in Tanzania attempting to elucidate and map the boundaries of coral reefs in relatively finer details. Therefore, in order to identify and map the boundary between coral reef and other marine habitats, a decision must be made on the boundary characteristics between marine habitats.

The basemap information of coral reef boundaries and adjacent habitats produced in this study can be used for future management of coral reefs in Zanzibar. The information can also be used as a baseline dataset for determining changes in coral reef ecosystem of the same area in the future. Finally the information from this study can be used for validating remote sensing satellite imageries.

4.2 Distribution of digitate and tabulate *Acropora* corals

This study has revealed aggregated distribution pattern of tabulate *Acropora* on the investigated areas (Bawe and Mnemba reefs). Whereas aggregated distribution pattern of digitate *Acropora* was revealed on the selected areas of Bawe and Mnemba reefs flats, random and dispersed distribution pattern were observed on Bawe and Mnemba reef slopes respectively. The observed similar distribution pattern on Bawe and Mnemba reef flats for digitate and tabulate *Acropora* suggest that the two areas have similar habitat types. Wallace *et al.,* (2001) explained that *Acropora* fauna is restricted to particular habitat type. Moreover the aggregation of tabulate *Acropora* could be associated with exposure to more frequent disturbance from wave energy (Kramasky and Loya, 1998). The random distribution pattern of digitate *Acropora* on Bawe reef slope could be attributed by the suitable hard substrate (Fig. 5) and weak ocean currents of the reef habitat (Mohammed *et al.,* 2002). The dispersed distribution pattern of digitate *Acropora* coral and absence of tabulate *Acropora* could be associated with high level of anthropogenic disturbances and strong ocean current of Mnemba reef slope (Bergman and Ohman, 2001).

In previous studies coral reef distribution were mapped using combined in situ surveys and video method (Reigl *et al.,* 2001), remote sensing (Serge and Hector, 2005).

Although these a generalized pattern on coral reef community distribution. They are not capable of resolving the subgroups of reef corals in the coral reef habitats. The other disadvantage of these approach is that it is difficult to map the reef habitats under turbid water and cloudy conditions. In the present study using in-situ survey, GPS unit and GIS methods, *Acropora* coral growth form (digitate and tabulate) distribution were mapped and their pattern revealed. Therefore reef corals growth forms can be mapped and their distribution pattern quantified using the combination of in-situ surveys, GPS unit and GIS technology. The present study was the first case study in Tanzania where mapping of coral reef habitats has been attempted at growth form level.

Although the approach used in the present study is relatively time demanding and also depending on the technical skills needed to distinguish different coral groups, the approach is considered to be one of the most effective methods in mapping resources at lower levels. The distributional maps produced in this study can be used as source of information on the location and pattern of digitate and tabulate *Acropora* for further research on the same corals. The methods used in this study for elucidating the location and distribution of digitate and tabulate *Acropora* is unique and can be used in the mapping of other reef corals into their growth form and specie level.

4.3 Contribution of digitate and tabulate *Acropora* corals in the selected reefs

This study has revealed that Bawe reef flat, Bawe reef slope and Mnemba reef flat are dominated by hard corals and algal turf while Mnemba reef slope is dominated by soft corals and fleshy algae. Moreover, it revealed that *Acropora* were among the genera with high contribution in the hard coral cover on Bawe reef and Mnemba reef slope, and least contribution on Mnemba reef slope (Figs. 7 to 10). The observed high cover of hard corals on Bawe reef could be attributed by the absence of specific coral reef threat (Mohammed *et al.,* 2002) As for Mnemba reef flat, the observed high hard coral cover could be associated with protection of the reef area from fishing pressure (Bergman and Ohman, 2001). Digitate *Acropora* coral generally had high contribution in *Acropora* coral cover on all the reef habitats than tabulate *Acropora* coral. They were also found to be the dominant groups in terms of percentage contribution except at Bawe reef slope where tabulate *Acropora* coral showed higher percentage dominance (7.37%) than digitate *Acropora* corals (5.53%). The high diversity of reef coral genera and abundance of *Acropora* corals on Bawe reef and Mnemba reef flat could be explained by the high rugosity on the same reef habitats. Mnemba reef slope was found to have low rugosity, corresponding with low genera diversity (Fig. 10), low hard coral cover (Fig. 5) and very few *Acropora* (Fig. 13D) indicating poor reef complexity. The results of this study correspond to the study by Fuad (2010) which revealed high correlation between rugosity and coral cover and coral genera richness.

The higher covers in hard coral and *Acropora*, and the contribution of digitate and tabulate *Acropora* on the coral cover and percentage dominance on Mnemba reef flat could be associated with the protection of the reef from fishing pressure. Studies by MacClanahan and Shafir (1990), MacClanahan and Mutere (1994) and MacClanahan (1998) had revealed high coral cover and contribution of *Acropora* in protected reefs in contrast to unprotected reefs. Mnemba reef flat is a protected reef and supported high covers of hard coral and contribution of *Acropora*. Whereas the low coral cover and contribution *Acropora* on Mnemba reef slope could be attributed by high anthropogenic disturbances especially fishing pressure (Bergman and Ohman, 2001). While, the higher covers on Bawe reef could be associated with weak hydrodynamic conditions (Bergman and Ohman, 2001; Mohammed *et al.,* 2002). The high contribution of digitate and tabulate *Acropora* on Bawe reef could be attributed by the presence of very few competitors such as fleshy algae. The lower contribution on Mnemba reef slope could be associated with presence of high competition from fleshy algae (Fig. 5). Done (1992) and Pulido *et al.,* (2010) documented macroalgae as being potential competitors to Scleractinian corals. The high covers of soft corals, fleshy and calcareous algae on Mnemba reef slope could be associated with strong water currents as discussed by Bergman and Ohman (2001). Soft corals thrive well in environment with strong water movement (Fabricius, 1997) and calcareous algae do well on high wave energy environment (Björk *et al.,* 1995) and Mnemba reef slope supported high abundances of soft corals and calcareous algae.

Digitate *Acropora* showed high contribution on Bawe reef and Mnemba reef flats, areas of high wave energy and low contribution on Mnemba reef slope which has strong oceanic currents and high fishing pressure. Tabulate *Acropora* showed high contribution on Bawe reef slope, area of weak wave energy and oceanic current (Mohammed *et al.,* 2002) and no contribution on Mnemba reef slope, area of strong oceanic current and high anthropogenic disturbances (Bergman and Ohman, 2001). Therefore digitate *Acropora* thrives well in areas of strong oceanic currents and waves and is affected by anthropogenic disturbances, while tabulate *Acropora* is affected separately by strong wave action, oceanic current and anthropogenic disturbances. These findings will help managers and scientist in understanding the environment where digitate and tabulate *Acropora* occur. Moreover it will help them in the decision making on the management and conservation of digitate and tabulate *Acropora* in the same environment and other reefs.

4.4 Size structure of digitate and tabulate *Acropora* corals

Small sized colony individuals dominated the population of digitate *Acropora* on selected areas on Bawe reef and Mnemba reef flat, suggestive of high recruitment rate. Mnemba reef slope was dominated by only few small sized colonies of digitate *Acropora* which is indicative of a growing or recovering reef. Tabulate *Acropora* was dominated by small sized colonies on Bawe reef flat and slope, which is suggestive of high recruitment rate. On Mnemba reef flat, tabulate *Acropora* was dominated by medium sized colonies indicating lack of a recent recruitment, whereas on the reef slope no tabulate *Acropora* were present indicating unsuitable habitat. The high dominance of small sized digitate and tabulate *Acropora* may be indicative of the absence of competitors and presence of suitable habitats for supporting larval settlement. Alternatively, this could be indicative of suitable hydrodynamic conditions that support larval settlement. The domination of few small sized digitate and absence of tabulate *Acropora* lack of habitat due to presence of competitors, indicative of a degrading reef. This study revealed more distribution of small colony sized tabulate *Acropora* on Bawe reef as compared to Mnemba reef flats (Fig. 22). The study also revealed higher percentage of small colony sized of digitate *Acropora* on Bawe reef in than on Mnemba reef slopes (Fig. 19). Similarity in size frequency distribution was revealed within reefs of Bawe and Mnemba Island for both digitate and tabulate *Acropora*. Similar observations were found in the mean size of tabulate and digitate *Acropora* corals. The similarity of size frequency distribution of digitate *Acropora* corals between Bawe and Mnemba reef flats could be attributed to the similarity in mean size of the digitate *Acropora* corals (Table 6).

Studies by Bak and Meesters (1998) discussed that skewness of coral species provides valuable information on the size structure of the coral population which in turn describes the site recruitment rate and longevity of the reef corals. Positive skewness in a coral population shows that there are more small sized colonies than large one indicating a viable population and healthier reefs (Bak and Meesters, 1998; Meesters *et al.,* 2001;

Smith *et al.,* 2005 and MacClanahan *et al.,* 2007). Meesters *et al.,* (2001) in Netherlands Antilles and Barros and Pirres (2006) in southwestern Atlantic revealed more distributions of small sized colonies than that of large colonies for other coral species. Moreover they found differences in size frequency distribution of same coral species in different environment. Similar results for digitate and tabulate *Acropora* corals were revealed in this study.

Analysis of the relationship of size variation to mean and skewness in this study revealed that in a population dominated by small colonies of digitate *Acropora*, the frequency of occurrence of small colonies and size variation is large. The study further revealed that in a population dominated by small colonies of tabulate *Acropora*, the frequency of occurrence of small colonies and size variation is small. The relationship between mean colony size, coefficient of variation and skewness has been also documented for other coral species by Bak and Meesters (1998), Meesters *et al.,* (2001) and Barros and Pirres (2006).

The size frequency distribution of digitate and tabulate *Acropora* corals in this study showed that the corals on Bawe reef and Mnemba reef flat are healthier and have viable population and Mnemba reef slope is a recovering reef. The present study therefore provide an insight about health status of the investigated reefs and a population structure of digitate and tabulate *Acropora* corals of Bawe and Mnemba reefs. The results of this study therefore will help the coastal managers in delineation of marine conservation areas as well as planning future coral reef monitoring programmes.

4.5 Environmental parameters

4.5.1 Habitat type

This study revealed the dominance of hard substrate in most part of all the sampled reefs. However the benthic organisms on Mnemba reef slope were quite different from the rest of the reef habitat. While most of the hard substrate was covered by hard corals on Bawe reef and Mnemba reef flat, the dominant features on Mnemba reef slope were soft corals, erect algae, algal turf and calcifying algae. The availability of the suitable hard substrate and the absence or very few macroalgae and soft corals on Bawe reef and Mnemba reef flat could be the attribute that is related to the high covers and dominance of digitate and tabulate *Acropora* corals on the same habitats. Although Mnemba reef flat had higher covers of algal turf, it still had digitate and tabulate *Acropora* contributing to the coral cover. This suggest that algal turf has little competition with reef corals. On the other hand, the observed abundant macroalgae and soft corals on Mnemba reef slope might be associated with poor availability of digitate and absence of tabulate *Acropora* corals on the same habitat.

Several studies have documented the important factors in the recruitment and health of reef corals. Studies by Lieske and Myers (1994) and Moll (1998) documented that stable hard bottom is one of the major characteristics that influences reef coral recruitment. Done (1992) and Pulido *et al.,* (2010) showed that erect algae and soft corals are potential competitors reef corals for space on the reefs and Muhando (2003) attested that macroalgae influence the health status of coral reef. Thus, in the light of the present study and other past studies it has been established that Bawe and Mnemba reef have suitable hard substrate for coral reef growth. However the lower contribution or availability of digitate and the absence tabulate *Acropora* corals on Mnemba reef slope could be associated with spatial competition from erect algae and soft corals. Bergman and Ohman (2001) reported that Mnemba reef slope is under high pressure of fishing and has faced destructive fishing activities in the past. The lower availability of digitate and absence of tabulate *Acropora* could be associated with the destructive fishing activities in the past which influenced the domination of macroalgae and soft corals.

The results from this study can be utilized in the delineation of marine reserve areas. Despite the fact that Bawe reef is an open fishing zone, it has shown to have suitable habitat for coral reef growth. Therefore coastal resource managers and scientist can use the information from this study to design possible conservation strategies on Bawe reef.

4.5.2 Exposure status to oceanic waves and currents

Analysis of the photographs of corals from Bawe reef (Plate 5A, B, C, D, E and F) revealed clear reef coral surface with no sand particles, suggesting that the reef corals are under regular influence of waves which tend to wash away any sand particles deposited on the reef coral surface. On the other hand the reef coral surfaces of Mnemba reef flat (Plate 6A, B, C and D) and slope (Plate 7A, B, C and D) revealed some coral heads with sand particles while others did not. The sand particles on some of the reef corals of Mnemba reef indicate that the area has sediment problem whereby strong ocean waves and currents move the sediments on to the reef corals, therefore the results suggest that Mnemba it is exposed to strong oceanic waves and currents.

Ngoile (1990), Mbije *et al.,* (2002) and Bergman and Ohman (2001) have documented the exposure status to oceanic waves and currents of the reefs around Unguja Island including Bawe and Mnemba Island. In their studies they documented that the reefs on the western side of Unguja Island which include Bawe Island coral reefs are protected from strong oceanic waves and currents. Whereas the reefs on the eastern side of the Unguja Island including Mnemba Island coral reef are exposed to strong oceanic waves and currents. Furthermore, Mohammed *et al.,* (2002) noted that Bawe Island is protected therefore is under the influence of weak oceanic currents and waves. The results of the present study was consistent to the results by the past studies especially on the extent in exposure of the reefs to oceanic currents and waves.

4.5.3 Turbidity and depth

This study revealed that turbidity measures corresponded to the cover and contribution of digitate and tabulate *Acropora.* The lower turbidity on Bawe reef flat corresponded to higher cover of tabulate *Acropora* corals on the same area. By contrast, Bawe reef slope higher turbidity corresponded with lower cover and contribution of tabulate *Acropora* corals. Lower cover of digitate *Acropora* corresponded with lower turbidity on the reef flat and higher cover with higher turbidity on the slope of Bawe reef. On the other hand the abundance of digitate and tabulate *Acropora* revealed correspondence with depth in the surveyed areas. Whereas digitate *Acropora* showed increase of coral cover from the reef flat to slope of Bawe reef, tabulate *Acropora* coral characterized with a decrease in coral cover. Mnemba reef had less turbidity but had few covers of digitate and tabulate *Acropora.*

Rogers (1990) noted that turbidity in the ocean is associated with decrease in coral diversity and abundance. Muzuka *et al.,* (2010) noted that although sedimentation is stressful to corals, some corals are adapted to sedimentation situation. Huston (1985) documented that coral abundance and diversity increased with increasing depth up to a limiting depth of 20m and decrease again with further depth. A study by Meij and Viser (2011) documented that digitate *Acropora* thrive in a wide range of environmental conditions and Artez (2010) explained the occurrence of tabulate *Acropora* corals in shallow water due to enough light intensity.

In this study digitate *Acropora* coral showed increase in percentage cover from reef flat to reef slope. Tabulate *Acropora* corals on the contrary showed decrease in cover from reef flat to reef slope on Bawe reef (Fig. 23). The lower covers of digitate and tabulate *Acropora* in Mnemba reefs could be related with many other factors such as strong hydrodynamic conditions on the reef flat and anthropogenic disturbances on the reef slope. Therefore this study is consistent with previous studies which noted that depth and turbidity influence coral cover and growth form. The study provides information on the range of environment that digitate and tabulate *Acropora* can thrive. The information from this study can be used by coastal resource managers and scientists for designing appropriate reef conservation strategies and planning future studies respectively.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The present study was the first case study in Zanzibar where mapping of coral reefs has demarcated the boundaries of coral reefs and the adjacent habitats around Bawe and Mnemba Islands. Coral reefs on Bawe Island were bordered by seagrasses, erect algae, sand and rocks, while Mnemba Island coral reefs were bordered by only sand and seagrasses. The methods used in this study can be used to map the boundaries of other coral reef areas.

In this study, relative contribution and size frequency distributions of digitate and tabulate *Acropora* were determined. Higher cover of digitate *Acropora* was found on Bawe reef slope compared to Mnemba reef slope. As for the reef flats, no significant difference was observed. Comparison analysis within reefs sites, revealed higher covers of digitate *Acropora* on the reef flat as compared to reef slope on Mnemba reef, with no significant difference on Bawe reef corals. There was no significant difference for tabulate *Acropora* within Bawe reef and between Bawe and Mnemba reef habitats. High proportion of small sized colonies of digitate and tabulate *Acropora* were revealed in all sampled areas in this study. More distribution of small sized colonies of digitate *Acropora* was revealed on the reef slope of Bawe compared to Mnemba reef. Tabulate *Acropora* was revealed to have more small sized colonies on the reef flat of Bawe compared to Mnemba reef. Similar size frequency distribution was revealed for other habitat comparison.

The spatial distribution pattern of digitate and tabulate *Acropora* showed marked differences. Digitate *Acropora* was more aggregated than tabulate *Acropora* on Bawe and Mnemba reef flats. On Bawe reef slope digitate *Acropora* were randomly distributed whereas on Mnemba reef they were dispersed. The distribution of tabulate *Acropora* on Bawe reef slope was aggregated.

Monitoring the environment where reef corals are found is fundamental in understanding the influence of environmental parameters on the distribution of reef corals. This study has shown a relationship between the distribution of digitate and tabulate *Acropora* and, depth, turbidity and habitat type.

5.2 Recommendations

1. Further studies for mapping coral reef boundaries in the region should be done in order to have more location information of coral reef areas and their adjacent ecosystems.

2. Mapping of the boundaries of other marine ecosystems should also be done for future studies on ecosystem change.

3. Further monitoring studies on the distribution of reef corals environmental parameters is recommended to provide considerable insight of the effect of environmental factors on reef corals health and distribution.

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