Coral Reef Rugosity and Coral Biodiversity

Bunaken National Park, North Sulawesi, Indonesia

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by
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Abstract

Rugosity is a simple measurement of the surface roughness that has been used routinely by coral reef biologists. Areas of high rugosity allow corals to attach and grow on higher substrata not influenced by sand and sediment movement along the bottom. Rugosity of coral reef also reflects the effect of disturbance and stressors on the reef. The aims of this research were to asses the coral reef rugosity in the different environmental condition, the pattern of coral genera biodiversity, and the relationships between rugosity and reef corals biodiversity.

The reef corals biodiversity data collection was conducted by Line Intercept Transect. The rugosity of coral reef was measured by carefully laying a steel chain to the reef surface. A rugosity index, ***C***, is calculated as ***C***=*1-d/l*. where d is horizontal distance covered by chain that follows the contour of the reef and *l* is its length with fully extended. Comparison of rugosity index between fishing dominated area and tourism dominated area was analysed by independent t-test. Coral genera biodiversity pattern was analyzed using Two Way Indicator Species Analysis (TWINSPAN). The relationships between rugosity index and coral biodiversity were analysed using correlation test, linear regression analysis, and second order polynomial regression analysis.

A total 44 coral genera were found in the Bunaken National Park and the average of live coral cover is 46%. *Porites* is the dominant coral genera in the study area. Coral genera can be distinguished in four groups based on its occurrence and cover. An independent t-tes revealed that there was no significant difference between coral reef rugosity index in Bunaken Island and Tombariri. A percent live coral cover is the variable that has highest correlation with coral reef rugosity and then followed by genera richness, Shannon diversity index, and evenness. The highest coefficient of determination of linear regression was found in the linear regression analysis between rugosity index and coral cover (r^2=0.321). Tombariri has higher coefficient of determination of linear regression (r^2=0.526) than Bunakan Island (r^2=0.296). None of second order polynomial regression was significant. Therefore linear regression model can better explain the variation of percent live coral cover, genera richness, Shannon diversity index, and evenness rather than a second order polynomial regression model, at least in the Bunaken National Park. However rugosity index can only explain very low variation of genera richness, diversity index and evenness.

Keywords: Coral, Coral reef, Rugosity, Biodiversity, Coral genera composition, TWINSPAN, Disturbance, Tourism activities, Fishing activities, Bunaken National Park

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1. Introduction

1.1. Background

Coral reefs are highly dynamic and productive marine ecosystems. Coral reefs occur in tropical and sub tropical regions (Wilkinson and Buddemeier 1994). They provide habitat for a number of marine organisms including fish, algae, vertebrates, and invertebrates (Alquezar and Boyd 2007). Coral reefs are not only one of the most spectacular marine ecosystems on the Earth, but also offering valuable economic resources for the people living along the coast (Bertels et al. 2008).

Coral reefs ecosystems are endangered. It is generally caused by the unsustainable human exploitation and pollution, also by global climate change. Anthropogenic disturbances have threatened the coral reef biodiversity. The protection and management of the coral reefs are not only important for the coral reef habitat itself, but also for local people that mainly depend on it as a natural resource. The reefs represent substantial resources in the form of food or as tourist attraction for humans (Wilkinson and Buddemeier 1994).

Reef coral biodiversity is influenced by its habitat and environmental conditions, including biotic interactions. Environmental conditions that have a role in reef coral biodiversity are water temperature, salinity, wave action, currents, sediment load, which some of it depend on the distance to the nearest river mouth (Moll 1986; Veron 2000). Other habitat conditions that influence the reef coral biodiversity are bottom structure (complexity/rugosity) (Aronson and Precht 1995),bottom substrate, depth, and reef geomorphology (Moll 1986; Veron 2000; Andréfouët and Guzman 2005). All of these environmental conditions may play a major responsibility in determining the structure and dynamics of coral reef habitats and may be critical to the maintenance of biodiversity of the coral reef systems.

Biodiversity on coral reefs are routinely investigated using conventional field survey. Since the field survey are usually time-consuming and expensive to conduct over a wide scale, alternative and more feasible methods are needed to tackle this problem (Purkis et al. 2006). The only feasible way to assess the life coral cover over large spatial and temporal scale is to use remote sensing. It offers many advantages while field survey is complicated to do particularly in remote areas (Mumby et al. 2004).

Remote sensing generally provides many advantages in coral reef mapping. A routine method for the analysis of earth observation data by means of remote sensing of the reef areas is by using spectral feature space (Purkis et al. 2006). This technique is effective in the majority of cases since different benthic bottom type of coral reefs frequently display separable optical signatures (Hochberg et al.

2003). However, spectral reflectance characteristic of features within a coral reef environment are optically similar, so confusion can arise in identification of the coral reef (Holden and Ledrew 1999). An alternative and complementary method for the coral reef biodiversity mapping is by the analysis of rugosity derived from remote sensing imagery as coral reef biodiversity indicator (Brock et al. 2004; Perez et al. 2004) It looks promising since a more complex habitat supports a greater variety of species.

Based on the description above, this research will assess the relationship between rugosity and the biodiversity of reef building corals. The study was conducted in Bunaken National Park, and done together with colleagues Juan Pablo S Rojas.

1.1.1. Coral Reef

There are three types of reefs that proposed by Darwin that widely accepted today. The first type is a fringing reef. Fringing reefs are characterized by their location which closed to the land, occurring in shallow water area, border shorelines of continents and Islands in tropical seas. This type of reefs is commonly found in the Indo-Pacific region, the South Pacific Hawaiian Islands, and parts of the Caribbean (Veron 1986; Barnes 1999) Fringing reefs are formed closed to inshore on rocky coastlines by the growth of corals and associated *Hydrozoans* (stinging corals), *Alcyonarians* (soft corals) and calcareous algae.

The barrier reef is the second type of reef. This reef occurs farther on the offshore and separated from the land by a lagoon or wide channel resulted from erosion and coastal subsidence(Barnes 1999). Barrier reefs are common in the Caribbean and Indo-Pacific (Veron 1986). One of the well known barrier reef is The Great Barrier Reef in northern Australia in the Indo-Pacific region which is considered as the largest barrier reef in the world.

If the land mass is a relatively small Island, it may disappear below the ocean surface due to land subsidence or sea level rise, and the reef becomes an atoll. This type of reefs is namely Atolls. They typically placed surround a central shallow sandy lagoon. Atolls also commonly occur in the Indo-Pacific. Furthermore, Veron (1986) proposed the fourth type of reef namely Platform reef. The diagrammatic showing the principal types of reef are presented in the Figure 1.

Reefs are built from coral species, but not all coral produce reefs. (Barnes 1999; Veron 2000) The main reefs builders are the stony or hard corals namely a *hermatypic* corals which have a symbiotic relationship of microscopic brown alga called *Zooxanthellae* .Corals are restricted in an area within 70 m of the surface in clear seas where the temperature remains above 20°C throughout the year. If the water is colder, the reefs are poorly developed or nonexistent. Corals may still exist at the depths below 70 m which is colder and or turbid waters in suitable hard substrata as long as there is sufficient light for photosynthesis. But this condition will reduce the capabilities of corals to secrete limestone for growth and built the reef although the symbiotic relationship with *Zooxanthellae* often persistent. Most of coral reefs lies between the latitudes of 30 degrees north and south where the sea temperatures are warmest (Barnes, 1999)

The center of reef coral biodiversity is laying on the coral triangle in the South East Asia, Australia and in Caribbean Archipelago. A recent study conducted by scientists in Pulau Seribu Reef complex Indonesia has found a total of 13 families,44 genera, and 158 Species (Cleary et al. 2006). Similar study in Ambon, eastern Indonesia, rhas found a total of 42-99 species, while 45-75 species found in Sulawesi, and 24-99 species found in Java Sea (Edinger and Risk 2000).

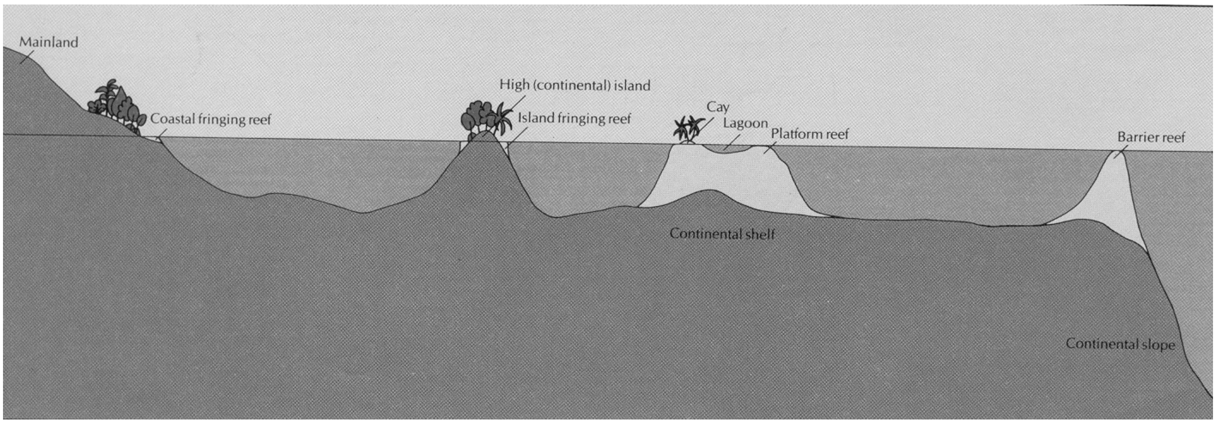


Figure 1 The Diagrammatic Showing the Principal Types of Reef (Veron 1986)

1.1.2. Coral Reef Rugosity

Rugosity is a simple measurement of the surface roughness that has been used routinly by the coral reef biologists. Rugosity is the state of ruggedness or irregularity of a surface (Magno and Villanoy 2006). In marine ecology, rugosity is describing as the amount of “wrinkling” or roughness of the reef profile. Rugosity has been called in many different ways, such as habitat complexity, topographic complexity, and substrate heterogeneity (Beck 1998). The issue of habitat complexity is approached intuitively by most scientists, there is a consensus that more complex habitat support a greater variety of species (Gratwicke and Speight 2005). Bottom surface rugosity is an important ecological parameter (Friedlander and Parrish 1998). Areas of high rugosity are likely to provide more cover for reef fish and more places of attachment for algae, corals and various sessile invertebrates (Rooney 1993; Mumby 2006)

Rugosity often correlates well with fish community characteristic, coral cover, disturbance regime and nutrient uptake. Numerous researches have documented the role of rugosity in the structure and composition of fish assemblage (Luckhurst and Luckhurst 1978; McCormick.MI 1994; B. Gratwicke and M. R. Speight 2005; Kuffner et al. 2007). Aronson and Precht (1994, 1995) was used rugosity as integrated measure of disturbance on the reef systems. They found that rugosity is highly correlated with coral cover ,diversity, and disturbance regime. Several studies have shown another potential use of rugosity as bioindicator for nutrient uptake and particulate organic matter on coral reef systems. Cooper et al (2009) was measure rugosity on coral reef especially which dominated by *Porites* to linked it with water quality change in The Great Barrier Reef. They found that the surface rugosity of massive *Porites* increases when skeletal growth is unable to provide sufficient surface area at the higher growth rate due to nutrient enrichment. However, it is likely to be of limited use for short-term monitoring due to its slow response time (Cooper et al. 2009).

Rugosity has also been used to identity and classify the benthic habitat using light detection and ranging (LIDAR) (Brock et al. 2006; Kuffner et al. 2007) and remote sensing based on satellite imagery (Purkis et al. 2008). Recent research conducted by Dunn and Halpin (2009) was used rugosity as an indicator for detecting the hard bottom habitat at regional scale in the Atlantic coast of Florida-USA. They successfully predicted the presence or absence of the hard bottom habitat with ~70% accuracy (Dunn and Halpin 2009).

1.1.3. Disturbance on Coral reef

Coastal marine habitats in particular are exposed to and appeared to be susceptible to a wide range of natural and anthropogenic disturbances. The natural disturbances including rigorous tropical storms and wave action, tidal exposure (Huston 1985) temperature fluctuations, terrestrial run-off, and diseases are vary in their scale, intensity, and frequency (Connell et al. 1997). Man-induced physical disturbances are numerous, including over-harvesting of reef organisms, coral mining and dredging , destructive fishing practices (Chabanet et al. 2005) and tourism activities including trampling and diving-ship grounding (Zakai and Chadwick-Furman 2002; Chabanet et al. 2005; Fox and Caldwell 2006). Both anthropogenic and natural disturbance can resulting in similar effect on the reef (Fox and Caldwell 2006). However, those communities susceptible to natural disturbances are even more vulnerable to increasing pressure from anthropogenic factors (Wilson et al. 2006)

Disturbance can be acute or chronics (Connell 1997). Acute is a single disturbance that directly affects the environment temporarily. Whereas chronics ones are longer-term disturbance. If a series of acute disturbances that has occurred so frequently and gave only a short time in between to recover; this is then regarded as a chronic disturbance. Chronic disturbances are more damaging than acute ones, especially when considering coral reef recovery (Richmond 1993). It generally causes problems not only by stimulating coral mortality, but also by affecting reproduction and recruitment. Thus corals recovery would reduced by acute, short-term disturbances might recover faster or more complete than those afflicted by the chronic, the long-term ones(Connell 1997).

Disturbance plays a role in maintaining the coral reef systems. It may plays a major responsibility in determining the structure and dynamics of coral reef habitats and may be critical to the maintenance of diversity in these species-rich systems (Connell 1978; Huston 1985). At low level of disturbances, dominant competitors limit most other subordinate competitors. At intermediate level of disturbances, Cornell (1978) introduces disturbance-diversity relationships known as an intermediate disturbances hypothesis. It is suggestsed that diversity will be maximal at intermediate level of disturbances. This level of disturbance in a reef system will removed the competitive dominant when the dominant one is susceptible to disturbance. It did not allow more species to coexist as increase of the evenness among species that were already present. This disturbance limited the cover of competitive dominant, thus allow competitive subordinate to increased their growth, increase from low to intermediate level of cover. However, there is a considerable debate that the intermediate hypothesis would be applicable in all coral reef systems (Aronson and Precht 1995). In high level of disturbance, diversity may be reduced significantly. Extremely frequent or severe disturbance will prevent coral species from surviving (Huston 1985).

1.2. Research Problems

The use of rugosity data derived from remote sensing as an alternative and complement method for coral reef biodiversity assessment has been done by several scientists (Brock et al. 2004; Kuffner et al. 2007). This method needs a justification that rugosity as an indicator of substrate complexity of coral reef habitat has a strong relationship with coral biodiversity.

The structural complexity of habitats increases the heterogeneity. It will increase niches available for different species to occupy. Therefore, increasing the rugosity of habitat generally resulted on the increasing biodiversity of the assemblages that occur with them (Cranfield et al. 2004). Areas of high rugosity allow the corals to attach and grow on higher substrata which not influenced by sand and sediment movement along the bottom (Friedlander et al. 2003; Friedlander et al. 2005). Corals larvae are preferentially recruited to vertical surfaces, this pattern also applied to the areas of higher rugosity. (Rogers et al. 1984)

Rugosity of coral reef also reflects the effect of disturbance and stressors on the reef. Complete historical records of disturbance and stress do not available for most coral reefs. Even where historical records of disturbance are available, there is no obvious way to sum up each different disturbance to reflect the total disturbance regime. In other words, one cannot simply give the specific score for specific disturbance and sum it up to get the total disturbance that has been passed by the reef. Arronson and Precth (1994; 1995) proved that rugosity is an indicator of large-scale and long-term disturbance for coral reefs. They found that rugosity inversely related to total disturbance. The lower rugosity means the flatter terrain and suggesting more frequent, more recent and or more intense disturbance. Therefore improving our understanding on rugosity of coral reef does not only improve our understanding about coral biodiversity itself, but also it gives insight in the disturbance and its effect on coral reefs.

Even though there are many scientists who studied the rugosity, only a few have related it directly to the reef coral biodiversity itself. Most of them were studied the relationships between coral reef rugosity with reef fish diversity, benthic micro fauna, and macro fauna (Knudby and LeDrew 2007; Knudby et al. 2007).

Since it is clear that rugosity plays a role in coral biodiversity, it also offers the possibility to use rugosity as an indicator for coral biodiversity and disturbance on coral reef. Therefore understanding the relationships between rugosity and coral diversity is very important. Biodiversity indices that used are genera richness, Shannon index of diversity, evenness, and dominant species. In addition percent of live coral cover is also analyzed. The result of this research will contribute to coral reef mapping and monitoring, with the use of remote sensing technique.

1.3. Research Objectives

1.3.1. Main Objective

The aims of this research are to asses the coral reef rugosity and its relation to reef coral biodiversity.

1.3.2. Specific Objectives

1. To analyze the pattern of reef corals biodiversity in the study area.
2. To analyze coral reef rugosity in the Bunaken National Park
3. To asses the relationship between coral reef rugosity and coral biodiversity.

1.4. Research Questions

1. How is the pattern of reef corals biodiversity in the study area?
2. Do the coral reefs in different environmental conditions (dominated by fishing practises and recreational activities) have a different rugosity index?
3. Is there any relationship between rugosity index and investigated biodiversity indices and coral cover? If so which are the biodiversity indices that are highly correlated with the rugosity Index?

1.5. Research Hypotheses

$H1_o$: The coral reef rugosity index do not have a significant different between Tombariri and Bunaken Island

$H1_1$: The coral reef rugosity index in Bunaken Island is higher than in Tombariri

$H2_o$: There is no relation between coral reef rugosity, coral cover, and investigated biodiversity indices.

$H2_1$: There is a relation between rugosity , coral cover and investigated biodiversity indices.

2. Material and Methods

2.1. Study Area

Bunaken National Park (BNP), founded in 1991, is considered as one of the most strategically important Marine Protected Areas in the world. Located near the centre of the 'coral triangle'(1’37’ N 124’ 45’ E), the reefs of North Sulawesi are of crucial conservation importance (Fava et al. 2009). The Park covers approx. 90,000 ha of coral reefs, mangrove forests and a sea grass bed supports a local population of some 22,000 villagers. In general, BNP divided in two sections; the northern section and the southern section. The northern section of BNP consist five Islands (Bunaken, Siladen, Manado Tua, Nain, and Mantehage) and the coastal area between Molas village to Tiwoho village so called “Wolas-Wori” coast. Each Island is surrounded by fringing reefs and characterized by reef flats with different extension and steep walls out of the edge (Fava et al. 2009).The other section of this national park covers entirely area between Popoh coastal areas until Popareng village wich is known as the “Arakan – Wowontulap “ coast.

Sea surface temperature in BNP is relatively stable throughout the year. It range from 27 to 29 degrees Celsius in the open water, but can be up to 30 degrees Celsius over the reef flat at low tide. Tidal type in the BNP is semi diurnal which means there are two low tides and two high tides in one day. The average range between high tides and low tides can be up to 2.6 meters. In general, there are two season in the area, namely wet season and dry season. In the dry season, drier wind came from southwest direction. It occurs between May until October and resulting on calm seas. On the contrary, in the wet season heavy-cool wind blow from northwest, it caused some tropical storm and high wave. As a result, the western and northern sides of the Islands and coast in BNP are exposed to storms and large waves (Turak E and DeVantier 2003). This moment occurs from November until February (Mehta 1999).

The coral reef in The Bunaken National Park that becomes focus in this research is the fringing reef on Bunaken Island and Tombariri, represent of the northern and southern section respectively. The coral reef communities in that area are threatened by natural and anthropogenic disturbances. Recreation and diving activities are considered as major threats to the reef corals in Bunaken Island (Turak E and DeVantier 2003). There are 18 dive sites and more than 41 diving clubs that operated in this area. Type of reef in Bunaken Island is the Island fringing reef with higher degree of steepness. In contrast, coral reef in Tombariri is the coastal fringing reef with lower degree of steepness. Coral reef in Tombariri is severe form destructive fishing practises and sedimentation but there are less diving activities and other recreational activities compared to Bunaken Island (DeVantier and Turak 2004; DeVantier et al. 2006). There are two river mount which closed to Tombariri reef area. The first river is located in the eastern part, while the second one is in the western section.

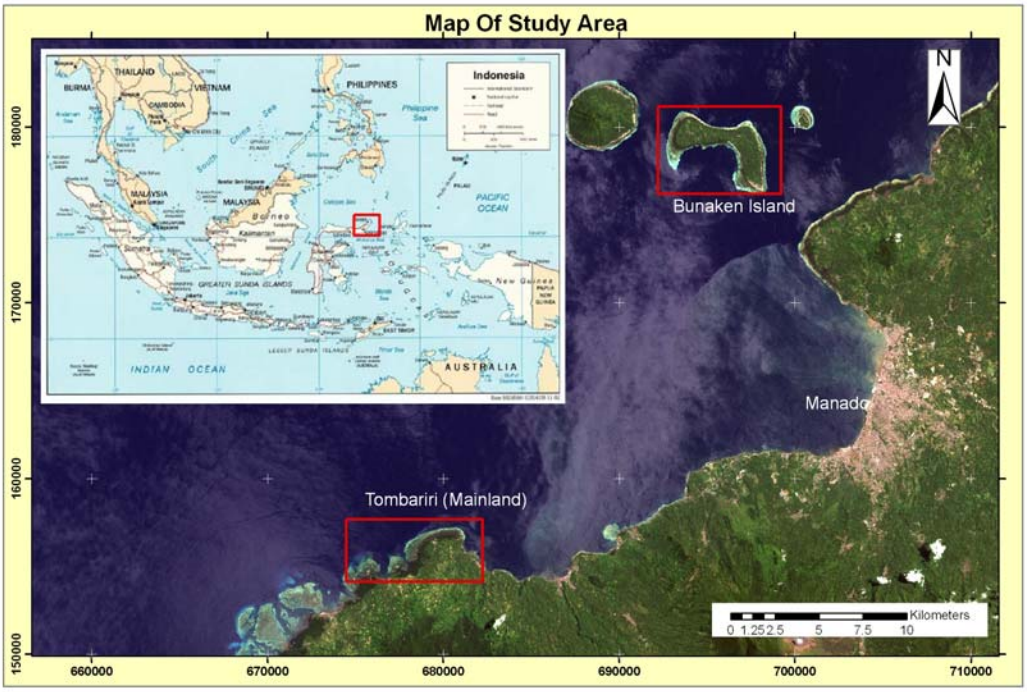


Figure 2 Study Area

2.2. General Methodology

Overall methodological steps of the research are in the logical sequence as follows. First is benthic map creation by visual interpretation of aerial photograph. The corals strata in benthic map then used as a guidance and was sampled afterwards. The next step is coral reef rugosity and coral biodiversity data collection. Coral cover and coral diversity data was collected by Line Intercept Transect method, while the rugosity of the reef was measured using steel chain resulting rugosity index. Then these two data were analyzed using the correlation and regression analysis to find the possible relationship between them. Figure 3 summarizes the investigation process in finding the relationship between rugosity and coral biodiversity in the Bunaken National Park.

Field work was carried out on the 13 of September until 5 October 2009 in Bunaken Island and Tombariri reef areas. Due to logistic limitation and effectiveness, some works were done together with colleagues Juan Pablo S Rojas. He is studying the relationship between reef front heterogeneity and coral biodiversity. The works that were done together are geometric correction, visual interpretation of aerial photograph, benthic cover estimation for benthic map creation, and coral biodiversity data collection.

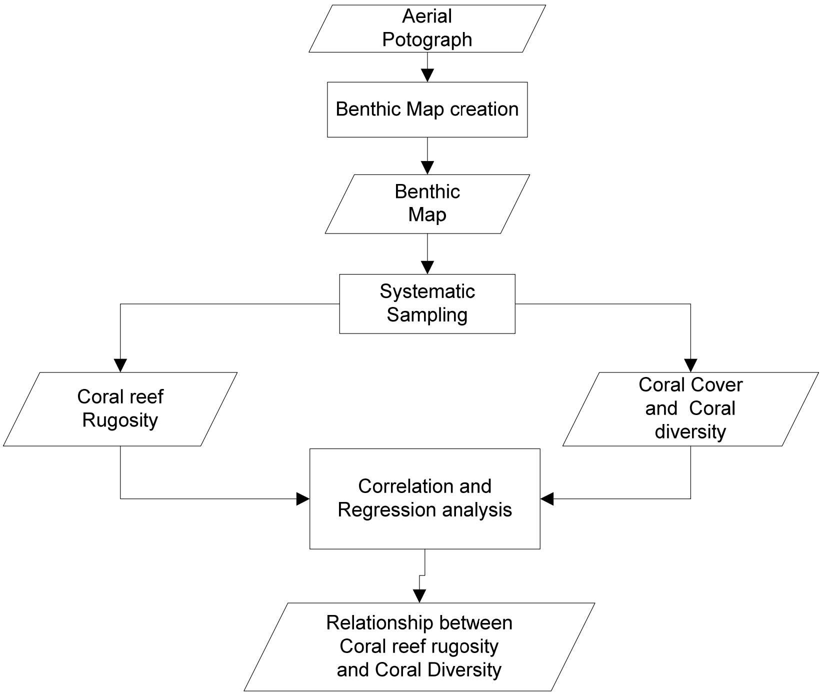


Figure 3 Research Flowchart

2.3. Sampling Design

Field data collection in this study is addressed to get data of coral biodiversity, coral cover as well as bottom rugosity. Sample locations are designed to spread out in the entire area (systematic sampling). These sample locations are placed in the coral zone stratum from benthic map (refer to the result). Forty one coral reef locations were visited during the fieldwork. Due to time constraints, some locations are having less sample points compared to the others.

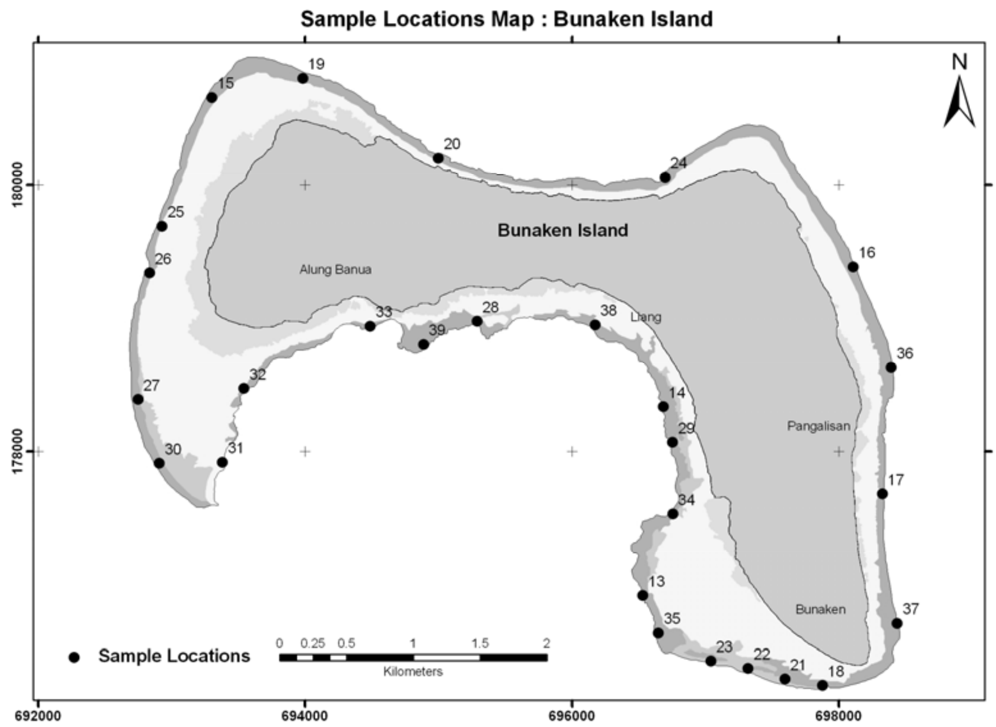


Figure 4 Sample Location: Tombariri

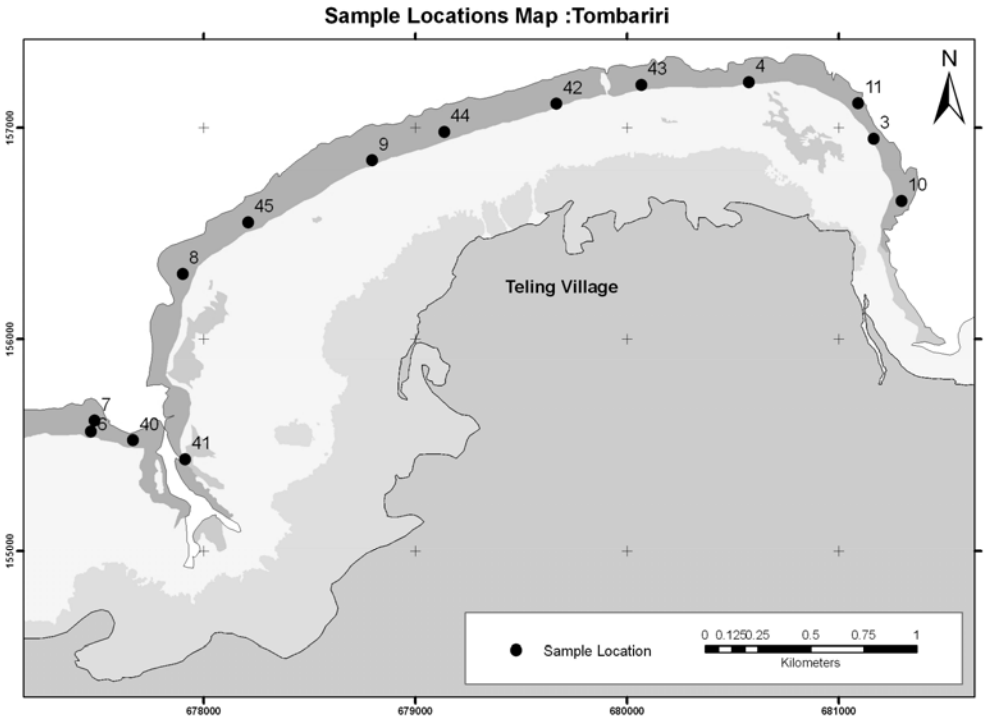


Figure 5 Sample Location: Bunaken

2.4. Data Collection

2.4.1. Fieldwork Preparation

Field work preparation was done by preparing the aerial photograph (Google image) of the study area. Then geo-referenced to WGS -1984 as geographic coordinate system and UTM Zone 51N as a projection system. The geo-referencing process is resulting in geo-referenced images of Tombariri which has an accuracy value of 2.85 m, while it is 3.05 m for Bunaken Island. The next step is visual interpretation of aerial photograph. Fourteen classes were created based on the visual interpretation of aerial photograph.

2.4.2. Benthic Cover Estimation

Benthic cover estimation is needed in order to correlate with a benthic map derived from aerial photograph Interpretation. While the final benthic map which showed the coral reef area is used as a guidance and will sampled afterwards for reef coral biodiversity and rugosity measurement. The percent cover of bottom types is estimated by snorkelling on the reef. Estimation of benthic cover was done by either snorkelling on the reef or by looking from the boat with the coverage approximately 100m^2. The list of bottoms types that estimated are presented in table 1.

Table 1 List of Bottom Types

No	Bottom Types
1	Live Coral
2	Dead Coral
3	Dead Coral Covered by Algae
4	Rubble
5	Sea grass
6	Algae
7	Sand

2.4.3. Coral Biodiversity Data Collection

The reef corals biodiversity data collection was conducted by measuring and calculating the number of benthic categories, the percent coverage of each benthic category, and the number of coral genera (genera richness). The most common requirement of coral reef data collection methods is that it will enable to detect the coral abundance change in the site. There are five main methods regularly used in coral reef monitoring; Line intercept Transect (LIT), Line-point transect (LPT), Photo-quadrate, Video transect and Mapped Quadrate transect (Leujak and Ormond 2007). A Study of comparing the efficiency of these data collection methods have failed to reach a clear conclusion as to which methods are preferred. Each method has the advantages and the disadvantages in the term of accuracy, time and cost efficiency, generic diversity, precision and sampling effort. In this research, we used LIT as a coral reef biodiversity data collection method. LIT is the cheapest and simplest method compared to others. While it still gives good results with regard to generic diversity and percent coral cover compared with LPT, Video transect, and photo quadrate (English et al. 1997)

The Line Intercept Transect (LIT) technique was developed in terrestrial plant ecology, and was subsequently adopted by coral reef ecologists (Loya 1978 in English et al 1997). Information obtained by this method is percentage cover of benthic communities' e.g. hard coral, soft coral, sponges, algae, rock, and dead coral. Medium to detailed information can be collected from growth forms (shape) to family, genus or species level depending on objectives or expertise available. In this research, the corals biodiversity investigated in a genus level. The LIT has been used for objectives ranging from large-scale spatial problems to morphological comparisons of coral communities and studies assessing the impact of natural and anthropogenic disturbances.

In general, A 20 m long measuring tape will be carefully laid on the shallow reef area parallel as close as possible to the reef escarpment. The location of sampling marked with IPAQ Mobile GPS. All objects (benthic types) under the roll meter are recorded, the transition (end number of roll meter) length of each object is written down (all data are written down on the waterproof paper using waterproof pencil). A list of benthic categories that used in the research is presented in the table 2:

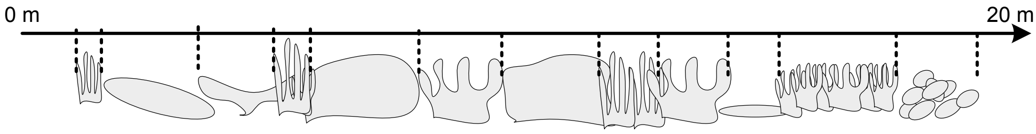


Figure 6 Line Intercepts Transect Method

Table 2 List of Benthic Categories

Category	Explanation	Category	Explanation
LC	Live hard coral (Scleractinia)	MU	Mud (muddy material)
DC	Bleached / white dead coral	SG	Sea grass
DCA	Dead coral covered by algae	SC	Soft coral
RU	Rubble and Rock	AL	Algae
SA	Sand (sandy material)	OT	Others

If LC found in the transect line, then identify the genus and record the size (Figure 2 and 5). In case of uncertainty, then a picture is taken using underwater camera. Genus identification was done on the land using reference book (Suharsono 1996; Veron 2000). If the tape overlies a sample of the SG category, then it will be identified to species level (*Enhalus acoroides, Thalissia hemprichii, Cymodocea rotundata*, *C. serullata, H. pinifolia, Halodule uninervis, Halophila ovalis, H. minor, Syringodium isoetifolium, Thalassodendron ciliatum*). The algae category consists of macro algae (MA), turf algae (TA), Halimeda (HA), coralline algae (CA), algal assemblage (AA). Others category consists of man made objects (MM), ascidians (ASC), sea anemones (AN).

2.4.4. Coral Reef Rugosity Measurement

The rugosity of coral reef was measured by carefully laying a steel chain (links of 2.5 cm long) to the reef surface. The rugosity measurement is in line with the location with LIT for coral biodiversity measurements. The 20 meter chain was used in this measurement following the length of measuring tape that used in LIT (Figure 4 and 5). A rugosity index ,C, is calculated as C=1-d/l. where d is horizontal distance covered by chain that follows the contour of the reef and l is its length with fully extended (20 m) (Risk 1972; Aronson and Precht 1995, 1994; Knuby and LeDrew 2007).

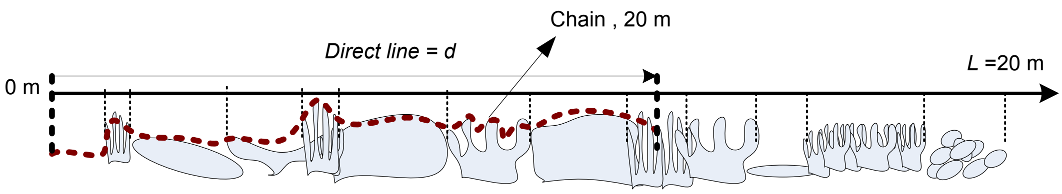


Figure 7 Rugosity Measurement

Figure 8.Coral biodiversity and Rugosity Measurement

2.5. Data Analysis

2.5.1. Coral biodiversity Data

Coral biodiversity data was analyzed using the percent coral cover and biodiversity Indices i.e. diversity index, genera richness, evenness, and dominant genus. Diversity index is a composite indicator which represents richness and evenness. Shannon diversity index is a method that has been most widely used in coral reef biodiversity research among all methods (Meixia et al. 2008).

Genera richness ***(S)*** was calculated by counting the number of genera that found under the roll meter line. Shannon diversity was calculated as ***H'***=*-Σpi ln(pi)*, where *pi* is the proportion cover of the *i*th genera along the roll meter line. ***H'*** was not calculated based on the number of colonies but based on proportional cover of genera since it was not able to define that the coral found is belong to the same colony. Shannon evenness was calculated as ***EH***= *H'/lnS*. Dominant genus is identified based on the percent cover for each genus.

2.5.2. Coral Genera Composition

A coral genus was grouped based on their occurrences and abundance. The expected result is that coral genus would be in the group of similar location/habitat. Coral genera composition analysis was done using *TWINSPAN* (Two-way indicator species analysis) software. This analysis is designed to construct ordered two-way tables, and the method of doing so is by identification of differential genus. The samples are classified first, and then the genus is classified second, using the classification of the samples as a basis. The two classifications are then used together to obtain an ordered two-way table that expresses the genus '*synecological'* relations, which grouped the coral genera based on similar location/habitat, as succinctly as possible.

The steps of coral genera composition analysis using *TWINSPAN* are as follows.

1. Coral genera data are constructing in a two way table, reflecting its occurrence and percent cover.
2. Exporting the data into full format text file that accepted by the software

3. Importing data and specify the type of analysis.
4. Define the cut level for percent cover value. The cut level is chosen to 0,10, 20,30, and 40 reflecting the abundance and cover of each coral genus.
5. Define the maximum number of division level (4), minimum number of group size that can be further divided (5), and maximum number of division level (2).

In addition, the result table was exported to the GIS software in order to get insight of geographical distribution of group member.

2.5.3. Coral Reef Rugosity

Coral reef rugosity is indicated by an index that resulted from coral reef topography measurement. In order to compare the rugosity index in Bunaken Island and in Tombariri area, an independent t-test was performed. The independent t-test is used to asses the statistical significant different between the means of two variable which are independent one from another and belong to continuous data (Moore et al. 2009). The significant level of 95% is chosen as well as a rule of thumb in the natural resources. The SPSS software was employed to do the *t-test*.

2.5.4. Relationship between Rugosity and Coral biodiversity

The relationships between rugosity and coral biodiversity were tested using a correlation test. It is usually written as r. The correlation measures the direction and strength of the linear relationships between two quantitative variables. Correlation requires both variables to be quantitative. Therefore, dominant genera indices were excluded in the correlation analysis.

The commonly used correlation test is a *Pearson* correlation (Moore et al. 2009). The correlation is always a number between -1 and 1. Values of r near 0 indicate a very weak linear relationship. The strength of relationship increases as r moves away from o toward either -1 or 1. The null hypothesis most commonly tested with Pearson’s correlation coefficient is that the population correlation coefficient equals zero. And then the significance of correlation was rested using a t statistic. Correlations analyses were done using SPSS software. The null hypothesis in this case is there are no relation between investigated biodiversity indices and coral reef rugosity index.

A relationship between rugosity and coral biodiversity also were explored using linear and second order polynomial regression. Second order relationship was employed because there is an intermediate disturbance hypothesis which stated that diversity will be maximal at intermediate level of disturbances (Connell 1978). The coefficients of determination,r^2, of these regressions are reported, and an independent t-test was performed to check if the regression coefficients for linear regression or second order coefficients for polynomial regression were significantly different from zero.

Data transformation is suggested for data that reflects to the percentage or proportional data before statistical analysis, i.e. coral cover and Rugosity. The recommended data transformation for this case is the arcsine-transformation. Species richness data which are in the form of counts data also require transformation using logarithmic transformation. In contrast, Shannon diversity index data are normally distributed therefore does not require any transformation (Magguran 1998). However, statistical analysis of transformed and untransformed data yielded a similar result. Thus for the calculations presented in the next chapter are based on the untransformed data.

3. Result

3.1. Benthic Map

In Total, 188 observation points were visited during the fieldwork in order to correlate the benthic type as a result of visual interpretation and in the field. And then the data acquired from benthic estimation were classified using classification system presented in table 3 in order to create benthic map classes. The detailed of observation point and its cover is presented in the appendix B. Two thematic maps in figure 9 and 10 shows the benthic types of Bunaken Island and Tombariri respectively. A total of 11 class benthic types and other 3 classes are displayed, namely dense coral, open coral, dead coral,dead coral covered by algae, dense segrass *Thallasia hemprichii*, dense seagrass *Enhalus acoroides*, dense seagrass *Thallasodendron ciliatum*, open segrass *Thallasia hemprichii*, open segrass *Halodule ovalis*, rubble, sand, water, mangrove and Land. Note that dense segrass *Enhallus acoroides*, open seagrass *Halodule ovalis* and dense seagrass *Thallasodendron ciliatum* only found at Tombariri area.

Table 3 Classification Scheme for Benthic Classess

Live Coral	Dead Coral	Seagrass	DC Algae	Rubble	Algae	Sand	Classes
>=40%							Dense Coral
20<=LC<40							Open Coral
LC<20	>=50						Dead Coral
	DC<50%	>=50%					Dense Seagrass *
		20%<=SG<50%					Open Seagrass *
		SG<20%	>=50%				Dead Coral Covered by Algae
			<50%	>=50%			Rubble
					<50%	>=70%	Sand
						LC + DC > 20	Open Coral
						RU+S>60	Rubble
							Water
							Mangrove
							Land

* Species level

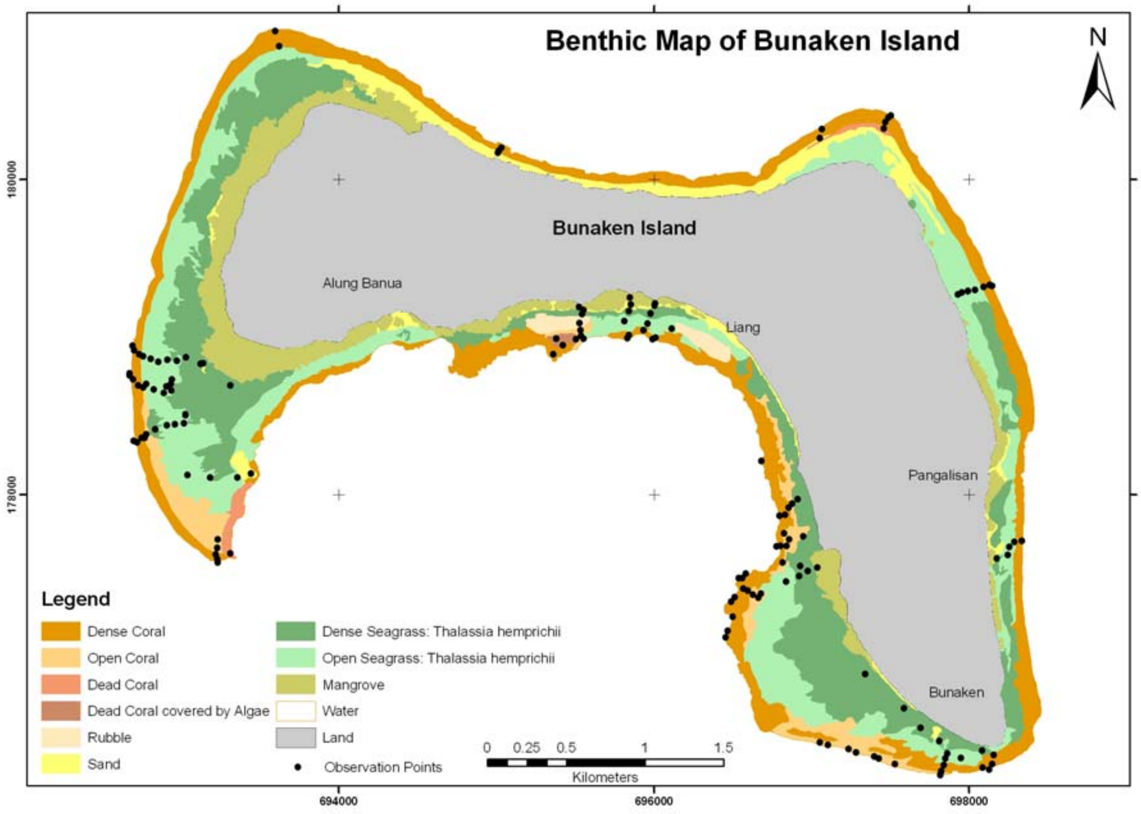


Figure 9 Bunaken Benthic Map

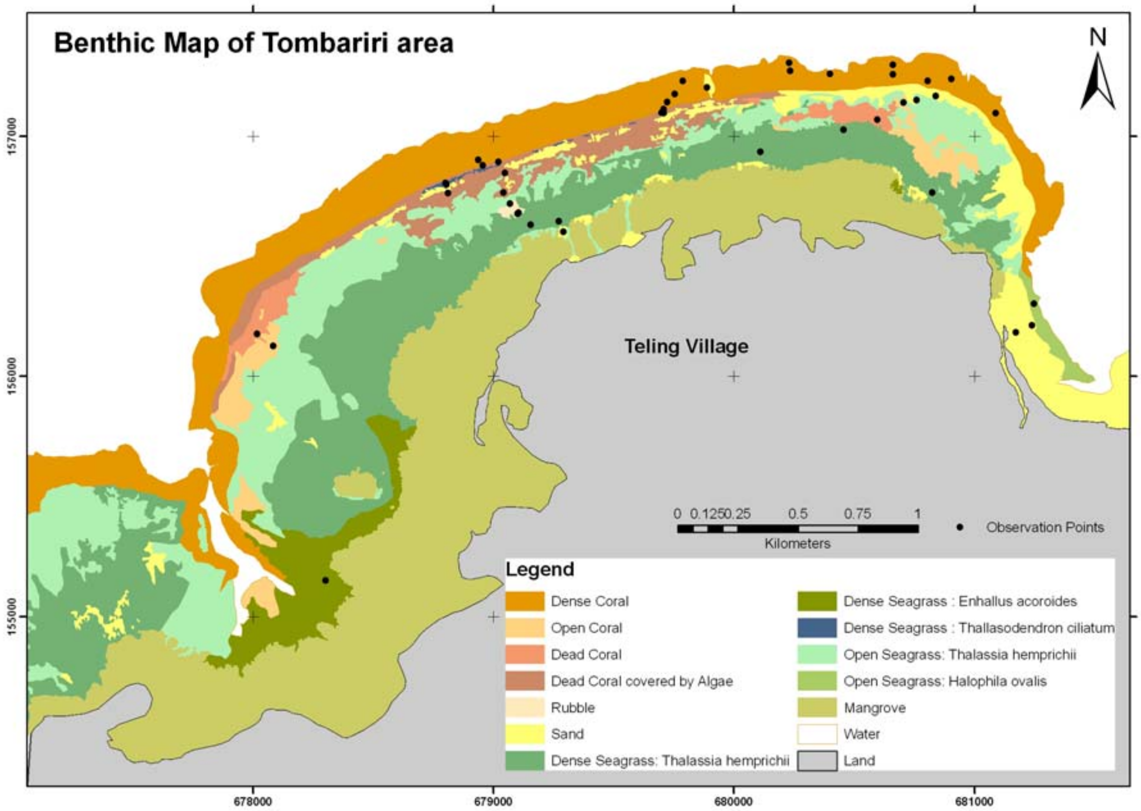


Figure 10 Tombariri Benthic map

3.1.1. Accuracy Assesment

Accuracy assessment for benthic map was performed based on error matrix presented in table 4. Total of 188 observation points were used as the reference points. Note that the same points were used in the classification process also used in the accuracy assessment. The overall accuracy achieved is 71.8%. The highest source of error in accuracy assessment is coming from the dead coral. There are 6 of 14 points were classified as dense coral and open coral which is 9 of 28 reference point are classified as dense coral. In addition, in the dense sea grass *Thallasia hemprichii* class error also noticed. There are 6 out of 14 reference points were classified as open sea grass *Thallasia hemprichii*. But it is still acceptable since they are the same species sea grass.

Table 4 Accuracy Assessment

Classes	Dense Coral	Open Coral	Dead Coral	Dead Coral covered by Algae	Dense Seagrass *Thalassia hemprichii*	Dense Seagrass *Enhalus Acoroides*	Dense Seagrass *Thallasodendron ciliatum*	Open Seagrass *Thalassia hemprichii*	Open Seagrass *Halophylla ovalis*	Rubble	Sand	Water	Mangrove	Grand Total	User Accuracy
Dense Coral	37	9	6	1						2		1		56	66%
Open Coral	1	14	3	1				1		2	5			27	52%
Dead Coral			4											4	100%
Dead Coral covered by Algae		1		6							1			8	75%
Dense Seagrass: *Thalassia hemprichii*		1			19			2						22	86%
Dense Seagrass : *Enhalus acoroides*						1								1	100%
Dense Seagrass : *Thallasodendron ciliatum*							2							2	100%
Open Seagrass: *Thalassia hemprichii*		3	1		6			23		1				34	68%
Open Seagrass: *Halophila Ovalis*									1					1	100%
Rubble	1							1		2				4	50%
Sand					1			2			10			13	77%
Water												12		12	100%
Mangrove													4	4	100%
Grand Total	39	28	14	8	26	1	2	29	1	7	16	13	4	188	83%
Producer Accuracy	95%	50%	29%	75%	73%	100%	100%	79%	100%	29%	63%	92%	100%	76%	**71.8%**

3.1.2. Comparison between Benthic Cover by Estimation and Measurement

Comparison was done in order to know how well or reliable the result of benthic estimation is compared to measurement (Table 5). The result shown that benthic cover resulted from estimation is highly correlated with the value from Line intercept transect (r=0.866 df=9, $p<0.001$). The coefficient of determinations of the linear regression between this two variable is high and statistically significant (r^2=0.75 df=9 t=5.193, $p<0.001$: fig 11). Therefore the benthic cover estimation is comparable with benthic cover estimation by means Line Intercept Transect.

Table 5 showed that in general the closer the distance between benthic estimation point and benthic measurements, the lower the differences between estimation and measurement.

Table 5 Comparison between Coral Cover Estimation and Measurement

No	Location	Coral Cover (%)		Distance (m)
		Estimation	LIT	
1	Bunaken Island	30	29.4	11.8
2	Tombariri	20	44.5	17.6
3	Bunaken Island	40	44.7	25.3
4	Bunaken Island	90	86.2	25.6
5	Bunaken Island	30	24.2	41.7
6	Bunaken Island	40	51.3	50.0
7	Bunaken Island	70	71.6	57.1
8	Bunaken Island	70	54.8	58.5
9	Tombariri	70	78.2	63.4
10	Bunaken Island	5.0	36.1	68.1
11	Bunaken Island	30	41.4	72.2

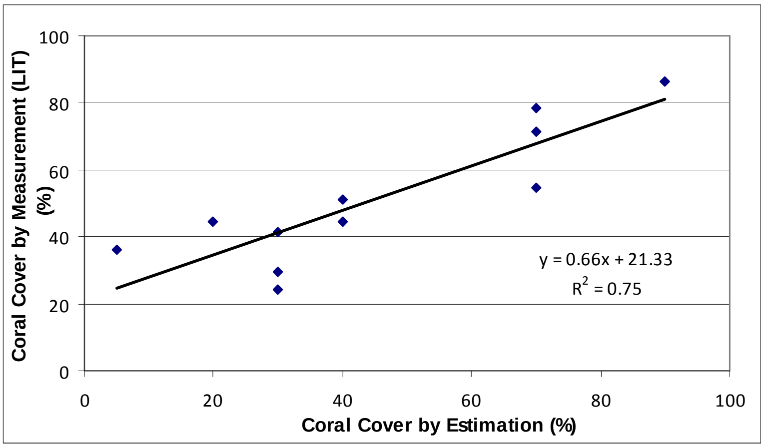


Figure 11 Linear Regression Analysis between Coral Cover by Estimation and Measurement

3.2. Coral Cover in The Coral Zone

Percent of Coral cover in the study area range between 6%-80% with an average is 46%±0.22 (Mean±SD). The lower percent coral cover in Tombariri area is 6% and the maximum value is 78%. The lower percent coral cover in Tombariri occurs in the area which is near the river mouth (sample 10 and 41, Figure 13b). In addition, these areas surprisingly have higher percent cover of soft coral. The higher coral coverage found in the reef which is located in the wave exposed area. In Bunaken Island, percent coral cover seems to be higher than Tombariri area and has the range between 10%-80%. The area with higher coral cover is lies in the eastern part of Bunaken Island, from Pangalisan until in front of Bunaken Village (Figure 13a). While the lowest coral cover value is found in the reef located on the western part of Bunaken Island. Like wise, the percent coral cover is tend to be higher in the sheltered area than in the wave exposed area.

On average, coral cover proportion in Bunaken Island is higher than in Tombariri, namely 47% and 44% respectively. However, a statistical analysis have showed that there is no significant difference in percent coral cover between Tombariri and Bunaken Island (t-test, t= -0.401 , df= 39 , P >0.05).

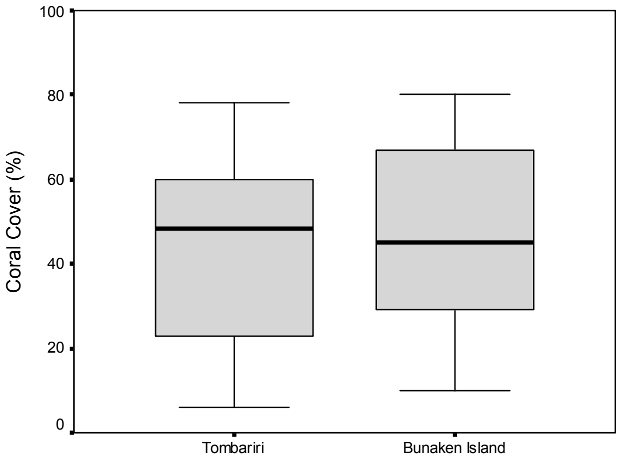
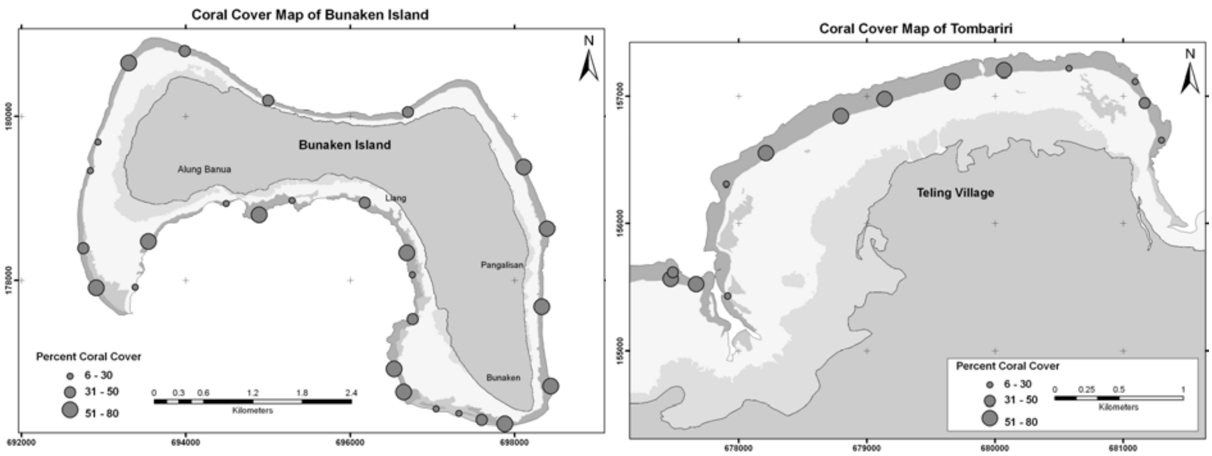


Figure 12 Comparison of Percent Coral cover in Tombariri and Bunaken Island.



(a) Bunaken Island (b) Tombariri

Figure 13 Coral Cover Map

3.3. Coral Biodiversity in The Coral Zone

Coral genera diversity data was collected using Line intercept transect in 41 locations in Tombariri and Bunaken Island Area. A 44 coral genus were found during data collection. The detailed data contained the list of each genera and its cover are presented in appendix C1-C2. Then data was analysed for biodiversity indices (appendix D). The diversity indices that used here are Genera richness **(S)**, Diversity Index (***H'***), Evenness (***E***), and dominant genus.

3.3.1. Genera Richness

Genera richness was calculated by counting all coral genera that found under roll meter line. Overall, the average genera found per sample in the study area is 10.7±4.33 (mean±SD). The result shows that Bunaken Island generally has less coral genera than Tombariri area (figure 14). The total number of coral genera found in samples at Bunaken Island is ranging from 5 to 19 with the average is 10.48 ±4.37 (Mean±SD). The higher genera richness in Bunaken Island is located in the sheltered area, following the pattern of percent coral cover (figure 15a). While the minimum, maximum, and the average number of coral genera in Tombariri is 5, 18, and 11±4 (Mean±SD) respectively. Here, the more coral genera were found in the central part of Tombariri reef (figure 15b).

On average, Tombariri has slightly higher genera richness than Bunaken Island but it is not statistically significant (t test, t=0.359. df= 39, p>0.051)

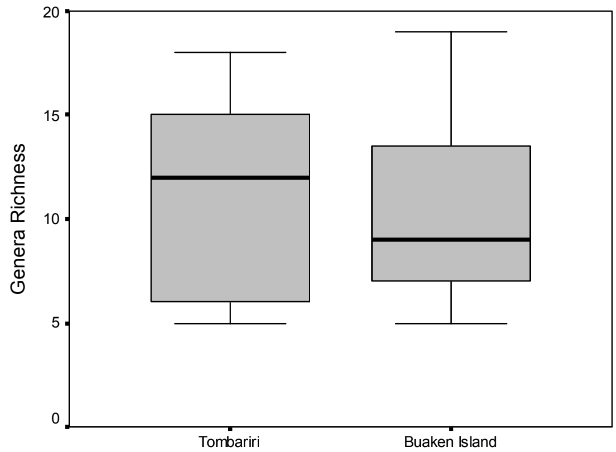
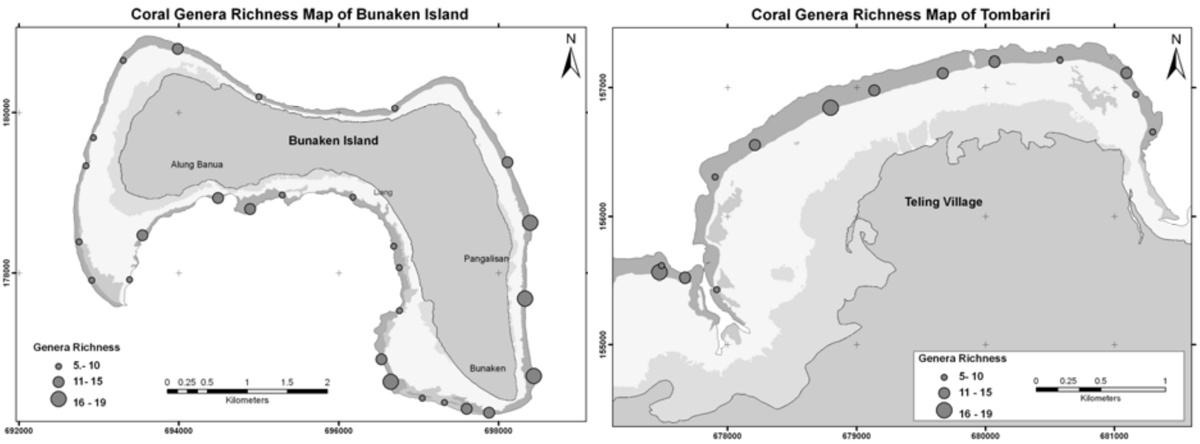


Figure 14 Comparison between Coral Genera Richness in Bunaken Island and Tombariri



(a) Bunaken Island (b) Tombariri

Figure 15 Coral Genera Richness Map

3.3.2. Diversity Index

Shannon diversity index (H') method was used instead of other diversity index to explain the diversity of corals in the study area. Overall, the average of diversity index in the study area is 1.65±0.46 (mean ± SD). The figure 16 shows that the range of *H'* in Bunaken Island is wider that in Tombariri area but the median value is similar. In Bunaken Island the Shannon diversity Index range from 0.45 to 2.34 with the average value is 1.58 ±0.48 (Mean±SD). In Tombariri area, diversity index ranged between 0.87 until 2.40 with the average 1.77±0.41 (Mean±SD). There is one sample that has very low diversity index in the Tombariri reef, namely sample 3 with the Shannon diversity index value 0.87. This sample is located in the eastern part of Tombariri reef zone, relatively closed to the river mouth. But when this value compared to the lowest value in Bunaken Island (0.45), this value is not too extreme. The geographic distribution of diversity index in Bunaken Island and Tombariri can be found in the figure 17a and 17b respectively.

On average, diversity index of reef-building corals in Tombariri and Bunaken Island is seems to be similar. A statistical analysis was performed to confirm this statement and resulting that there is not a significant difference in diversity index between Tombariri and Bunaken Island (t-test, t= 1.249, df= 39, P > 0.05).

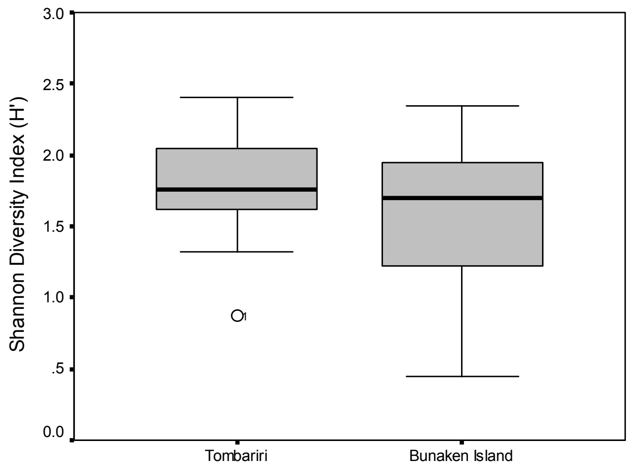
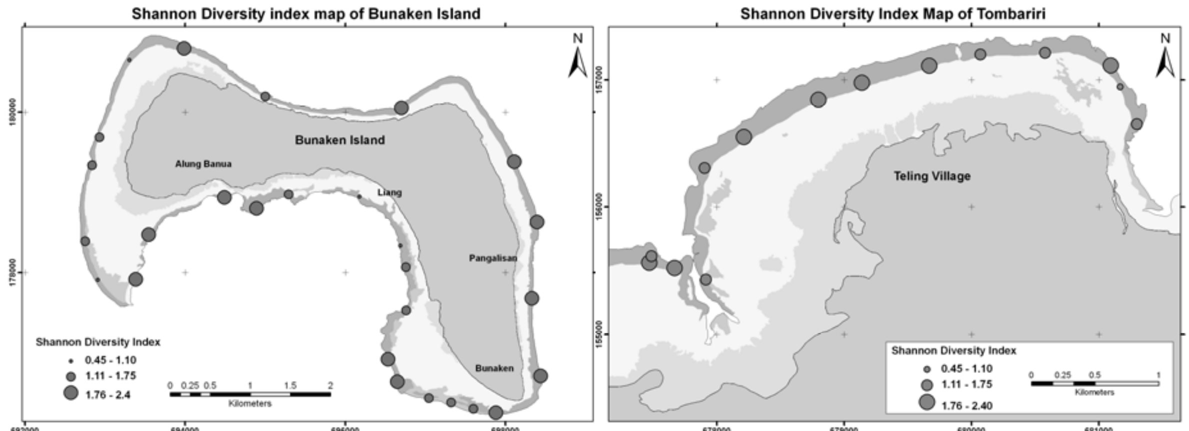


Figure 16 Comparison of Diversity Index in Tombariri and Bunaken Island



(a) Bunaken Island (b) Tombariri

Figure 17 Shannon Diversity Index Map

3.3.3. Evenness

The Evenness value may range from 0 to almost 1 indicating pronounced dominant and almost equal abundance of all genera respectively. The figure 18 shows the value of Evenness in both of area, Bunaken Island and Tombariri area respectively. A coral genera evenness value in Bunaken Island is ranging from 0.28 to 0.89 with the average value is 0.69±0.14 (Mean±SD). The lowest evenness value is found on sample number 14 located in front of Liang Beach. This value is very low compared with others. Furthermore, the highest evenness value is found at the western part of Bunaken Island, i.e. sample number 31.The minimum value of evenness in Tombariri is 0.54, the maximum value is 0.95, and the mean value is 0.76±0.11 (Mean±SD). Surprisingly, both minimum and maximum values are located in the eastern part of Tombariri area. The distribution of evenness value in Bunaken Island and Tombariri can be found in Figure 19a and 19b respectively.

Overall, the mean value of evenness in the study area is 0.72 and the standard deviation is 0.14. On average, the evenness value in Tombariri is slight higher than in Bunaken Island. However, a statistical analysis revealed that there is no significant difference of coral genera evenness value in Bunaken and Tombariri (t test, t= 1.693, df = 39, p>0.05).

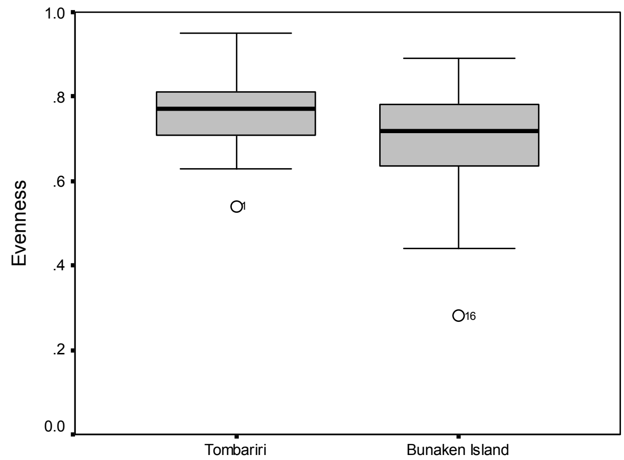
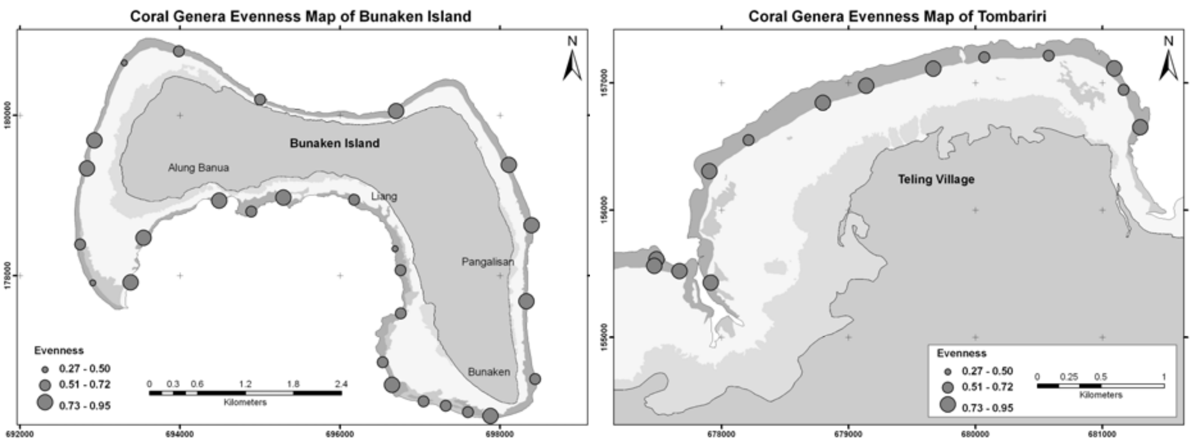


Figure 18 Comparison of Coral Genera Evennes in Tombariri and Bunaken Island



(a) Bunaken Island (b) Tombariri

Figure 19 Coral Genera Evenness Map

3.3.4. Dominant Genera

In both of study area, *Porites* is the dominant coral genera*. Porites* has the higher cover than others in 28 samples (68%) which are 8 samples in Tombariri and 20 samples in Bunaken Island (Figure 20). They most dominated the sheltered and wave-exposed area in Bunaken Island (Figure 21a).

The pattern of dominant genera in Tombariri is different compared to Bunaken Island. Here *Porites* was not the only dominant genera in the wave exposed area but together with *Montipora, Astreopora* and *Acropora*. In addition, there are 2 specific sample locations that dominated by *Stylophora*. Both of them are located near the river mouth, namely sample 10 and 41 (figure 21b).

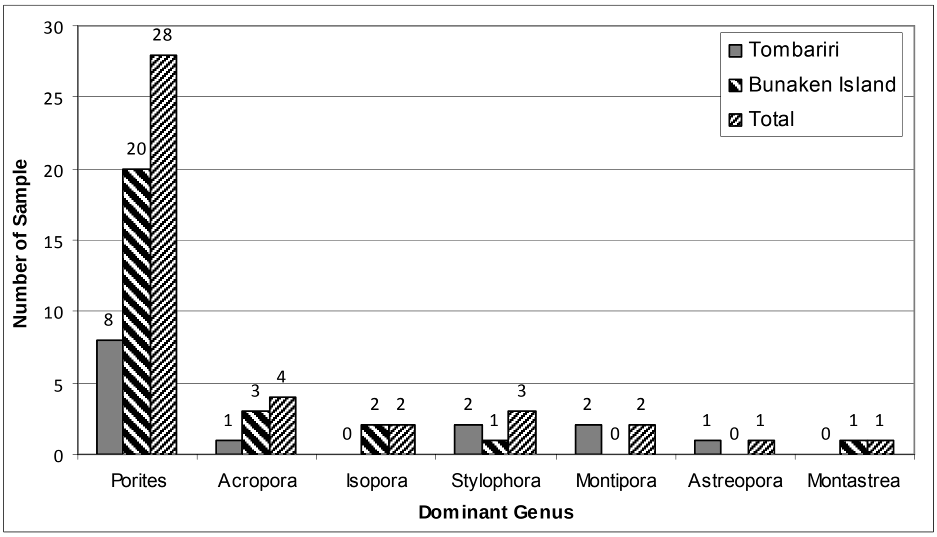


Figure 20 Dominant Coral Genera in the Study Area

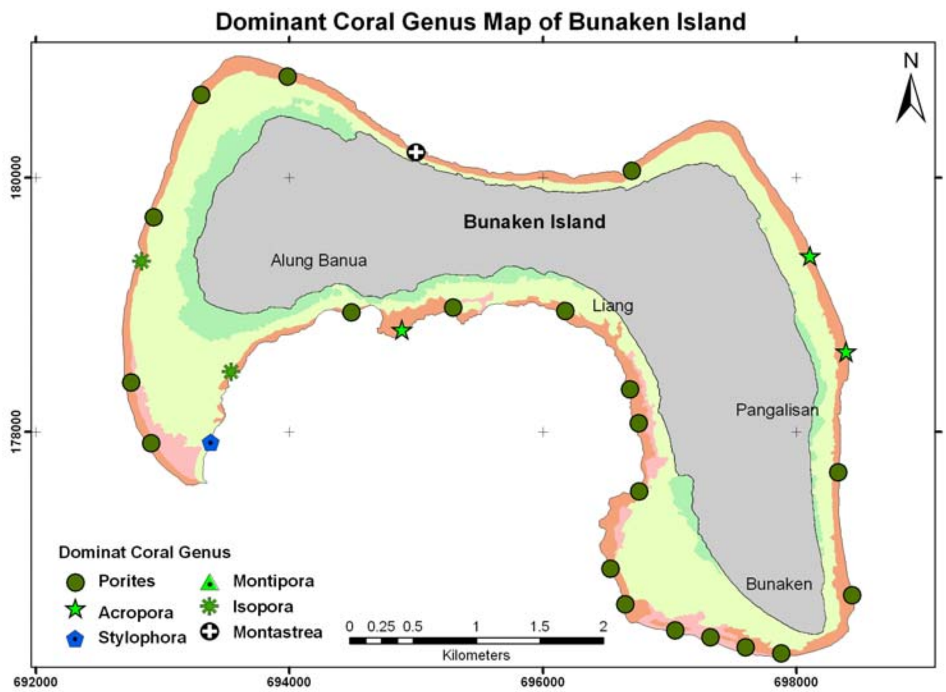
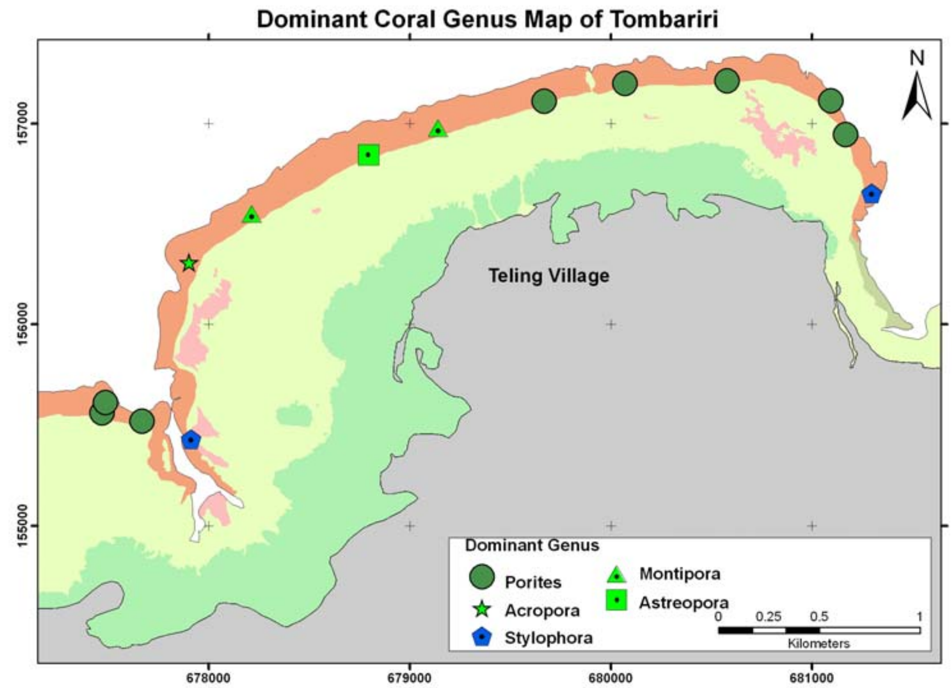


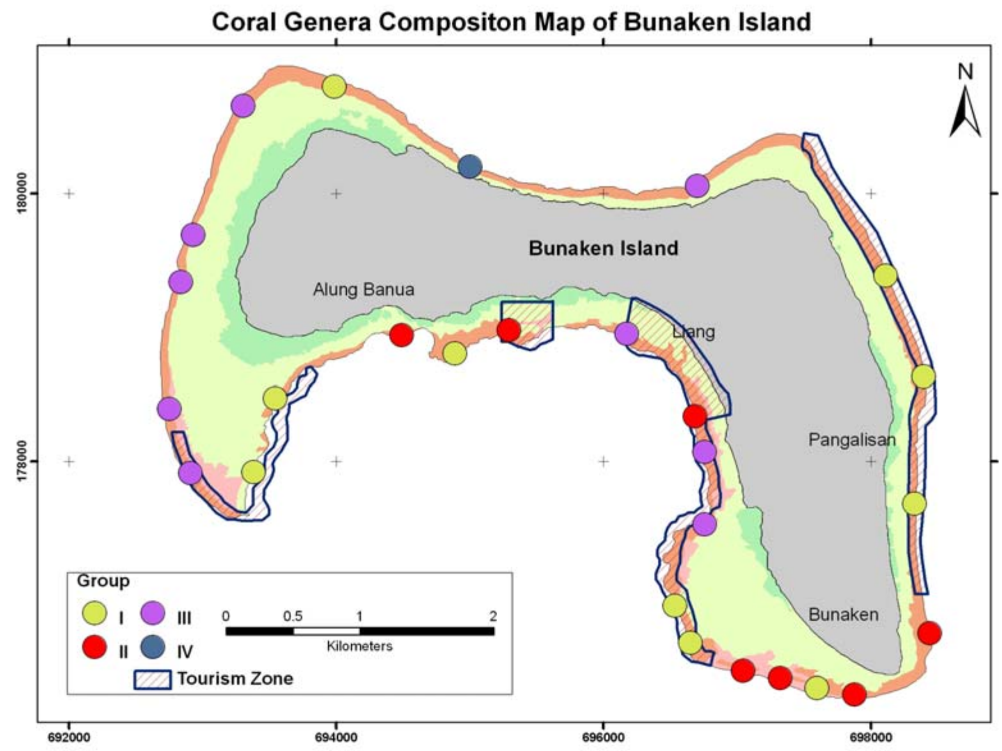
Figure 21a. Dominant Genus Map Bunaken Island



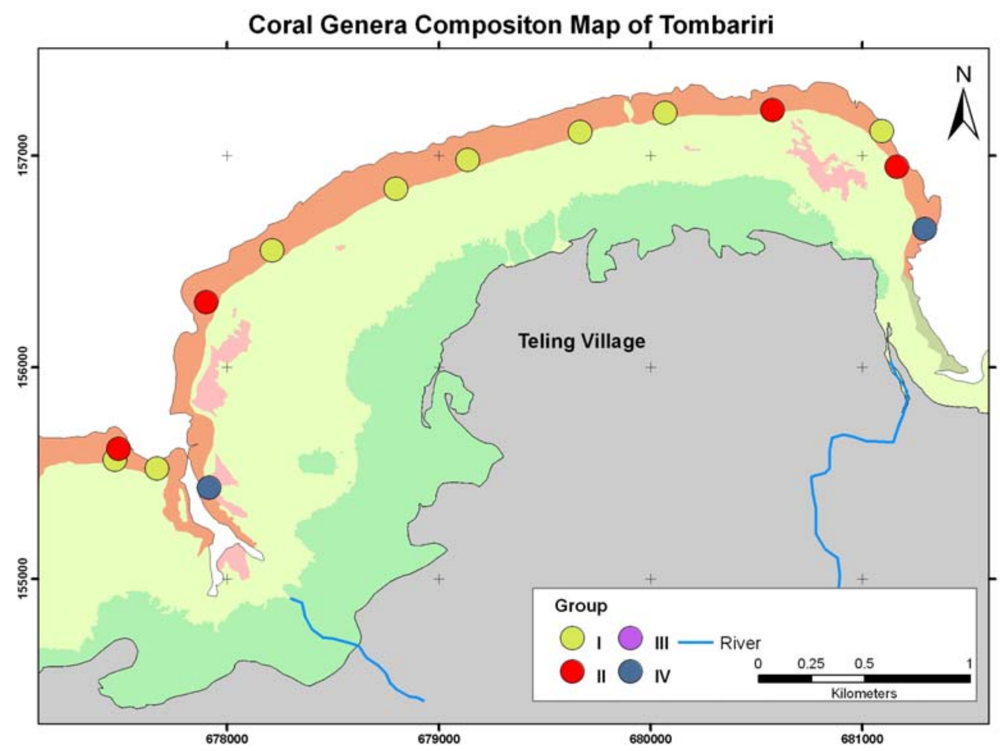
21b. Tombariri
Figure 21 Dominant Genus Map in Bunaken Island and Tombariri.

3.3.5. Coral Genera Composition

Coral reefs in the study area were grouped by its genera composition using TWINSPAN software. Four groups were revealed indicating the different community structure of coral reef (Table 6). Group 1 was identified by specific genus which has more abundance in this group compared to others, namely *Astreopora, Acropora, Chypastrea, Leptastrea, Montipora, Pocillopora, Stylocoeniella*, and *Pachyseris*. In contrast, the second group was renowned by absence of *Astreopora, Chypastrea, Leptastrea, Pocillopora, Stylocoeniella*, and *Pachyseris*. Furthermore *Galaxea and Montastrea* also could not found in most of the group member. In addition, the presence of *Turbinaria* has noticed in this group. The third group recognized by the presence of *Heliopora* and *Isopora* but less abundance of *Goniopora, Goniastrea, Montipora, Pocillopora* and *Acropora* compared to group 1 and group 2. The last group is the group which has less both coral cover and genera present (group IV). The maps showing the distribution of each group member in both Bunaken Island and Tombariri are presented in figure 22a and 22b respectively.



a. Coral Genera Composition Map: Bunaken Island



b. Coral Genera Composition Map: Tombari

Figure 22 Coral Genera Composition Map

Table 6 Coral Genera Composition

	Sample 13	Sample 19	Sample 31	Sample 32	Sample 35	Sample 11	Sample 06	Sample 09	Sample 16	Sample 17	Sample 21	Sample 36	Sample 42	Sample 39	Sample 40	Sample 44	Sample 43	Sample 45	Sample 03	Sample 04	Sample 07	Sample 08	Sample 14	Sample 18	Sample 22	Sample 23	Sample 28	Sample 33	Sample 37	Sample 15	Sample 24	Sample 25	Sample 26	Sample 27	Sample 29	Sample 30	Sample 34	Sample 38	Sample 10	Sample 20	Sample 41	
Acropora	1	1	1	2	1	1	1	1	3	1		3	2	4	1	2	1	2	1	1	1	1	1	1			1	1	1					1								0
Montipora	1	1			1	1	2	1	1	1	1	1	2	1	1	3	1	2	1		1			1	1			1	1	1					1	1						0
Symphyllia	1	1	1	1	1		1		1		1	1	1		1	1	1	1						1	1	1			1													0
Astreopora		1		1	1	1		2	1	1					1	1		1							1													1				0
Cyphastrea		1	1	1	1		1				1			1	1		1	1																			1					0
Leptastrea	1					1		1			1	1	1	1	1	1	1	1																								0
Pocillopora	1				1	1	1	1		1	1		1	1		1	1	1												1	1				1						1	0
Stylocoeniella							1	1		1			1	1	1	1																										0
Pachyseris				1						1				1	1														1													0
Acanthastrea					1							1																														0
Echinopora									1			1		1																												0
Hydnophora												1	1																													0
Oxypora											1		1																1													0
Cycloseris										1																			1													0
Oulophyllia									1		1	1																														0
Pectinia								1	1	1														1																		0
Anacropo							1	1																																		0
Psammocora							1	1																																		0
Ctenactis						1																							1													0
Turbinaria																				1	1	1																				0
Fungia					1					1					1						1		1					1											1			1
Pavona		1			1		1						1			1				1									1					1								1
Goniopora	1			1		1	1			1							1	1	1		1			1	1		1		1				1						1		1	1
Goniastrea	2	1	1	1	1		1		1	1	1	1	1	1	1	1	1	1	1	1	1			2	1	1	1	1	1	1	1	1				1	1	1				1
Galaxea	1	1			1	1			1	1	1	1	1			1		1										1	1		1						1		1	1	1	10
Montastrea			1		1		1	1					1	1	1	1	1	1										1	1		1	1			1				-	3	-	10
Diploastrea												1						1															1	1							1	11
Heliopora																															1	1	1							1		11
Favia		1	1	1	1		1			1	1	1								1				1		1		1	1		1				1	1	1	1				11
Favites		1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1	1		1	1	1	1	1	1		1	1	1	1	1	1	1			1		11
Porites	3	3	1	1	3	1	2	1	2	3	3	2	3	3	3	2	4	2	4	2	2	1	5	2	2	2	2	1	4	5	2	1	1	3	1	5	3	3			1	11
Stylophora	1	1	1	1	1		1	1	1	2										1			1	1				1	1	2	1					1	2		1	1	1	11
Isopora			1	3	1							1		1																	1		2	2		2						11
Lobophyllia	1				1								1				1							1		1								1			1	1		1		11
Platygyra				1																																				1		11
Seriatopora																1																										11
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	
	Group I																		Group II											Group III									Group IV			

Note : The value presented in the table are the range of percent cover of coral genera. 1 = 1-9 %, 2=10-19%, 3= 20-29%, 4= 30-39%, 5= >40%

3.4. Coral Reef Rugosity

Rugosity index in the 41 locations are ranged from 0.07 to 0.38 and the average is 0.24± 0.07 (Mean ± SD). Rugosity index (***C***) of coral reef was classified into 3 categories (Table 7), low (less than or equal to 170), moderate (0.170 <C≤ 0.275), and high (greater than 0.275). Based on table 7, 34% of the reef in Bunaken National Park has high rugosity, then 51% in moderate condition, and the rest are has flatter surface (15%).

The rugosity index in Bunaken Island ranged from 0.06 to 0.38. The mean value and standart deviation is 0.25 and 0.08 respectively. The flatter surface in Bunaken Island found on the north and northwest part of Bunaken Island namely samples 20 and 24. While the higher roughness of reef surface is generally found at eastern part of Bunaken Island, lies from Pangalisan until Bunaken Village. However, there are two locations in the north and northwest part of Bunaken Island surprisingly has high rugosity index, namely sample 15, 19, and 26.

In Tombariri reefs, fishing practises considered as the most treat to coral reef and has been thought has the more destructive effect on coral reef than the recreational activities. The rugosity index is generally similar between sample locations. It ranged from 0.15 to 0.28. The mean and the standard deviation is 0.23 and 0.05. The flatter reef surface is found in the western part of Tombariri reef near to the river mount.

On average, the reef surface in Tombariri is flatter than in Bunaken Island, but it is not statistically significant (t-test, df=39 t=-0.980, p>0.05).

Table 7 Classification and Proportion of Rugosity Index in Bunaken Marine National Park

Rugosity Index Class	Value	Bunaken Island		Tombariri		Total	
		n	%	n	%	n	%
Low	< 0.170	3	7%	3	7%	6	15%
Moderate	0.171 - 0.275	12	29%	9	22%	21	51%
High	> 0.275	12	29%	2	5%	14	34%

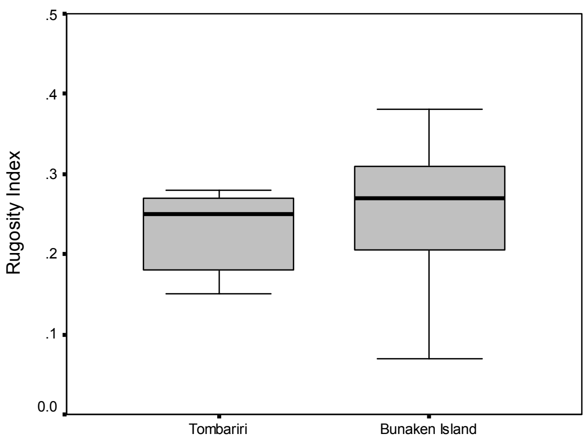
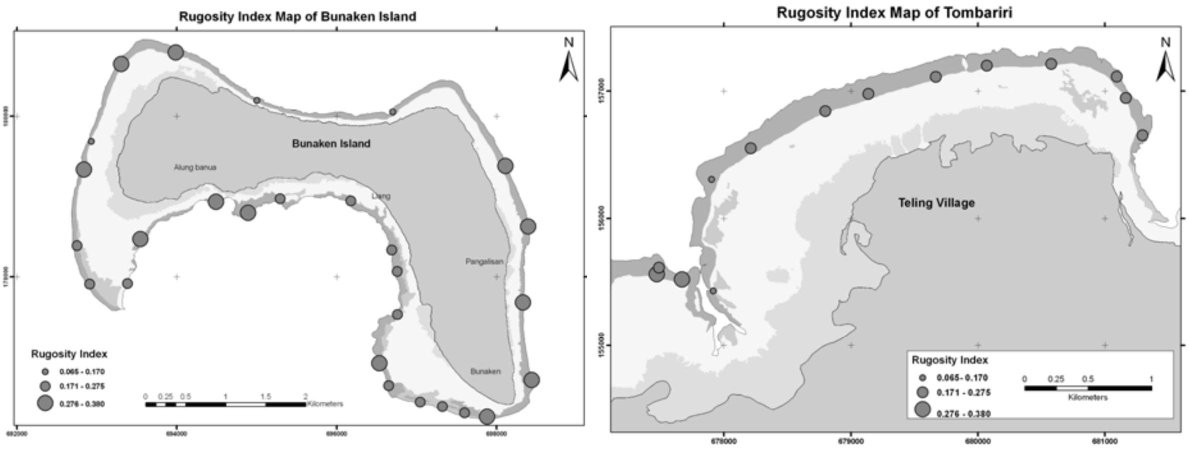


Figure 23 Comparison of Rugosity Index between Bunaken Island and Tombariri



(a) Bunaken Island (b) Tombariri

Figure 24 Rugosity Index Map of Bunaken Island and Tombariri

3.5. Relationships between Rugosity and Coral Cover

The relationship between rugosity and percent coral cover were explored using correlation test, linear regression analysis, and second-order polynomial regression analysis (Appendix E1-E3 and Fig.25). Rugosity index was positively correlated with percent coral cover (r=0.565, df=39, p<0.01). Coefficient of determination for linear regression between rugosity index and percent coral cover is also significant (r^2=0.321, t=4.29, df=39, p<0.01; Fig. 25a). In contrast, a second-order polynomial regression between rugosity index and coral cover was not significant (r^2=0.324, t=0.378, df=38, p> 0.05; Fig. 25b).

While analysis expanded in the basis of different location, ie Bunaken Island and Tombariri, Rugosity index in Tombariri generally has better correlation with coral cover (r=0.734, df=12, p<0.01) compared to Bunaken Island (r=0.38, df=25, p<0.05). Likewise, a linear regression between rugosity index and coral cover in Tombariri also gives higher coefficient of determination than Bunaken Island (Tombariri: r^2=0.52, df=12, t=3.64, p<0.01: Fig. 25e; Bunaken Island : r^2=0.296, df=25, t= 3.245, p<0.01: Fig. 25c). Second order polynomial regression in both of study area were not statistically significant (Tombariri : r^2=0.54, df=11, t=0.675, p>0.05: Fig.25f; Bunaken Island : r^2=0.303,df=24,t=0.481,p>0.05: Fig 25d).

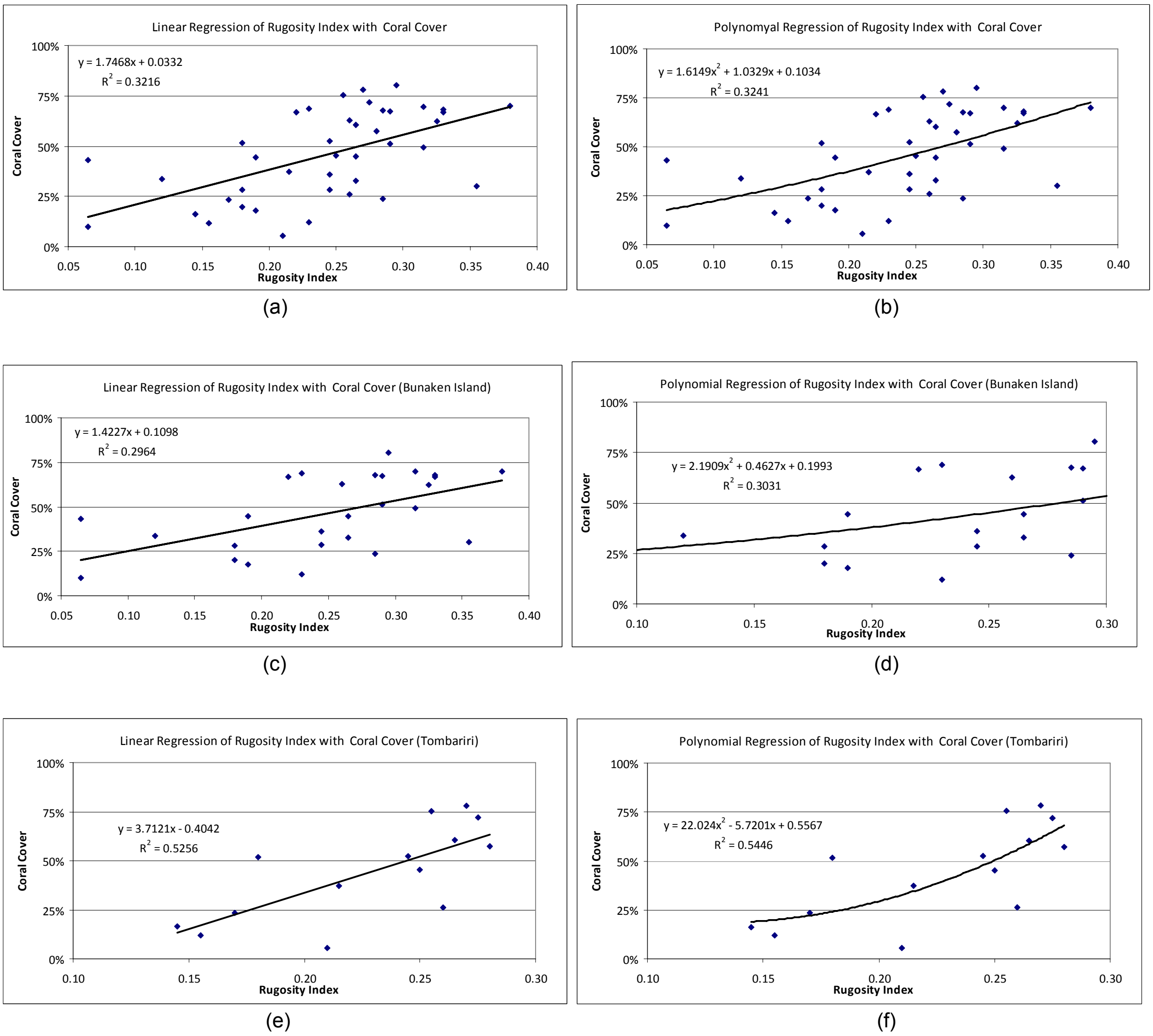


Figure 25 Relationship between Rugosity and Coral Cover

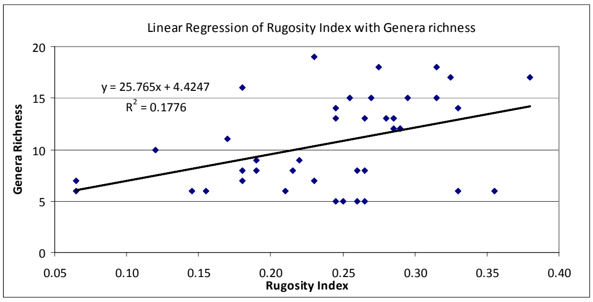
3.6. Relationships between Rugosity and Coral Biodiversity

The relationship between rugosity and coral biodiversity were explored using correlation test, linear regression, and second-order polynomial regression analysis. Detailed result of correlation test are presented in appendix E1-E3 .Second order polynomial regression analysis was performed reflecting the intermediate disturbance hypothesis on coral biodiversity proposed by Connel (1978).

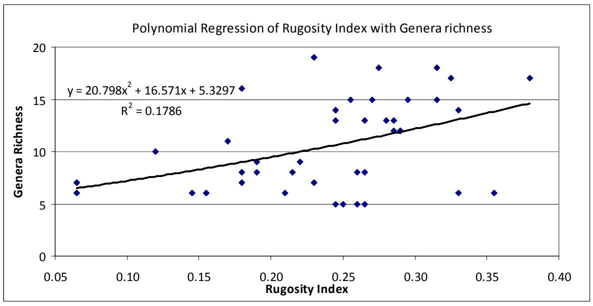
3.6.1. Rugosity-Coral Genera Richness Relationship

Overall, rugosity was positively correlated with genera richness (r=0.423,df=39,p<0.01). A linear regression analysis between rugosity and genere richness was highly significant (r^2=0.177, df=39, t=2.901,p<0.01 : Fig 26a). In contrast, a second order polynomial regression was not significant (r^2=0.178, df=38,t=0.222, p>0.05 : Fig. 26b).

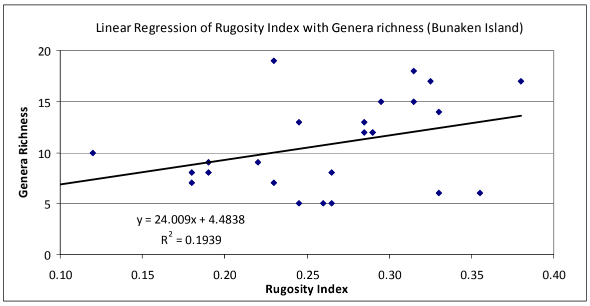
In Bunaken Island, genera richness was positively correlated with rugosity (r=0.441, df=25.p<0.01). Likewise, in Tombariri rugosity also positively correlated with genera richness and even better (r=0.480 df=12,p<0.05). A linear relationship between rugosity and genera richness in Bunaken Island was significant (r^2=0.193,df=24 t=2.45,p<0.05 :Ffig.26c) but a second order polynomial regression was not significant (r^2=0.202,df=24,t=0.511, p>0.05 : Fig.26d). In contrast, a linear relationship between rugosity and genera richness in Tombariri was marginally significant (r^2=0.22,df=11,t=1.85,p<0.1: Fig. 26e). A second order polynomials relationship also not significant (r^2=0.242,df=11,t=0.535,p>0.05 : Fig.26f).



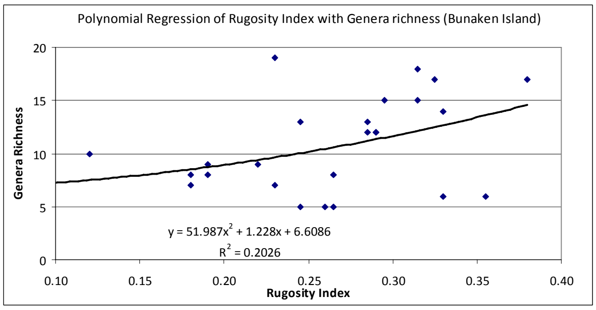
(a)



(b)



(c)



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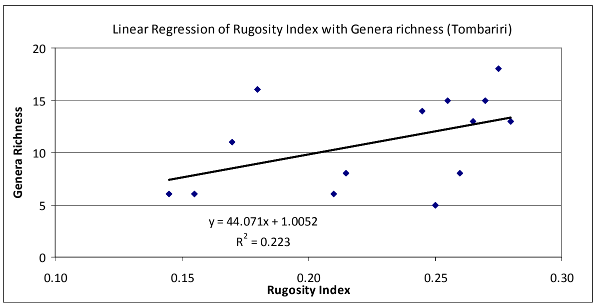
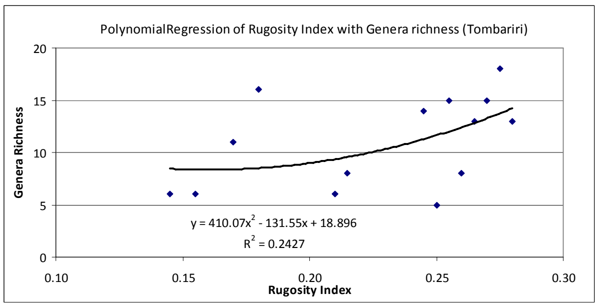


(e)



(f)

Figure 26 Rugosity –Genera Richness Relationship

3.6.2. Rugosity-Diversity Index Relationship

Correlation coefficient between rugosity and diversity index is surprisingly very weak (r=0.195,df=39,p>0.05). A linear relationship between rugosity and diversity index was not significant and accounted for almost none of the variance (r^2=0.03, df=39, t=1.239, p>0.05: Fig.27a). Likewise, a second order polynomials regression was not significant (r^2=0.04, df=38,t=0.313,p>0.05 : Fig.27b). While analysis employed in the basis of location, i.e. Bunaken Island and Tombariri, The result both of linear and second order polynomials regression had extremely low coefficient of determinations and event not significant (Bunaken Island, Linear regression : r^2=0.069,df=25,t=1.36,p>0.05 :Fig 27c; Second order polynomial regression :r^2=0.093, df=24, t=0.80, p>0.05: Fig.27d; Tombariri, Linear regression ;r^2=0.01, df=12, t=0.417, p>0.05. Fig. 27e; Second order polynomial regression r^2=0.024, df=11, t=0.331, p>0.05. Fig. 27-f)

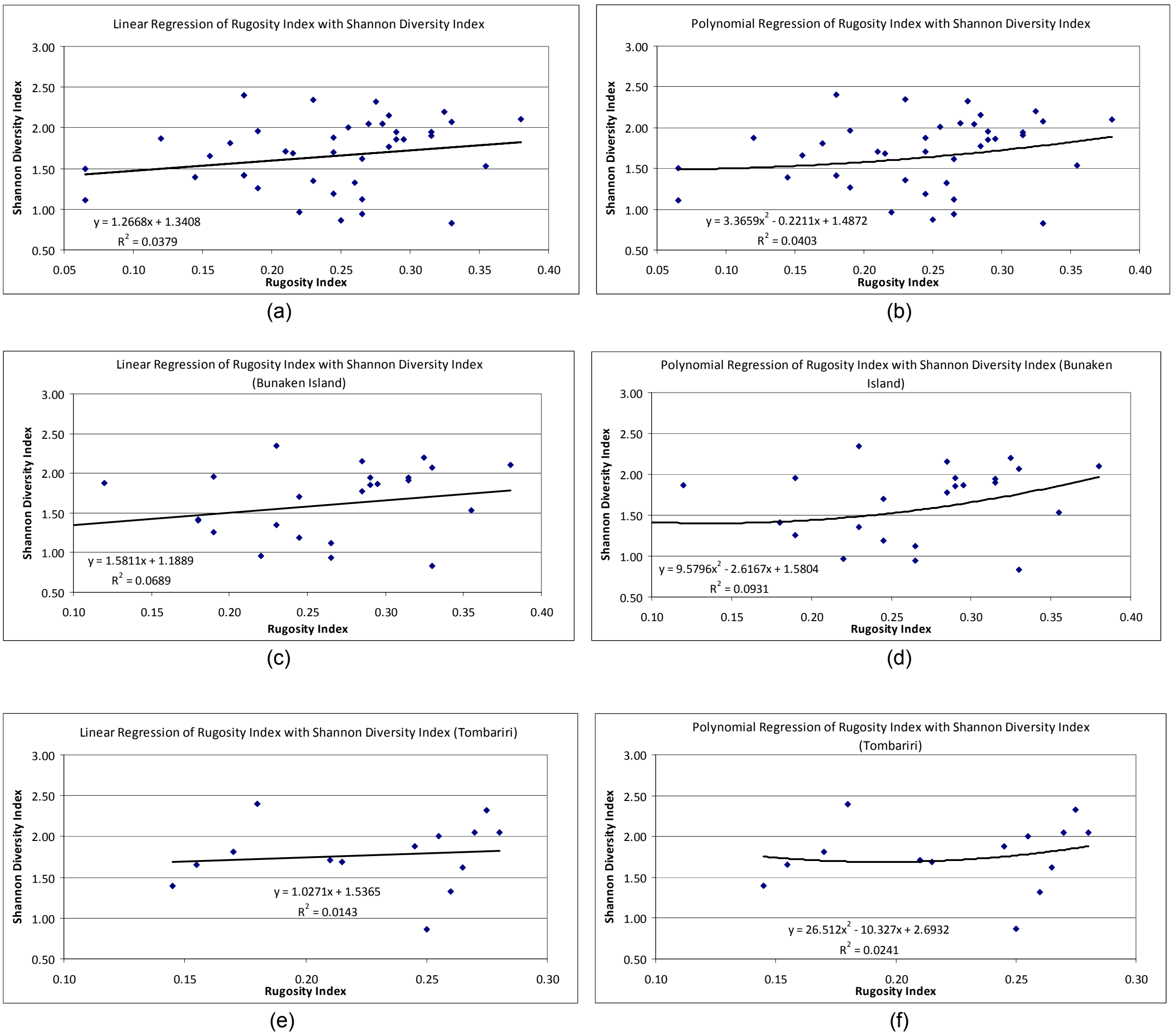


Figure 27 Rugosity-Diversity Index Relationships

3.6.3. Rugosity-Genera Evenness Relationship

In general, rugosity index was negatively correlated with evenness but it was not significant (r=-0.127,df=39,p>0.05). A linear relationship was not significant and accounted for almost none of the variance (r^2=0.016,df=39,t=0.8119,p>0.05 :Fig.28a). A second order polynomials relationship also has very weak coefficient of determination (r^2=0.023,df=38,t=0.529,p>0.05 : Fig.28b).

In Bunaken Island, rugosity has neary no correlation with evenness (r=0.0001,df=27,p>0.05). A second order polynomials regression between rugosity index and evenness was not significant and very low r square (r^2=0.04,df=24,t=1.05,p>0.05 : Fig.28d). A linear relationship was not significant and explained even less of the variance (r^2=2.72*E-6, df=25, t=0.0008, p>0.05: Fig. 28c). In opposites, rugosity index in Tombariri was negatively correlated with evenness and it was significant (r=-485,df=12,p<0.05). A linear relationship between rugosity and evenness was marginally non significant (r^2=0.233, df=12,t=-1.91,p>0.1 : Fig.28e). Similarly, a second order polynomial regression was not significant (r^2=0.0233,df=11,t=0.001,p>0.05 : Fig.28f).

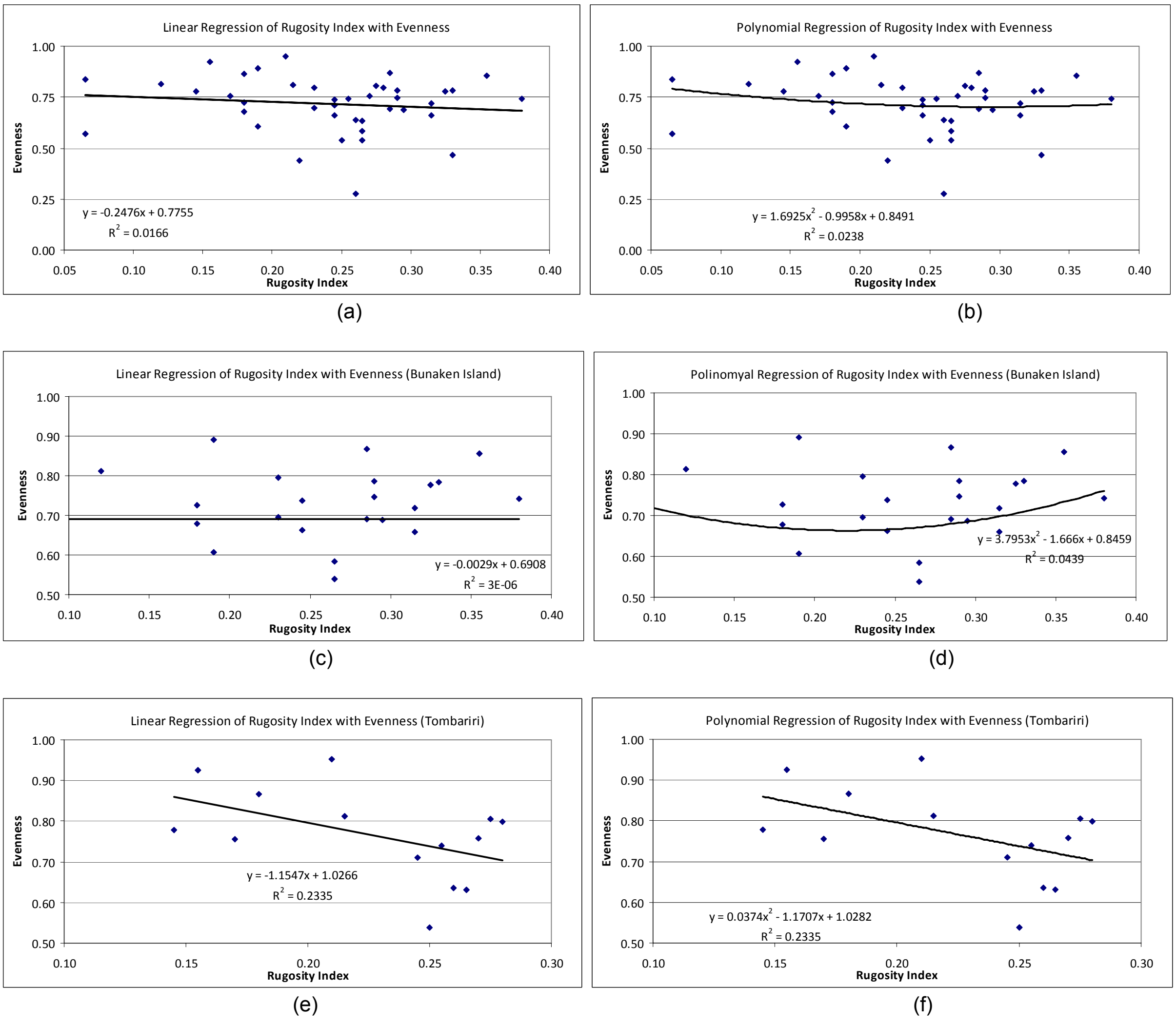


Figure 28 Rugosity-Evenness Relationships

4. Discussion

4.1. Coral Cover in The Coral Zone

In total, forty four corals genera were found during the three weeks field data collection with average percent live coral cover 46%. The percent live coral cover in Bunaken Island and Tombariri doesn't have a significant difference. In Bunaken Island the highest percent coral cover is placed in the wave-sheltered area especially in the east part of Bunaken Island. In contrast, in Tombariri the wave-exposed area surprisingly has higher coral cover compared to those in sheltered area. Wave generally reduce the abundance of coral by breaks the coral colony and turns into rubble, especially the branching and foliose coral. How ever wave can also be as an agent for coral fragmentation that leads to production of a new coral colony (Dollar 1982). In Tombariri, the low live coral cover in the wave sheltered area might be due to sedimentation and run-off from nearby river. Compared to previous research in the study area that conducted by Mehta in the year 1999, the spatial pattern of coral cover was altered. In the year 1999 the highest percent coral cover was found in the western part of Bunaken Island while the eastern part had a lower percent coral cover. This finding is contradicting with the present result. It might be due to changes in disturbance and stressor gradients.

4.2. Coral Biodiversity

There were no significant difference in the average of genera richness, Shannon diversity index and evenness between Bunaken Island and Tombariri. Genera richness and diversity index in Bunaken Island and Tombariri also has a similar distribution pattern with coral cover. Higher value of genera richness and diversity index in Bunaken Island was also found in the wave-sheltered area. While in Tombariri the higher value of genera richness and diversity index was found in wave-exposed area.

Comparisons with previous study and with others location were also performed in order to get insight about the coral biodiversity in the study area. Nevertheless it is difficult to perform these comparisons. Not only does the taxonomic expertise of the two sets of researchers have to be equivalent and the methodologies comparable but also the location must be specified in both studies. In our study we choose coral genera level instead of species level because of limited experience of the observers. The most recent study that conducted in the Bunaken National Park is who conducted by Turak and de vantier (2004). In total, they found 390 species from 63 genera and 15 families of reef-building corals. Compared with our results, this finding is higher. It may be because of them also investigating coral biodiversity not only in the shallow water area, but also in the deeper area. Another possible reason is because we only did the line intercept sampling in the coral zone in Bunaken Island and Tombariri but they did in the whole area of The Bunaken National Park. A recent study that conducted by scientist in Pulau Seribu Reef complex Indonesia found a total of 13 families,44 genera, and 158 Species (Cleary et al. 2006). Overall, the total number of genera found in both of study area (44 coral genera) is high compared to similar study that conducted by Meixia in Luhuitou reef, Senya China. They only found 24 genera and 69 coral species (Meixia et al. 2008). Shannon diversity index in Bunaken National Park consistently higher (1.65) compared to Lohuitou reef, Senya China (1.04) and even higher than in Madang lagoon Papua New Guinea (1.11) (Pandolfi and Minchin 1996). Here confirmed that the Bunaken National Parks has high coral biodiversity. However the coral genera in Bunaken National park have uneven distribution since *Porites* was dominant in more than 65% of sample locations.

Further analysis was done by grouping the coral genera based on its occurrence and abundance. Four groups of location that have a similar coral genera composition were revealed. In Bunaken Island, it seems like there were 3 pattern of the distribution of group member of four coral genera groups. In the eastern part of Bunaken Island, the reef was dominated by *Astreopora, Acropora, Chypastrea, Leptastrea, Montipora, Pocillopora, Stylocoeniella*, and *Pachyseris*. (Group I) The second is the reef that placed along Bunaken Village until in front of Tawara lagoon. Here the pattern is uncertain; it might be due to high level of anthropogenic disturbance. This area is the centre of tourism activities like diving, snorkelling, and bottom-glass touring (DeVantier and Turak 2004). The last, is the reefs that located in the north and west portion of Bunaken Island that dominated by member of group III. This is may be as a result of wave action that limits the occurrences of specific corals. Only corals that have a strong structure and resistant to physical disturbance can growth in the wave exposed area (Dollar 1982). In Tombariri, there was a specific group that located near the river mount namely group IV. This group is the group which has less both coral cover and genera present. It might be because of the sediment contamination and freshwater runoff from nearby river. In contrast, this location has high percent cover of soft coral. Sedimentation in certain level will limits the coral growth and coral recruitment. The presence of soft coral also has negative effect on corals. Some soft corals can secrete a toxic that might be responsible for causing localized mortality and decreasing in survivorship of hard corals (Sammarco et al. 1983; Fabricius 1997).

4.3. Comparing Coral Reef Rugosity In The Different Environmental Condition

The idea of comparing rugosity index in Bunaken Island and Tombariri is based on the different environmental condition that may play a role in the structuring of the reef in the two areas. Bunaken Island is high attractive location for tourist. Most of tourist activities are diving, snorkeling and bottom glass touring. In contrast, reef in Tombariri historically are much more vulnerable due to destructive fishing practises and sedimentation. It has been thought that tourism-related activities are has a less effect on coral reef compared to the other utilization of the reef and fishing practises. Here, rugosity index is used as an approach to the integrated and long term effect of disturbance on coral reef.

The rugosity index of coral reef in the study area is ranged from 0.07-0.38 and the overall average is 0.24. In Bunaken Island the mean rugosity index is 0.25 and in Tombariri 0.23. It seems that the reef surface in Tombariri is flatter than in Bunaken Island. But an Independent t- test revealed that it was not significant. It may imply that the different environmental condition in the study area did not have a different effect on rugosity of coral reef. Both of disturbance and stressors in Bunaken Island and

Tombariri have the equal effect on coral reef rugosity. The effect of environmental condition that measured by means of rugosity is an integrated and in the long term scale because the effect of individual disturbance and stressor on coral reef are difficult or even almost impossible to separate (Aronson and Precht 1995).

In Bunaken Island, where is highly-exploited tourist area, the disturbance may came from diving related activities, snorkelling, and bottom-glass boat touring. Diving-related activities that can be a cause of flattering the reef surface is anchoring the dive mark, the diving-boat anchoring, and trampling. Diving activities itself is generally have less effect on the reef structure compared to the diving related activity. Study that conducted in Bunaken National Park in 2005 revealed that the effect of 3 boats that accidently strikes the coral reef are much more destructive than the effect of 100 divers that dive in one location simultaneously (DeVantier and Turak 2004). In addition, the storm that occurs in the period October to March also as a source of disturbance, especially for the reef that lays on the north-west side of Bunaken Island. Both of these disturbances results in an increase in coral fragmentation and a loss of three dimensional structural complexity of the reef (Rogers 1993; Zakai and Chadwick-Furman 2002; Fava et al. 2009).

In Tombariri area, the anthropogenic factor which is considered as a major treat to coral reef is destructive fishing practices. This area was historically severe from blast fishing and other destructive fishing techniques. Blast fishing is anthropogenic disturbance that physically change the reef structure and turned into lower rugosity (Fox and Caldwell 2006). It was not only kills the targeted fish but also breaks the coral skeleton and creates coral rubble. Blast fishing is illegally fishing method, but wide spread and considered as a major treat to reefs (McManus et al. 1997). Over 50% of coral reefs in South East Asia are threatened from this illegal activity. However, a recent study that conducted in Komodo National Park, Indonesia revealed that the reefs that severe from blasting are considerably recover in 5 years (Fox and Caldwell 2006) .But the recovery rate of coral reef after blasting might be different over the area due to recruitment ability and others factors. Reefs affected by anthropogenic mechanical damage such as blasting can recover from that damage if two conditions are met. First, they are protected from further damage and the second is some reefs in the area are undamaged (Pearson 1981; Edinger et al. 1998). The reefs in Tombariri area also had more severe from sedimentation than Bunaken Island. Sedimentation will limit the coral growth; as a result it will inhibit the reef development (McClanahan and Obura 1997). As a consequence, the rugosity index in the location that near to the river generally has lower value (sample 10 and 41).

During the field work, we noticed that the reef most exposed to wave action (those on the northwest-facing portions of Bunaken Island and Tombariri) especially in Bunaken Island had a flatter terrain than those in more protected positions. Wave action generally reduces the rugosity of the reefs by breaks the corals structure especially the branching corals. Therefore, the analysis was expanded in the basis of wave-exposure level, i.e. wave-exposed area and wave sheltered area. On the average, rugosity index in the wave exposed area is lower than in wave-sheltered area, namely 0.23±0.08 and 0.26±0.06 respectively (Mean±SD). Surprisingly, the statistical analysis shown that there was not significant different in rugosity index between coral reef in the wave-exposed area and wave-sheltered area (t-test, df=39, t=1.277, p>0.05: appendix F2.). This finding is contradicting with similar study that conducted in Belize, Jamaican and Hawaiian coral reefs. The reefs in those areas that placed in the wave-exposed area are significantly flatter than in the wave-sheltered area (Aronson et al. 1994; Aronson and Precht 1995; Friedlander et al. 2003; Alvarez-Filip et al. 2009). The possible reason is that the wave action is not the only major variable that structuring the reefs in the study area. The possible factor that together with wave action in structuring the coral reef in Bunaken National Park is anthropogenic influence as mentioned above. The second possible reason is since we have two locations that separated kilometres away, the wave action might be different, it should not only analyzed in the basis of wave exposure but also combined with the Island basis (Bunaken Island and Tombariri). Thus, the future work with the specific sampling design is definitely needed if we want to compare the rugosity index between wave -exposed and wave-sheltered area.

In order to get insight about the status of coral reef rugosity in Bunaken National Park, comparison between rugosity index in Bunaken Island and elsewhere was also performed. So far, the coral reef rugosity status is well documented in the Caribbean coral reefs. In Carrybow Cay and Curlew reefs Belize, rugosity index is ranged from 0.2 to almost 0.8 (Aronson and Precht 1995). A recent study that conducted in Caribbean region involving 250 sampling sites also revealed that the range of rugosity index in that region is from 0.1 to 0.8 (Alvarez-Filip et al. 2009) . Similar study that conducted in Hawaiian coral reef shown that the rugosity index of coral reef in this area ranged from 0.28 to 0.64 (Friedlander et al. 2003). They also found a trend in decreasing surface roughness in Caribbean region during last decades. In the periods of 1969-2009, the proportion of complex reef (rugosity>0.5) has decline from 45% to 2%. And the average of rugosity index also decreases from 0.65 to 0.3. They suggest that this flattering process might be due to anthropogenic and natural disturbances. Special concern is given to anthropogenic disturbance that rising dramatically in the last decade. Compared to Bunaken National Park, those values are higher. In Bunaken National Park there was no one of samples location that had rugosity index more than 0.4. Most of them (51%) are between 0.171-0.275. But the mean value of rugosity index in Bunaken National Park is only slight lower that in those in Caribbean, namely 0.24 and 0.3 respectively.

In summary, the coral reef that sited in the different environmental setting in Bunaken Island and Tombariri did not have a different rugosity index. If compared to other area in the world the average of rugosity index in Bunaken National Park is slight lower but can be assume to be a similar. This flattering of reef surface is as a result of both natural and anthropogenic disturbance that simultaneously faced by the reef.

4.4. Relationship between Rugosity-Coral Cover, and Coral Biodiversity

The relationships between rugosity, percent coral cover and coral biodiversity were explored using correlation test and linear regression analysis. Since rugosity is also indicator for integrated and long-term disturbance, a second order polynomial regression analysis also was employed. A second order polynomial regression curve is predicted to be concave downward reflects the intermediate disturbance hypothesis that stated diversity will be maximal in the intermediate level of disturbance.

Based on correlation analysis, percent coral cover is the most variable that highly significant and positively correlated with rugosity index in Bunaken National Park($r=0.565$, $p<0.01$). The coefficient of determination for linear regression between rugosity index and percent coral cover is also highly significant ($r^2=0.321$ $p<0.01$). Tombariri generally have higher correlation coefficient and coefficient of determination of linear regression than Bunaken Island. The same trend is also applied to rugosity-coral biodiversity relationships.

In the whole study area, the biodiversity indices that have highest correlation with rugosity is genera richness then followed by diversity index and evenness. Nevertheless, only genera richness that has significant correlation with rugosity index ($r=0.423$, $p<0.05$). The trend is similar in Bunaken Island and Tombariri except genera evenness. Genera evenness was negatively and significantly correlated with rugosity index in Tombariri ($r =-0.485$ $p<0.05$). The coefficient of determination for linear regression between rugosity index and biodiversity indices is relatively low. Thus it only can explain less variation of coral biodiversity. A second order polynomial regression analysis between rugosity index and coral biodiversity also cannot explain the variations of these variables better than linear regression. None of the second order polynomial regression curve is concave downward, and even was not significant. This result is contradicted with similar study in Belize coral reef that conducted by Arronson and Precth (1995). They successfully proven that second order polynomial regression between rugosity index and coral biodiversity is highly significant and even the regression curve is concave downward supporting the intermediate disturbance hypothesis.

The possible reasons for this different result are follows: first, the dominant source of disturbance and stressor in Bunaken National Park is not only from nature but also from anthropogenic disturbance that can be acute and or chronics. Second, the dominant species in the study area is *Porites* with massive colony. Massive coral colony is more resistant to disturbance than branching corals (Jackson 1991). Thus the intermediate disturbance hypothesis would most be applicable in the shallow coral reef that dominated by fragile corals such as branching corals and foliose corals (Rogers 1993).

In summary, among all variable, percent coral cover is the most variable that highly correlated with coral reef rugosity, then followed by genera richness, diversity index, and evenness. Linear regression model can better explain the variation of percent coral cover, genera richness, Shannon diversity index, and evenness rather than a second order polynomial regression model. However rugosity index can only explain very low variation of genera richness, diversity index and evenness. A part of consideration, it implies that the intermediate disturbance hypothesis may not applicable in the coral reef in Bunaken National Park.

4.5. Limitation of The Research

The research conducted fairly well, but a number of obstacles were faced during research. These include:

- Lack of hidro-oceanographic data such as salinity, wave action, surface current, tides and depth.
- Large part of Aerial photograph showed scattering of waves, which hides the reflection of the bottom. Therefore interpretation of these areas is not reliable.

5. Conclusions and Recommendation

5.1. Conclusions

- A total 44 coral genera were found in the Bunaken National Park and the average of live coral cover is 46%.
- The abundance and biodiversity of reef corals did not have a significant different between Bunaken Island and Tombariri.
- Four groups of coral genera and its distribution can be distinguished. Group I is located in the eastern part of Bunaken Island and the central part of Tombariri. Group II has no certain distribution. Group III is dominant in the north and west portion of Bunaken Island, and group IV is mainly located in the western and eastern part of Tombariri reefs near the river mounth.
- The coral reef in Bunaken Island and Tombariri which is sited in the different environmental condition did not have a different rugosity index.
- Coral cover is the variable that has highest correlation with coral reef rugosity and then followed by genera richness, Shannon diversity index, and evenness.
- The highest coefficient of determination of linear regression was found in the linear regression analysis between rugosity index and coral cover (r^2=0.321). Tombariri has higher coefficient of determination of linear regression (r^2=0.526) rather than Bunakan Island (r^2=0.296).
- None of second order polynomial regression was significant. Therefore linear regression model can better explain the variation of percent live coral cover, genera richness, Shannon diversity index, and evenness rather than a second order polynomial regression model, at least in the Bunaken National Park. However rugosity index can only explain very low variation of genera richness, diversity index and evenness.

5.2. Recommendation

1. Future research is exploring remote sensing method (LiDAR and SAR) to obtain information on coral reef rugosity with a major goal to replace *in-situ* measurements.

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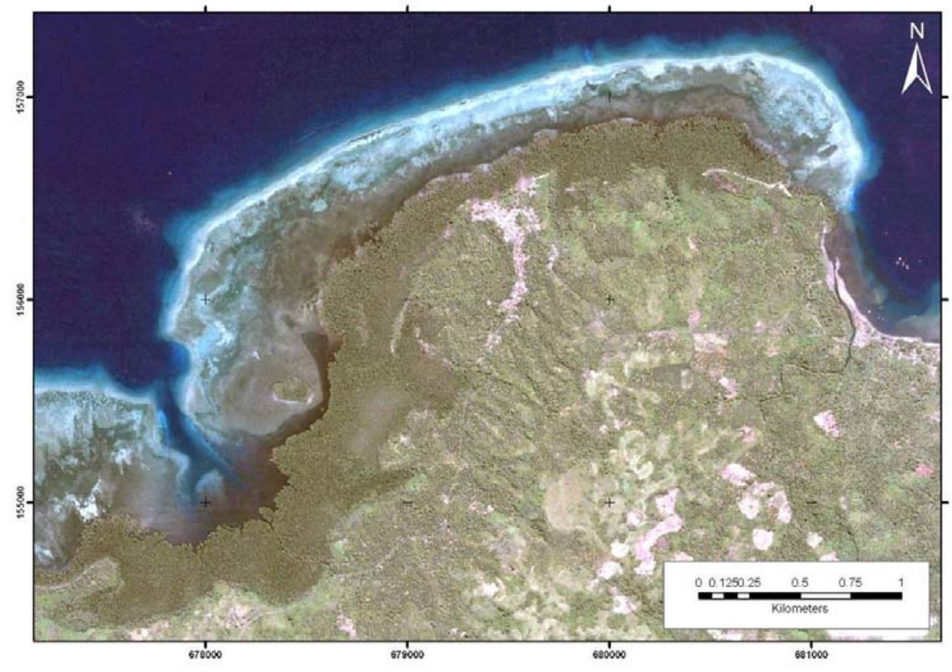
Appendices

Appendix A. Aerial Photograph of study area downloaded from Google Image

A1. Bunaken Island



A2 Tombariri

Appendix B Benthic estimation sample points

No	Coordinate		Coral	Dead Coral	Dead Coral Covered by Algae	Rubble	seagrass	Algae	Sand	Classes
	X	Y	(%)	(%)	%)	(%)	(%)	(%)	(%)	
1	696490	177319	15	80	0	5	0	0	0	Dead Coral
2	696796	177865	15	80	0	0	0	0	0	Dead Coral
3	680234	157271	15	60	0	10	0	0	15	Dead Coral
4	697428	176319	10	85	0	5	0	0	0	Dead Coral
5	693309	177625	10	75	0	0	0	0	15	Dead Coral
6	692724	178690	10	70	0	10	0	0	10	Dead Coral
7	693217	177617	5	80	0	10	0	0	5	Dead Coral
8	697529	176284	5	80	0	0	0	0	15	Dead Coral
9	693228	177589	5	75	0	20	0	0	0	Dead Coral
10	698254	177666	5	70	0	20	0	0	5	Dead Coral
11	678016	156175	5	70	0	0	0	0	25	Dead Coral
12	680595	157070	1	99	0	0	0	0	0	Dead Coral
13	697457	180324	0	70	0	20	0	0	10	Dead Coral
14	697820	176227	0	60	0	30	0	0	10	Dead Coral
15	695380	178988	10	0	60	30	0	0	0	Dead Coral covered by Algae
16	695505	178983	10	0	60	30	0	0	0	Dead Coral covered by Algae
17	679019	156893	10	0	60	0	0	0	30	Dead Coral covered by Algae
18	696831	177872	5	0	70	25	0	0	0	Dead Coral covered by Algae
19	696840	177674	5	0	60	30	0	0	5	Dead Coral covered by Algae
20	678810	156762	0	0	80	10	0	0	10	Dead Coral covered by Algae
21	679047	156847	0	0	50	25	0	0	25	Dead Coral covered by Algae
22	679707	157096	0	0	50	0	0	0	50	Dead Coral covered by Algae
23	698145	179324	90	10	0	0	0	0	0	Dense Coral
24	698335	177703	90	10	0	0	0	0	0	Dense Coral
25	696454	177090	80	10	0	10	0	0	0	Dense Coral
26	698084	176262	70	30	0	0	0	0	0	Dense Coral
27	697486	180395	70	20	0	10	0	0	0	Dense Coral
28	698130	179330	70	20	0	10	0	0	0	Dense Coral
29	679723	157143	70	20	0	5	0	0	5	Dense Coral
30	695033	180201	70	20	0	0	0	0	10	Dense Coral
31	697064	180321	70	10	0	5	0	0	15	Dense Coral
32	697839	176279	70	0	0	20	0	0	10	Dense Coral
33	696561	177468	60	40	0	0	0	0	0	Dense Coral
34	692720	178330	60	35	0	5	0	0	0	Dense Coral
35	692692	178729	60	30	0	5	0	0	5	Dense Coral
36	696567	177399	60	25	0	0	0	0	15	Dense Coral
37	696466	177131	60	20	0	20	0	0	0	Dense Coral
38	696596	177388	60	20	0	0	0	0	20	Dense Coral
39	693594	180944	60	10	0	0	0	0	30	Dense Coral
40	696803	177672	50	30	0	0	0	0	0	Dense Coral
41	681090	157097	50	30	0	0	0	0	20	Dense Coral
42	680806	157231	50	25	0	20	0	0	5	Dense Coral
43	696010	178994	50	20	0	10	0	0	20	Dense Coral
44	697468	180366	50	20	0	5	0	0	25	Dense Coral
45	698147	176286	50	20	0	0	0	0	30	Dense Coral
46	695361	178889	50	10	0	0	0	0	40	Dense Coral
47	679706	157112	45	45	0	0	0	0	10	Dense Coral
48	692700	178912	40	40	0	20	0	0	0	Dense Coral
49	697233	176380	40	40	0	10	0	0	10	Dense Coral
50	697822	176240	40	40	0	10	0	0	10	Dense Coral
51	679754	157176	40	40	0	5	0	0	15	Dense Coral
52	692749	178361	40	40	0	5	0	0	15	Dense Coral
53	696538	177468	40	35	0	25	0	0	0	Dense Coral
54	698156	176343	40	30	0	0	15	0	15	Dense Coral
55	695421	178947	40	30	0	20	0	0	10	Dense Coral

No	Coordinate		Coral	Dead Coral	Dead Coral Covered by Algae	Rubble	seagrass	Algae	Sand	Classes
	X	Y	(%)	(%)	%)	(%)	(%)	(%)	(%)	
56	678936	156901	40	30	0	10	0	0	20	Dense Coral
57	680662	157258	40	30	0	10	0	0	20	Dense Coral
58	695015	180181	40	30	0	10	0	0	20	Dense Coral
59	695528	179086	40	20	0	40	0	0	0	Dense Coral
60	695932	179040	40	20	0	20	0	0	20	Dense Coral
61	692731	178888	40	20	0	10	0	0	30	Dense Coral
62	695523	179188	0	0	0	0	0	0	0	Mangrove
63	695846	179250	0	0	0	0	0	0	0	Mangrove
64	696007	179210	0	0	0	0	0	0	0	Mangrove
65	697037	177534	0	0	0	0	0	0	0	Mangrove
66	678955	156879	30	60	0	0	0	0	10	Open Coral
67	695552	178986	30	60	0	0	0	0	10	Open Coral
68	692777	178381	30	50	0	10	0	0	10	Open Coral
69	695839	179010	30	50	0	0	0	0	20	Open Coral
70	697284	176358	30	40	0	30	0	0	0	Open Coral
71	692766	178361	30	40	0	10	0	0	20	Open Coral
72	697053	176423	30	40	0	10	0	0	20	Open Coral
73	693226	177659	30	40	0	5	0	0	25	Open Coral
74	696513	177346	30	30	0	40	0	0	0	Open Coral
75	697102	176408	30	30	0	20	0	0	20	Open Coral
76	680661	157298	30	20	0	10	0	0	40	Open Coral
77	696816	177567	30	20	0	10	0	0	40	Open Coral
78	692906	178681	30	20	0	0	0	0	20	Open Coral
79	693231	177714	30	20	0	0	0	0	50	Open Coral
80	696627	177362	30	10	0	20	0	0	40	Open Coral
81	692854	178841	30	0	0	0	30	0	40	Open Coral
82	696111	179050	30	0	40	10	20	0	0	Open Coral
83	693029	178869	25	0	0	0	60	0	15	Open Coral
84	696499	177220	20	70	0	10	0	0	0	Open Coral
85	698092	179317	20	60	0	15	0	0	5	Open Coral
86	693621	180847	20	60	0	10	0	0	10	Open Coral
87	697398	176332	20	60	0	0	0	0	20	Open Coral
88	679787	157230	20	40	0	10	0	0	30	Open Coral
89	695537	179005	20	20	0	50	0	0	10	Open Coral
90	679041	156765	20	0	5	20	0	0	55	Open Coral
91	680229	157305	15	35	0	35	0	0	15	Open Coral
92	692758	178676	10	40	0	40	0	0	10	Open Coral
93	695533	179040	10	10	0	40	0	0	40	Open Coral
94	681247	156302	0	0	0	0	40	0	60	Open Seagrass *Halophylla ovalis*
95	692889	178641	10	10	0	0	40	0	40	*Open Seagrass Thalassia*
96	692958	178448	10	10	0	0	40	0	40	*Open Seagrass Thalassia*
97	698286	177697	10	10	0	0	30	0	50	*Open Seagrass Thalassia*
98	696677	177367	5	5	0	15	30	0	45	*Open Seagrass Thalassia*
99	692972	178847	5	0	0	0	30	0	65	*Open Seagrass Thalassia*
100	692759	178874	0	25	0	10	25	0	40	*Open Seagrass Thalassia*
101	692824	178665	0	10	0	0	30	0	60	*Open Seagrass Thalassia*
102	698036	179298	0	5	0	0	40	15	40	*Open Seagrass Thalassia*
103	696836	177446	0	5	0	0	30	5	60	*Open Seagrass Thalassia*
104	697946	176323	0	5	0	0	30	0	65	*Open Seagrass Thalassia*
105	693309	178688	0	0	0	0	45	0	0	*Open Seagrass Thalassia*
106	692776	178699	0	0	0	20	40	0	40	*Open Seagrass Thalassia*
107	693357	178106	0	0	0	0	40	20	40	*Open Seagrass Thalassia*
108	692911	178851	0	0	0	0	40	0	60	*Open Seagrass Thalassia*
109	697847	176318	0	0	0	25	35	0	40	*Open Seagrass Thalassia*
110	697860	176350	0	0	0	5	35	0	60	*Open Seagrass Thalassia*

No	Coordinate X	Coordinate Y	Coral (%)	Dead Coral (%)	Dead Coral Covered by Algae %)	Rubble (%)	seagrass (%)	Algae (%)	Sand (%)	Classes
111	696927	177545	0	0	0	30	30	10	30	*Open Seagrass Thalassia*
112	695960	179084	0	0	0	20	30	0	50	*Open Seagrass Thalassia*
113	693183	178108	0	0	0	5	30	5	60	*Open Seagrass Thalassia*
114	693016	178453	0	0	0	5	30	0	65	*Open Seagrass Thalassia*
115	693027	178505	0	0	0	0	30	10	60	*Open Seagrass Thalassia*
116	679291	156601	0	0	0	0	30	0	70	*Open Seagrass Thalassia*
117	696003	179197	0	0	0	0	30	0	70	*Open Seagrass Thalassia*
118	680760	157151	0	0	40	30	20	0	10	*Open Seagrass Thalassia*
119	679103	156680	0	0	0	40	20	10	30	*Open Seagrass Thalassia*
120	697811	176430	0	0	0	40	20	0	40	*Open Seagrass Thalassia*
121	692939	178729	0	0	0	10	20	0	70	*Open Seagrass Thalassia*
122	697928	179269	0	0	0	0	20	30	50	*Open Seagrass Thalassia*
123	697955	179281	0	0	0	0	20	15	65	*Open Seagrass Thalassia*
124	696825	177751	15	10	0	60	0	0	15	Rubble
125	680905	157238	10	30	0	50	0	0	10	Rubble
126	680400	157260	0	5	0	80	0	0	15	Rubble
127	679099	156677	0	0	0	80	5	0	15	Rubble
128	692908	178440	0	0	0	60	5	0	35	Rubble
129	679069	156718	0	0	40	30	0	0	30	Rubble
130	696948	177734	0	0	30	40	0	0	30	Rubble
131	697054	180264	15	15	0	0	0	0	70	Sand
132	678084	156125	10	20	0	10	0	5	55	Sand
133	696663	177344	10	15	0	10	15	0	50	Sand
134	696858	177716	10	10	0	30	0	0	50	Sand
135	680840	157168	5	30	0	0	0	0	65	Sand
136	696855	177916	5	0	0	20	0	0	75	Sand
137	679887	157204	1	0	0	0	0	0	99	Sand
138	693442	178132	0	10	0	0	10	0	80	Sand
139	696876	177942	0	10	0	30	0	0	60	Sand
140	695008	180169	0	10	0	10	0	0	80	Sand
141	678799	156805	0	5	0	0	2	0	90	Sand
142	693137	178830	0	0	0	0	15	0	85	Sand
143	695852	179203	0	0	0	0	10	0	90	Sand
144	695554	179168	0	0	0	10	0	0	90	Sand
145	681173	156182	0	0	0	0	0	0	100	Sand
146	681239	156212	0	0	0	0	0	0	100	Sand
147	678301	155152	0	0	0	0	80	0	20	Seagrass *Enhalus Acoroides*
148	692937	178657	10	0	0	0	60	0	30	*Seagrass Thalassia*
149	692834	178416	10	0	0	0	50	0	40	*Seagrass Thalassia*
150	693040	178124	5	10	0	0	50	5	30	*Seagrass Thalassia*
151	698245	177615	5	5	0	5	50	0	35	*Seagrass Thalassia*
152	692933	178700	5	0	0	0	70	0	25	*Seagrass Thalassia*
153	692805	178860	0	10	0	0	50	0	40	*Seagrass Thalassia*
154	697585	176638	0	0	0	0	90	0	10	*Seagrass Thalassia*
155	695813	179099	0	0	0	0	85	5	10	*Seagrass Thalassia*
156	695544	179143	0	0	0	0	85	0	15	*Seagrass Thalassia*
157	680456	157026	0	0	0	0	80	5	15	*Seagrass Thalassia*
158	697340	176858	0	0	0	0	80	0	20	*Seagrass Thalassia*
159	695840	179163	0	0	0	0	70	10	20	*Seagrass Thalassia*
160	693123	178828	0	0	0	0	70	0	30	*Seagrass Thalassia*
161	696913	177971	0	0	0	0	70	0	30	*Seagrass Thalassia*
162	697691	176514	0	0	0	0	70	0	30	*Seagrass Thalassia*
163	696976	177513	0	0	0	0	65	20	15	*Seagrass Thalassia*
164	695977	179145	0	0	0	10	60	0	30	*Seagrass Thalassia*
165	679154	156630	0	0	0	0	60	20	20	*Seagrass Thalassia*

No	Coordinate		Coral	Dead Coral	Dead Coral Covered by Algae	Rubble	seagrass	Algae	Sand	Classes
	X	Y	(%)	(%)	%)	(%)	(%)	(%)	(%)	
166	697993	179292	0	0	0	0	60	0	40	*Seagrass Thalassia*
167	698081	176370	0	0	0	0	60	0	40	*Seagrass Thalassia*
168	680109	156935	0	0	0	0	55	25	20	*Seagrass Thalassia*
169	696920	177479	0	0	0	0	55	15	30	*Seagrass Thalassia*
170	679271	156646	0	0	0	0	50	25	25	*Seagrass Thalassia*
171	680705	157141	0	0	0	0	50	20	30	*Seagrass Thalassia*
172	680825	156764	0	0	0	0	50	20	30	*Seagrass Thalassia*
173	698176	177593	0	0	0	0	50	10	40	Seagrass Thalassia
174	678805	156799	0	0	0	0	80	5	15	Seagrass *Thallasodendron ciliatum*
175	679700	157099	0	0	0	0	50	40	10	Seagrass *Thallasodendron ciliatum*
176	692671	178752	0	0	0	0	0	0	0	Water
177	692672	178767	0	0	0	0	0	0	0	Water
178	692690	178941	0	0	0	0	0	0	0	Water
179	692697	178342	0	0	0	0	0	0	0	Water
180	693230	177568	0	0	0	0	0	0	0	Water
181	695830	178989	0	0	0	0	0	0	0	Water
182	695990	178983	0	0	0	0	0	0	0	Water
183	696581	177497	0	0	0	0	0	0	0	Water
184	696681	178213	0	0	0	0	0	0	0	Water
185	696777	177669	0	0	0	0	0	0	0	Water
186	697502	180406	0	0	0	0	0	0	0	Water
187	697818	176213	0	0	0	0	0	0	0	Water
188	698128	176251	0	0	0	0	0	0	0	Water

Appendix C.Coral genera found and Its percent Cover

C1 Coral genera found in Tombariri and its percent cover

Sample ID	3	4	6	7	8	9	10	11	40	41	42	43	44	45
X	681165	680577	677470	677487	677903	678798	681297	681093	677669	677915	679668	680069	679138	678212
Y	156946	157214	155562	155613	156307	156843	156652	157114	155520	155430	157111	157201	156978	156551
Place	Tombariri	Tombariri	Tombariri	Tombariri	Tombariri	Tombariri	Tombariri	Tombariri	Tombariri	Tombariri	Tombariri	Tombariri	Tombariri	Tombariri
Acroporidae														
Acropora	1.8	1.0	4.4	5.7	6.9	5.5		1.1	6.9		15.9	5.5	15.6	10.3
Anacropora			2.0		0.3	1.9								
Astreopora						9.5		0.5	1.1				5.6	0.8
Isopora														
Montipora	4.8	0.0	13.6	7.3		5.0		6.0	3.7		10.9	5.7	21.5	15.3
Astrocoeniidae														
Stylocoeniella			0.5			2.8			1.1		4.3		1.1	
Agaridae														
Leptoseris														
Pachyseris									1.6					
Pavona			6.8								0.9		2.8	
Dendrophylliadae														
Tubastrea					0.5									
Turbinaria		0.7	0.5	0.8	1.1									
Euphillidae														
Euphyllia							1.2							
Fungidae														
Fungia				1.0			0.8		1.6					
Ctenactis								1.0						
Cycloseris														
Favidae														
Caulastrea						1.1								
Cyphastrea			0.7						6.1			0.7		0.6
Diploastrea										2.5				0.7
Echinopora														
Favia		0.7	1.6			0.4							0.5	
Favites			3.8	1.4	4.2	2.7	0.5	0.5	4.5		1.6	4.0	1.8	2.8
Goniastrea	1.2	2.4	8.3	2.4					5.2	0.0	3.3	2.2	1.9	0.6
Leptastrea						2.8		2.0	1.2		1.4	1.1	0.6	0.5
Leptoria														
Montastrea			1.5			0.5			1.0		2.6	2.8	1.0	0.7
Oulophyllia														
Platygyra														
Merrulinidae														
Hydnophora											1.0			
Merulina														
Mussidae														
Acanthastrea														
Symphyllia			0.5						1.7		1.5	1.1	0.6	1.0
Lobophyllia								0.4			1.1	0.8		
Oculinidae														
Galaxea		0.4					0.5	0.7		0.6	3.4	0.4	3.1	1.8
Pectinidae														
Oxypora											0.9			
Pectinia			0.4			2.0								
Pociloporidae														
Pocillopora			1.1			0.6		1.1		0.9	2.4	0.9	1.9	1.6
Seriatopora													0.9	
Stylophora		3.9	4.6			6.2	1.5		0.0	3.5				
Poritidae														
Alveopora						0.7								
Goniopora	3.3		2.2	4.1			1.1	1.0		2.1		1.1		1.0
Porites	34.1	15.9	18.0	14.7	3.4	9.0		9.3	22.1	2.3	27.3	34.4	17.0	15.0
Siderasteridae														
Psammocora			1.7			1.2								
Siderastrea													0.0	
Other														
Heliopora														

Appendix C2 Coral genera found in Bunaken Island and its percent cover

Sample ID	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
X	696534	696686	693303	698111	698328	697879	693984	695001	697598	697323	697043	696700	692930	692836	692750	695291	696757	692910	693382	693544	694490	696758	696651	698395	698441	696175	694889
Y	176916	178333	180655	179384	177678	176248	180800	180199	176296	176374	176429	180056	179689	179337	178388	178974	178065	177908	177916	178469	178937	177526	176636	178628	176708	178947	178800
Place	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken
Acroporidae																											
Acropora	0.7	2.1		22.0	6.0	4.4	1.7								0.7	5.6			0.7	15.4	2.9		8.2	19.7	3.8		32.0
Anacropora																											
Astreopora	0.4			5.8	1.4		1.0		0.4	0.9										1.4	0.4		1.0			5.3	
Isopora												1.9	0.0	14.1	12.5			13.4	0.9	20.3			1.8	2.4			1.4
Montipora	3.9		0.6	5.0	6.8	1.6	2.2		1.8	3.5							2.0	0.8			2.8		3.1	3.3	2.6		2.7
Astrocoeniidae																											
Stylocoeniella					0.7																						0.7
Agaridae																											
Leptoseris																											0.4
Pachyseris					2.1															2.6					0.6		0.7
Pavona							2.0								0.9								6.8		2.6		
Dendrophylliadae																											
Tubastrea	0.2																										
Turbinaria																											
Euphillidae																											
Euphyllia																											
Fungidae																											
Fungia		0.6			0.5															0.5	0.9		0.8				
Ctenactis																									1.9		0.5
Cycloseris																									0.6		
Favidae																											
Caulastrea																											
Cyphastrea							0.5		0.6										3.4	1.1	0.3	1.2	0.7		0.3		2.2
Diploastrea							0.5			0.4				3.8	1.6									3.0			
Echinopora		1.3		1.8																				1.6			3.1
Favia					0.8	1.5	1.3		0.9		1.7	1.3	0.4				0.7	1.2	1.2	2.7	1.6	0.7	1.2	1.1	0.7	1.7	
Favites				1.0	1.2	3.3	5.1	0.7	2.1	1.9	3.3	2.6	2.7	2.3	1.2	0.7	0.8	0.7		3.3	1.7	1.1	6.5	1.6	1.1		2.9
Goniastrea	15.4		1.6	1.5	8.7	14.2	0.9		5.0	1.0	7.8	1.9	1.2			1.2		1.3	1.3	7.2	4.9	0.8	6.9	2.2	3.9	0.8	1.6
Leptastrea	0.8								1.2									0.4					0.5	1.1			2.2
Leptoria																									2.4		
Montastrea			0.4					29.0			0.4	3.5	0.6	0.0	0.4		0.8		1.5		0.6		4.7	0.4	1.0		1.2
Oulophyllia				4.2					1.5															1.4			
Platygyra								0.6												1.4							

Appendix C2 continued

Sample ID	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
X	696534	696686	693303	698111	698328	697879	693984	695001	697598	697323	697043	696700	692930	692836	692750	695291	696757	692910	693382	693544	694490	696758	696651	698395	698441	696175	694889
Y	176916	178333	180655	179384	177678	176248	180800	180199	176296	176374	176429	180056	179689	179337	178388	178974	178065	177908	177916	178469	178937	177526	176636	178628	176708	178947	178800
Place	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken	Bunaken
Merrulinidae																											
Hydnophora																								2.9			
Merulina																								3.5			
Mussidae																											
Acanthastrea																							1.2	1.2			
Symphyllia	0.9			1.7		1.2	2.5		1.0	0.6	0.9												2.0	1.3	3.0		
Lobophyllia	1.6				0.4	0.9		3.5			1.0				0.8							2.7	0.8			1.9	
Oculinidae																											
Galaxea	4.9			0.5	0.7	0.4	4.0	6.0	0.5			7.7						0.4			2.1	0.6	0.7	0.8	5.1		
Pectinidae																											
Oxypora									0.8																1.0		
Pectinia				3.2	1.2	1.2																					
Pociloporidae																											
Pocillopora	3.1		3.1		1.1				0.9								0.6						0.9				9.4
Seriatopora																											
Stylophora	6.1	2.3	12.2	3.3	14.4	2.3	2.3	2.6				1.0						1.7	5.7	1.5	0.5	15.3	0.7		1.1		
Poritidae																											
Alveopora																											
Goniopora	1.4				1.6	2.0	0.5	0.0		0.6				2.5		5.3				2.2					1.5		
Porites	28.6	56.7	49.3	17.5	22.0	18.6	23.7		19.5	11.3	13.3	12.2	4.1	3.4	26.8	15.7	7.1	47.1	2.2	8.3	5.5	22.4	20.6	15.3	37.1	23.3	19.5
Siderasteridae																											
Psammocora																											
Siderastrea							1.5																				
Other																											
Heliopora								0.9				1.1	1.1	4.0													

Appendix D. Benthic cover and its Coverage

Sample Id	X	Y	Place	Live Cover	Dead Coral	Dead Coral algae	Rubble	Soft Coral	Sponge	Seagrass	Algae	Sand	others	Chain Distance	Rugosity Index	N (genera)	Shanon Index	Evenness
3	681165	156946	Tombariri	45%	18%	0%	5%	11%	0%	0%	0%	21%	0%	15.0	0.25	5	0.87	0.54
4	680577	157214	Tombariri	26%	63%	0%	7%	5%	0%	0%	0%	0%	0%	14.8	0.26	8	1.32	0.64
6	677470	155562	Tombariri	72%	11%	0%	1%	3%	0%	0%	0%	13%	0%	14.5	0.28	18	2.33	0.80
7	677487	155613	Tombariri	37%	15%	0%	21%	16%	0%	0%	0%	10%	0%	15.7	0.22	8	1.69	0.81
8	677903	156307	Tombariri	16%	43%	0%	1%	15%	0%	0%	0%	24%	0%	17.1	0.15	6	1.40	0.78
9	678798	156843	Tombariri	52%	26%	0%	5%	8%	0%	0%	0%	9%	1%	16.4	0.18	16	2.40	0.87
10	681297	156652	Tombariri	6%	29%	0%	5%	38%	8%	0%	0%	11%	3%	15.8	0.21	6	1.71	0.95
11	681093	157114	Tombariri	23%	25%	0%	6%	21%	0%	0%	0%	23%	1%	16.6	0.17	11	1.81	0.75
40	677669	155520	Tombariri	57%	16%	0%	1%	14%	0%	0%	0%	11%	0%	14.4	0.28	13	2.05	0.80
41	677915	155430	Tombariri	12%	25%	0%	3%	6%	2%	26%	2%	24%	0%	16.9	0.16	6	1.66	0.93
42	679668	157111	Tombariri	78%	16%	0%	0%	4%	0%	0%	0%	1%	0%	14.6	0.27	15	2.05	0.76
43	680069	157201	Tombariri	60%	13%	0%	0%	16%	0%	0%	0%	10%	0%	14.7	0.27	13	1.62	0.63
44	679138	156978	Tombariri	75%	16%	0%	3%	1%	0%	0%	0%	5%	0%	14.9	0.26	15	2.01	0.74
45	678212	156551	Tombariri	52%	43%	0%	2%	0%	0%	0%	0%	2%	1%	15.1	0.25	14	1.88	0.71
13	696534	176916	Bunaken	68%	21%	0%	4%	3%	0%	0%	0%	5%	0%	14.3	0.29	13	1.77	0.69
14	696686	178333	Bunaken	63%	14%	0%	12%	7%	0%	0%	0%	3%	1%	14.8	0.26	5	0.45	0.28
15	693303	180655	Bunaken	67%	24%	0%	1%	8%	0%	0%	0%	0%	0%	13.4	0.33	6	0.83	0.46
16	698111	179384	Bunaken	67%	26%	0%	2%	4%	0%	0%	1%	0%	0%	14.2	0.29	12	1.95	0.78
17	698328	177678	Bunaken	70%	11%	0%	1%	16%	0%	0%	0%	0%	2%	12.4	0.38	17	2.10	0.74
18	697879	176248	Bunaken	51%	27%	0%	6%	15%	0%	0%	0%	0%	0%	14.2	0.29	12	1.86	0.75
19	693984	180800	Bunaken	49%	21%	0%	0%	25%	0%	0%	2%	1%	1%	13.7	0.32	15	1.94	0.72
20	695001	180199	Bunaken	43%	41%	0%	2%	12%	2%	0%	0%	0%	0%	18.7	0.07	7	1.11	0.57
21	697598	176296	Bunaken	36%	29%	0%	21%	0%	0%	0%	1%	13%	0%	15.1	0.25	13	1.70	0.66
22	697323	176374	Bunaken	20%	48%	0%	15%	4%	0%	0%	0%	12%	1%	16.4	0.18	8	1.41	0.68
23	697043	176429	Bunaken	28%	58%	0%	13%	1%	0%	0%	0%	0%	0%	16.4	0.18	7	1.41	0.73
24	696700	180056	Bunaken	34%	58%	0%	1%	6%	1%	0%	0%	0%	0%	17.6	0.12	10	1.87	0.81
25	692930	179689	Bunaken	10%	35%	0%	11%	5%	0%	0%	0%	38%	1%	18.7	0.07	6	1.50	0.84

Appendix D *continued*

Sample Id	X	Y	Place	Live Cover	Dead Coral	Dead Coral algae	Rubble	Soft Coral	Sponge	Seagrass	Algae	Sand	others	Chain Distance	Rugosity Index	N (genera)	Shanon Index	Evenness
26	692836	179337	Bunaken	30%	49%	0%	2%	1%	0%	0%	0%	18%	0%	12.9	0.36	6	1.53	0.86
27	692750	178388	Bunaken	45%	45%	0%	8%	0%	1%	0%	0%	2%	0%	14.7	0.27	8	1.12	0.54
28	695291	178974	Bunaken	28%	20%	0%	8%	25%	0%	0%	0%	18%	0%	15.1	0.25	5	1.19	0.74
29	696757	178065	Bunaken	12%	56%	0%	6%	25%	0%	0%	0%	1%	0%	15.4	0.23	7	1.35	0.70
30	692910	177908	Bunaken	67%	23%	0%	2%	6%	1%	0%	0%	3%	0%	15.6	0.22	9	0.96	0.44
31	693382	177916	Bunaken	18%	49%	0%	18%	0%	0%	0%	0%	15%	0%	16.2	0.19	9	1.96	0.89
32	693544	178469	Bunaken	68%	21%	0%	7%	0%	1%	0%	0%	3%	0%	13.4	0.33	14	2.07	0.78
33	694490	178937	Bunaken	24%	71%	0%	5%	0%	0%	0%	0%	1%	0%	14.3	0.29	12	2.16	0.87
34	696758	177526	Bunaken	45%	18%	0%	36%	1%	0%	0%	0%	0%	0%	16.2	0.19	8	1.26	0.61
35	696651	176636	Bunaken	69%	30%	0%	0%	1%	0%	0%	0%	0%	1%	15.4	0.23	19	2.34	0.80
36	698395	178628	Bunaken	62%	7%	0%	9%	19%	2%	0%	0%	0%	0%	13.5	0.33	17	2.20	0.78
37	698441	176708	Bunaken	70%	6%	0%	2%	14%	1%	0%	0%	0%	7%	13.7	0.32	18	1.90	0.66
38	696175	178947	Bunaken	33%	31%	0%	8%	18%	0%	0%	0%	11%	0%	14.7	0.27	5	0.94	0.58
39	694889	178800	Bunaken	80%	8%	0%	0%	8%	0%	0%	0%	3%	1%	14.1	0.30	15	1.86	0.69

Appendix E. Correlation test

E1. Correlation test between Variable: Bunaken National Park (Bunaken Island + Tombariri)

		Rugosity Index	Coral Cover	Genera Richness	Diversity Index	Evenness
Rugosity Index	Pearson Correlation	1	.565(**)	.423(**)	.195	-.127
	Sig. (1-tailed)	.	.000	.003	.110	.214
	N	41	41	41	41	41
Coral Cover	Pearson Correlation	.565(**)	1	.670(**)	.250	-.343(*)
	Sig. (1-tailed)	.000	.	.000	.058	.014
	N	41	41	41	41	41
Genera Richness	Pearson Correlation	.423(**)	.670(**)	1	.816(**)	.251
	Sig. (1-tailed)	.003	.000	.	.000	.057
	N	41	41	41	41	41
Diversity Index	Pearson Correlation	.195	.250	.816(**)	1	.751(**)
	Sig. (1-tailed)	.110	.058	.000	.	.000
	N	41	41	41	41	41
Evenness	Pearson Correlation	-.127	-.343(*)	.251	.751(**)	1
	Sig. (1-tailed)	.214	.014	.057	.000	.
	N	41	41	41	41	41

** Correlation is significant at the 0.01 level (1-tailed).
* Correlation is significant at the 0.05 level (1-tailed).

E2 Correlation test between variable : Bunaken Island

		Rugosity Index	Coral Cover	Genera Richness	Diversity Index	Evenness
Rugosity Index	Pearson Correlation	1	.538(**)	.441(*)	.263	.000
	Sig. (1-tailed)	.	.002	.011	.092	.499
	N	27	27	27	27	27
Coral Cover	Pearson Correlation	.538(**)	1	.592(**)	.162	-.346(*)
	Sig. (1-tailed)	.002	.	.001	.209	.038
	N	27	27	27	27	27
Genera Richness	Pearson Correlation	.441(*)	.592(**)	1	.820(**)	.342(*)
	Sig. (1-tailed)	.011	.001	.	.000	.040
	N	27	27	27	27	27
Diversity Index	Pearson Correlation	.263	.162	.820(**)	1	.805(**)
	Sig. (1-tailed)	.092	.209	.000	.	.000
	N	27	27	27	27	27
Evenness	Pearson Correlation	.000	-.346(*)	.342(*)	.805(**)	1
	Sig. (1-tailed)	.499	.038	.040	.000	.
	N	27	27	27	27	27

** Correlation is significant at the 0.01 level (1-tailed).
* Correlation is significant at the 0.05 level (1-tailed).

E3 Correlation test between variable: Tombariri

		Rugosity Index	Coral Cover	Genera Richness	Diversity Index	Evenness
Rugosity Index	Pearson Correlation	1	.734(**)	.480(*)	.123	-.485(*)
	Sig. (1-tailed)	.	.001	.041	.337	.039
	N	14	14	14	14	14
Coral Cover	Pearson Correlation	.734(**)	1	.826(**)	.497(*)	-.339
	Sig. (1-tailed)	.001	.	.000	.035	.118
	N	14	14	14	14	14
Genera Richness	Pearson Correlation	.480(*)	.826(**)	1	.838(**)	.008
	Sig. (1-tailed)	.041	.000	.	.000	.490
	N	14	14	14	14	14
Diversity Index	Pearson Correlation	.123	.497(*)	.838(**)	1	.542(*)
	Sig. (1-tailed)	.337	.035	.000	.	.023
	N	14	14	14	14	14
Evenness	Pearson Correlation	-.485(*)	-.339	.008	.542(*)	1
	Sig. (1-tailed)	.039	.118	.490	.023	.
	N	14	14	14	14	14

** Correlation is significant at the 0.01 level (1-tailed).
* Correlation is significant at the 0.05 level (1-tailed).

Appendix F. Independent t-test

F1. Independent t-test for Bunaken Island and Tombari

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Rugosity Index	Equal variances assumed	2.565	.117	-.980	39	.333	-.0229	.02339	-.07025	.02438
	Equal variances not assumed			-1.151	38.300	.257	-.0229	.01993	-.06327	.01739
Coral Cover	Equal variances assumed	.359	.552	-.401	39	.690	-2.9127	7.25814	-17.59367	11.7682
	Equal variances not assumed			-.384	23.439	.705	-2.9127	7.58854	-18.59455	12.7691
Genera Richness	Equal variances assumed	.009	.923	.359	39	.721	.5185	1.44304	-2.40031	3.43735
	Equal variances not assumed			.358	26.254	.723	.5185	1.44645	-2.45331	3.49034
Diversity Index	Equal variances assumed	1.651	.206	1.249	39	.219	.1885	.15089	-.11673	.49366
	Equal variances not assumed			1.321	30.827	.196	.1885	.14262	-.10248	.47941
Evenness	Equal variances assumed	.611	.439	1.693	39	.099	.0743	.04387	-.01448	.16300
	Equal variances not assumed			1.823	32.299	.078	.0743	.04074	-.00869	.15721

F2. Independent t-test for Wave exposed and Wave-sheltered

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Rugosity Index	Equal variances assumed	1.519	.225	1.277	39	.209	.0281	.02201	-.01642	.07261
	Equal variances not assumed			1.267	34.817	.214	.0281	.02217	-.01693	.07312
Coral cover	Equal variances assumed	2.949	.094	-.380	39	.706	-2.6143	6.88717	-16.54489	11.3163
	Equal variances not assumed			-.381	38.219	.705	-2.6143	6.85415	-16.48717	11.2586
Genera Richness	Equal variances assumed	.578	.452	.297	39	.768	.4071	1.36970	-2.36335	3.17763
	Equal variances not assumed			.298	38.755	.767	.4071	1.36529	-2.35497	3.16926
Diversity Index	Equal variances assumed	.140	.710	.440	39	.662	.0641	.14562	-.23047	.35861
	Equal variances not assumed			.440	38.824	.663	.0641	.14568	-.23064	.35878
Evenness	Equal variances assumed	.296	.589	.573	39	.570	.0246	.04294	-.06227	.11146
	Equal variances not assumed			.574	38.989	.569	.0246	.04287	-.06212	.11131

Appendix G. Dive sites map of Bunaken Island