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Vertical distribution and effect of the depth on growth form and genus of hard coral on coral reef in Bunaken Island, North Sulawesi, Indonesia

Reskiwati[1]*, Medy Ompi[2], Unstain N.W.J. Rembet[3], Janny D. Kusen[2], Rose O.S.E. Mantiri[3], Deiske A. Sumilat[1]

[1] *Master Program of Aquatic Science, Faculty of Fisheries and Marine Science, Sam Ratulangi University, Jl. Kampus Unsrat Bahu, Manado 95115 Sulawesi Utara, Indonesia*
[2] *Marine Science Program, Faculty of Fisheries and Marine Science, Sam Ratulangi University, Sulawesi Utara, Indonesia*
[3] *Aquatic Resources Management Program, Faculty of Fisheries and Marine Science, Sam Ratulangi University, Sulawesi Utara, Indonesia*
*Corresponding author: reskiwati15@gmail.com

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Abstract: Bunaken Island generally has a 90° slope and it forms like an underwater wall. However, there are several locations in Bunaken Island that have a more gradually inclined slope. This study was aimed to identify the effect of depth and slope gradient toward vertical distribution on growth forms and genera of hard coral at three stations in Bunaken Island. The data was collected using Line Intercept Transect (LIT) method which was dragged vertically at 3-15 meters depth. The results of study showed two different types of slopes, steep and gentle slopes. Stations 1 and 2 were categorized as steep slope (90° and 55°, respectively) and station 3 was gentle slope (43°). Encrusting growth forms dominated at 90° slope, while at 55° and 43° slope was dominated by massive growth forms. Vertical distribution of the corals shows change in size and numbers of colonies along with increasing depth.

Keywords: zooxanthellae; coral reefs; hard coral; Bunaken island; North Sulawesi

INTRODUCTION

Coral reefs are distributed unevenly in almost all Indonesian waters due to different environmental conditions. Sulawesi is one of the areas in Eastern Indonesia where many genera of hard corals are found (Hadi *et al*., 2018). Located in North Sulawesi, Bunaken Island is one of the islands that is included in Bunaken National Park with an area of approximately 89.065 Ha. This island is well known for its fringing reef with high biodiversity of marine organisms and generally has a steep slope.

Previous study by Prabandari (2019) reported a number of 63 genera of hard corals, while Kambey (2014) had found only 29 genera of the taxa. Moreover, a study by Rojas (2010) and Kusen and Tioho (2009) reported 37 and 46 genera of hard coral in Bunaken Island, respectively. Percentage cover of hard coral on Bunaken Island has also been reported by several authors (Gumolili, 2019; Luasunaung *et al*., 2015; Kambey, 2014; Towoliu, 2014; Setiawan *et al*., 2013; and Kusen and Tioho, 2009). All the studies reported that percentage cover of hard corals in Bunaken Island are between poor and good categories. The studies were conducted in several locations.

All the previous study has used Line Intercept Transect (LIT) method which were laid horizontally at several different depth, so that there were data at depths that are not placed transects, and to cover the data, the method used is LIT which is placed vertically to describe the distribution and shape of coral growth at depth. Vertical distribution of hard coral describes the main pattern of genera at each depth in coral's community which is limited by several factors such as temperature, current, sunlight, tides and sedimentation (Mundy and Babcock, 2000; Done, 1982; Glynn, 1976).

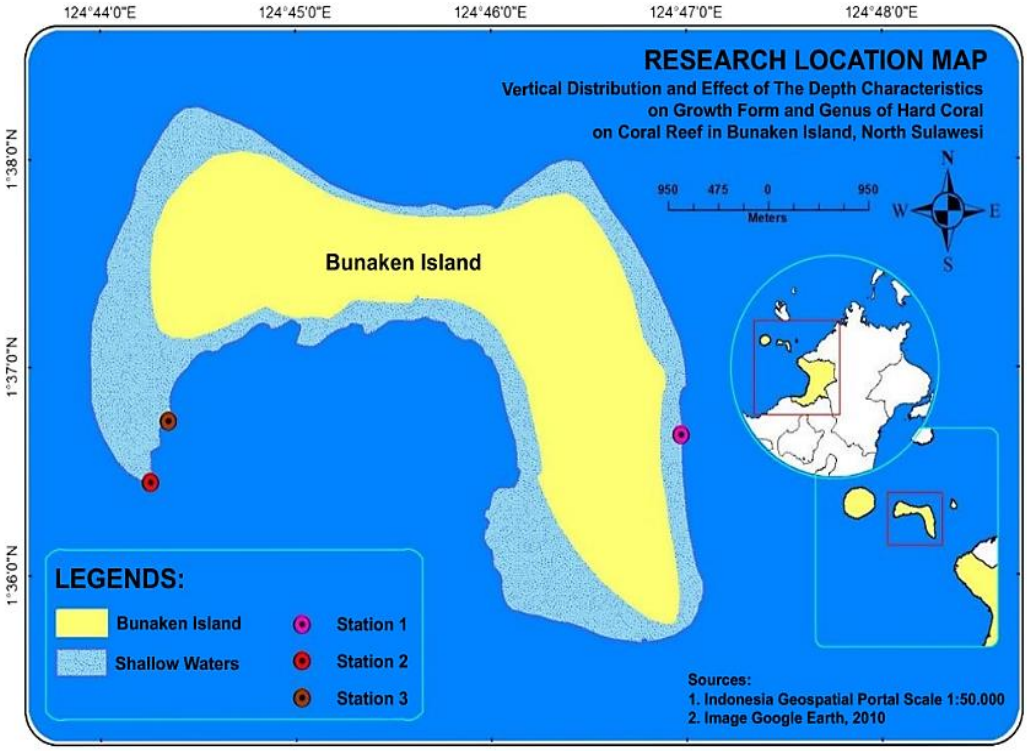

Figure 1. Map of study area

MATERIAL AND METHODS

Research Sites and Time

Research was conducted in Bunaken Island waters in December 2020 to June 2021 at three stations (Figure 1). All stations face towards east, so the exposure to sunlight should be identical. Station 1 and 2 were categorized as steep slope, respectively 90° and 55° meanwhile station 3 has a gentle slope (43°) (Table 1).

Types and Research Method

The data used in this study are primary and secondary data. Primary data was obtained by taking coral data directly using Line Intercept Transect (LIT) method (Hill and Wilkinson, 2004). Environmental parameters at each depth (temperature, salinity, transparency, and dissolved oxygen) were measured using HORIBA water quality checker. Hard corals were identified to species level based on coral guide books (Veron, 1986; Kelley, 2016). Meanwhile, secondary data was obtained from reports or archived relevant studies from related institutions or agencies. The data was collected at 3 different stations at 3-15 m depth. Two transects were dragged vertically from 3-15 m depth and each benthic component was recorded according to categories (in cms). The total length of transects was different at each station due to the differences in slope. Total transect length was 1.750 m at station 1, 2.220 m at station 2, and 6.410 m at station 3.

Table 1. Coordinates of research stations

Station	Latitude	Longitude
1	1°36'40" N	124°45'58" E
2	1°36'26" N	124°44'15" E
3	1°36'44" N	124°44'20" E

Ecology Analysis of Coral Reef

Percentage Cover. Percentage Cover of benthic lifeform was calculated based on English *et al*. (1997) as follows:

$$\text{Percentage Cover} = \frac{\text{Length of cover of benthic component}}{\text{Length of transect (in cm)}} \times 100$$

The condition of live hard coral was categorized based on the quality standard of Minister of Environment Decree No. 4 of 2001 with the criteria listed in Table 2.

Diversity Index (H'). Hard coral diversity index (H') was calculated using Shannon-Wienner diversity index (Krebs, 1989) as follows:

$$H' = -\sum_{i=1}^{s} \frac{ni}{N}\left(\log \frac{ni}{N}\right)$$

H' = Diversity Index
ni = number of individuals of type-i
N = total number of individuals
s = number of hard coral genera

Dominance Index (D). Dominance index was used to identify the dominance of certain hard coral genera in the study area. Dominance index was calculated using the equation of Simpson's Dominance equation (Krebs, 1989) as follows:

$$D = \sum_{i=1}^{s} \left(\frac{ni}{N}\right)^2$$

D = Dominance Index
ni = vertical length of the hard coral colony genera type-i
N = numbers of hard coral genera

Dominance Index should be between 0 and 1. If D is close to 0, then there is no dominance of a certain hard coral genus, and vice versa if D is close to 1, it indicates dominance of a certain genus of hard coral in the study area.

Mortality Index (MI). The level of health and condition of coral reef ecosystem was calculated using Mortality Index by English *et al*. (1997) as follows:

$$MI = \frac{\%\ \text{Dead Coral}}{\%\ \text{Dead Coral} + \%\ \text{Live Coral}}$$

The MI value range between 0 and -1. If the value close to 0, it indicates that the mortality ratio is low and coral reefs has a high level of health, whereas if the MI value is close to 1 it means that the mortality ratio of coral reefs is high and the coral health is low.

RESULTS AND DISCUSSION

Parameters of Water Quality

Measurement of water quality parameters shows that dissolved oxygen value is 8 mg/L on average for all stations and depths. This value still supports coral growth and according to Minister of Environment Decree No. 51 of 2004 concerning Water Quality Standards for Biota the level should be > 5 mg/L. The temperature at each depth ranges from 27°C to 28°C and water salinity 29 to 31‰. These values are still within the range to support coral growth (Giyanto *et al*., 2017). In addition, the transparency at each station exceeds a depth of 10 m, 14 m at station 1, 13 m at station 2, and 15 m at station 3.

Table 2. Criteria live coral percentage cover

Criteria		Percentage Cover (%)
Poor	Poor	0-24.9
	Moderate	25-49.9
Good	Good	50-74.9
	Excellent	75-100

Coral Growth Form and Genera of Hard Coral in Bunaken Island

Eight growth forms of hard coral were found in Bunaken Island. They include *Acropora* and non-*Acropora* growth forms with a total number of colonies of 282 from 38 genera of hard corals. At station 1 there were 85 colonies from 31 genera, at station 2 there were 104 colonies from 22 genera, and 93 colonies from 18 genera were found at station 3. Coral growth forms, number of colonies and genera of hard corals in Bunaken Island are shown in Table 3.

Branching, massive, and encrusting growth forms were the three most abundant colonies, namely 58 to 79 colonies. These growth forms are widely distributed on coral reef areas due to their ability to adapt and survive under changing environmental conditions. An example is an adaptation of branching growth form, which is growing in directions of the currents and forms thick branches (Done, 1982; Kramer *et al*., 2020). Massive and encrusting growth forms have an ability to adapt to the extreme environment such as strong currents, high temperature, and also high sedimentation (Chappell, 1980; Reza and Sancayaningsih, 2017).

Genus *Porites* has the highest number of colonies (104 colonies), and this genus also has the highest number of colonies at each station: 35 colonies at station 1, 30 colonies at station 2, and 39 colonies at station 3. The distribution of this genus is quite wide in Indonesian waters with varied growth forms such as massive, branching or encrusting (Suharsono, 2008). Furthermore, this genus is also able to survive under extreme environmental conditions. This ability makes them one of the most important components of coral reefs (Pichon, 2011).

Vertical distribution of hard corals showed that number of colonies are quite high at a depth of 3-9 m, where the highest number of colonies was at a depth of 5-6 m, with 70 colonies. At greater depths, the number of colonies began to decrease to the lowest at a depth of 10-15 m. This is due to the intensity of sunlight at a depth of 5-6 m are still enough to support the photosynthesis process by zooxanthellae. Meanwhile, at a depth of 10-15 m there is still enough light to support coral growth, but the number of colonies observed is slowly decreasing

Table 3. Coral growth forms, genera, and number of colonies of hard corals in Bunaken Island

Growth Forms	Number of Colonies	Genus	Number of Colonies	Growth Forms	Number of Colonies	Genus	Number of Colonies	Growth Forms	Number of Colonies	Genus	Number of Colonies
STATION 1				STATION 2				STATION 3			
ACB (*Acropora* Branching)	2	*Acropora*	2	ACB (*Acropora* Branching)	12	*Acropora*	12	ACB (*Acropora* Branching)	9	*Acropora*	9
	16	*Porites*	5	ACD (*Acropora* Digitate)	1	*Acropora*	1				
CB (Coral Branching)		*Hydnophora*	1	CB (Coral Branching)	23	*Porites*	13	CB (Coral Branching)	19	*Porites*	19
		Stylophora	2			*Pocillopora*	8				
		Dendrophyllia	5			*Stylophora*	2				
		Caulastraea	1				1				
		Pocillopora	1				7				
		Seriatopora	1				2				
CM (Coral Massive)	20	*Physogyra*	2	CM (Coral Massive)	33	*Euphyllia*	1	CM (Coral Massive)	26	*Montipora*	1
		Porites	2			*Goniastrea*	9			*Favia*	2
		Leptoria	2			*Lobophyllia*	1			*Gardineroseris*	1
		Lobophyllia	2			*Leptoria*	3			*Goniastrea*	3
		Favites	2			*Porites*	2			*Porites*	15
		Symphyllia	1			*Hydnophora*	2			*Lobophyllia*	1
		Goniastrea	3			*Galaxea*	2			*Symphyllia*	1
		Galaxea	2			*Cyphastrea*	2			*Galaxea*	1
		Platygyra	1			*Favites*	1			*Pavona*	1
		Favia	1			*Favia*					
		Diploastrea	1			*Symphyllia*					
		Plerogyra	1			*Physogyra*					
CE (Coral Encrusting)	42	*Porites*	28	CE (Coral Encrusting)	15	*Porites*	8	CE (Coral Encrusting)	15	*Porites*	5
		Pavona	2			*Hydnophora*	1			*Montipora*	2
		Montastraea	1			*Echinopora*	1			*Echinopora*	6
		Montipora	1			*Pavona*	3			*Pavona*	2
		Oxypora	1			*Merulina*	1				
		Turbinaria	1			*Montipora*	1				
		Echinopora	2								
		Pachyseris	4								
		Merulina	1								
		Acanthastrea	1								
CSM (Coral Submassive)	2	*Isopora*	2	CSM (Coral Submassive)	18	*Isopora*	18	CSM (Coral Submassive)	18	*Isopora*	10
										Plerogyra	1
										Turbinaria	4
										Heliofungia	1
										Goniopora	2
CMR (Coral Mushroom)	2	*Herpolitha*	1	CMR (Coral Mushroom)	2	*Cycloseris*	1	CMR (Coral Mushroom)	3	*Ctenactis*	2
		Fungia	1			*Fungia*	1			*Fungia*	1
								CF (Coral Foliose)	3	*Turbinaria*	3
			84				104				93

Figure 2. Encrusting growth forms at a slope of 90°

with increasing depth and coral growth form mostly changing into encrusting to obtain sufficient sunlight.

Ecological Status of Hard Coral

The percentage cover of hard coral at the three stations in Bunaken Island waters is in "good" category (Table 2) with percentage cover of 52.47 % at station 1, 53.84 % at station 2, and 67.25 % at station 3. The average percentage cover is 57.86%. This condition is due to the water quality that still supports the coral growth. Moreover, Mortality Index at the three stations shows a low coral mortality with a value of 0.03 at station 1, 0.11 at station 2, and 0.06 at station 3.

Dominance Index at the three stations showed that there was no indication of dominance of any particular genus of hard coral, with the value at each station of 0.189 at station 1, 0.144 at station 2, and 0.212 at station 3. The dominance of certain genera in an ecosystem will have an impact on the life of other genera due to habitat and food competitions. Diversity Index (H') of hard corals were categorized "moderate" with values of 1.122 at station 1, 1.040 at station 2 and 0.922 at station 3. Rondo *et al*. (2015) stated that the more species in an area and if there is no dominance of any particular species, the higher the diversity index value.

Effect of Slope on Coral Growth Form

Bunaken Island is famous for its steep beach slope. However, some locations on this island still have a less inclined slope. Based on observation during the research, the three stations can be categorized into two types of slopes. Station 1 and 2 are categorized steep slope with 90° and 55°, respectively. Station 3, on the other hand, is categorized as gradually inclined slope (43°). Encrusting growth form was more commonly found on the slope of 90° (Fig. 2), while massive growth forms are common on the slopes of 55° and 43° (Fig. 3). This is one of the coral adaptations to the environment where they live. Encrusting growth forms were commonly found at the slope of 90° because they are adapting to the slope so they still can be attached to the substrate. Massive growth form also found at this slope, but in relatively small size. This is because the possibility of massive corals to be dislodged from their substrate is very large if they grow in large sizes.

CONCLUSION

The difference in slope shows different coral growth forms, where at the slope of 90° the most common form of coral growth is encrusting, slope of 55° and 43° was generally dominated by massive growth forms. In addition, the characteristics of depth did not affect the genera of hard corals on Bunaken Island but did affect the number and size of colonies, where the number decreased with increasing depth as well as colony size.

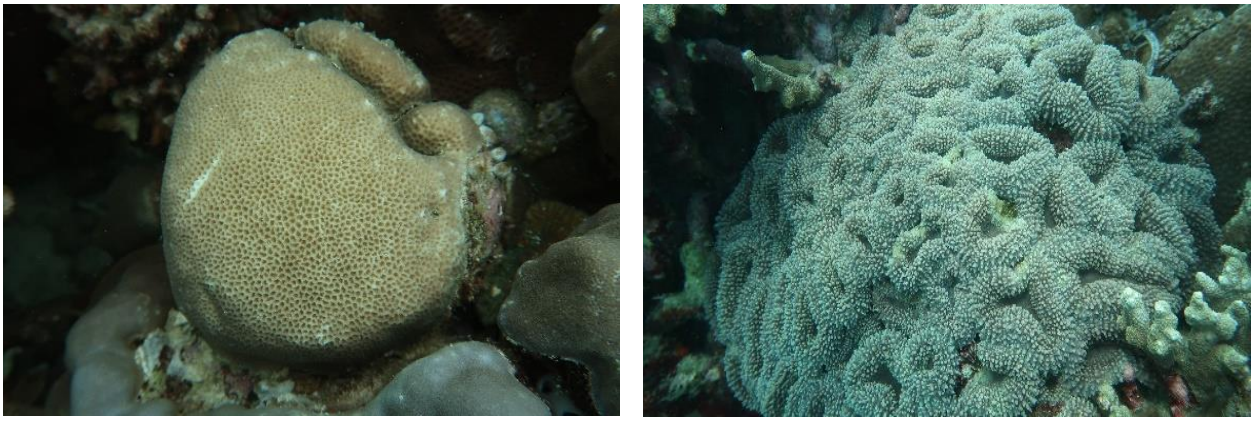

Figure 3. Massive growth forms at slopes of 55° (left) and 43° (right)

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