Distribution and Community Structure of Coral Reefs in The West Coast of Sumatra, Indonesia

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Abstract

This paper assesses the distribution and community structure of coral species in six locations along the west coast of Sumatra, namely Mentawai, Bengkulu, Nias, Padang Pariaman, Simeulue, and Central Tapanuli. Data collected using Line Intercept Transect (LIT) method obtained from 55 sites at six locations. The ordination analysis by using PRIMER 7 software indicates the corals do not distributed evenly. In this case, almost all of the corals distributed mainly in Central Tapanuli and followed by Bengkulu, making it the most diverse corals location in the west coast. Mentawai and Padang Pariaman were less diverse and relatively similar as clustered together, but Padang Pariaman reefs had more *Montipora* and *Pocillopora* while Mentawai reefs is mainly featured by *Pavona* and *Psammocora*. Although Nias reefs clustered into two different clusters, the main reef features were *Porites* and *Pavona*. Simeulue reefs appeared characterized by *Porites* and *Psammocora*. Porites known as a very common genus of coral and are found in the widest area of the world's coral reefs. *The within-site species richness determined by using species accumulation curve. K-dominance curve showed that Bengkulu and Mentawai seemed to have the lowest cumulative abundance but then crossed over Central Tapanuli at the third most abundance species.* There were 52 genera found from six locations, eight of them distributed in all locations. Approximately 90% of which were found in Central Tapanuli. *There were no differences between live coral coverage within locations, yet Caswell's neutral model showed that Mentawai and Bengkulu had more coral species than other locations, indicating that there were likely were less stress environmental conditions occurring in these two locations.*

***Keywords** : distribution, community, coral, west coast, Sumatra*.

Introduction

The reef building coral in Indian Ocean is one of the least known globally. Indian ocean is the second largest biodiversity for coral reefs, following the Pacific Ocean (Veron, 1995). Coral biogeography along the Indian Ocean is influenced by the current pattern both in the past and present, speciation and species extinction. Oceanography pattern in which explaining the global coral reefs biodiversity established including the region at Indian Ocean. In the atlas of Marine Ecoregion of The World (MEOW), west Sumatra waters located at the western Indo Pacific, in Andaman waters with ecoregion western of Sumatra (Spalding *et al*., 2007). The division of ecoregion based on the similarity of distribution and the richness of marine biota in certain area in the same boundaries, including the distribution and richness of coral species. Veron *et al*. (2009) estimates that the distribution of coral species in the western Sumatra reaches 386 species, in the range of 351 to 400 species of 40-60 genera and more than 12 families.

Studies of distribution and coral communities along the western waters of Sumatra are limited, but similar studies conducted on a local scale recently. Weh Island, which is located in the north-westernmost part of Sumatra has a distribution of coral genera dominated by *Acropora*, *Porites* and *Heliopora* (Baird *et al*., 2012). While (Quinn and Johan, 2015) recorded about 26 genera of corals in Pieh Island and surrounding areas, where coral species were dominated by *Pocillopora* spp.

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ijms.undip.ac.id
DOI: 10.14710/ik.ijms.24.1.51-60
Received : 17-01-2019
Accepted : 12-02-2019

Studies in the Indian Ocean including the eastern coast of Africa, the Madagascar Islands, the Seychelles and the Mascarene Islands found as many as 369 species of corals, in the range of 174 to 297 species between the locations (Obura, 2012). The diversity of coral species decreases to the north of Indian Ocean, including Bangladesh (66 species), Chagos, Sri Lanka, Maldive, Lakshadweep Islands (95 species), Andaman and Nicobar Islands (203 species), and 199 species of 37 genera in Indian waters (Rajasuriya, 2000) (Saroj and Gautam, 2016). Likewise in the south-western Indian Ocean, such as Christmas Island and Cocos (Keeling), Australia has only about 85-99 species of coral from 41 genera have been recorded (Veron, 1990) (Done and Marsh, 2000). The result of several taxonomic and biodiversity studies showed that the distribution and richness of coral reefs are locally specific.

Availability of wider data in the western waters of Sumatra can provide more information of the distribution and the biodiversity of coral species as well as the patterns between locations within the region. Previous study conducted at different locations along the northwest coast and at the outer islands of Sumatera. Data set of the presence and distribution of coral genera and the benthic community cover using the same method (Line Intercept Transect) were compiled from six regions namely Simeulue, Banda Aceh; Central Tapanuli and Nias, North Sumatra; The Islands of Mentawai and Padang Pariaman, West Sumatra and Bengkulu. The aim of this study is to know the distribution and the coral structures communities and other benthic biota as well as its patterns within the region.

Materials and Methods

Study areas

The study was conducted by surveying six locations along the west coast of Sumatra namely Mentawai (9 sites), Bengkulu (7 sites), Nias (8 sites), Padang Pariaman (10 sites), Simeulue (5 sites) and Central Tapanuli (13 sites) (Figure 1.).

Sampling

Benthic communities and substrates parameter on the locations were assessed by using Line Intercept Transect (LIT) (English and Baker, 1997). At each site, three replications of 10 m transect were laid parallel to the coast line at depth of approximately 5 m and each replication was separated by 20 m. The underlying benthos and substrates recorded with the accuracy up to cm. The benthic categories including hard coral, soft coral, sponge, macro algae, dead corals with algae, sand, rubble, silt and others (ascidians, hydroid, gorgonian, zoanthids, *etc*). Hard corals identified until genera level. Then, the categories pooled into four major categories, including hard corals, other live benthos (macro algae, sponges, soft corals, and others), DCA and other substrates (sand, rubble and silt).

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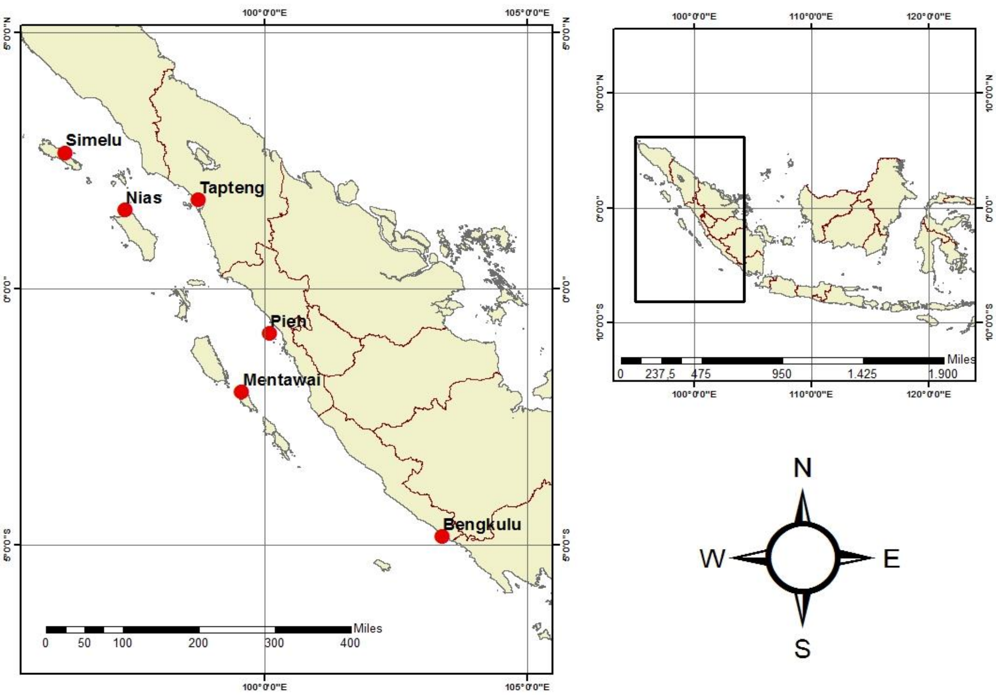

Figure 1. Map of research locations on the west coast of Sumatra

Analysis

Percent cover of benthic communities and substrates analyzed quantitatively by using one-factor analysis of variance (ANOVA) with location as the fixed factor in the S-PLUS software. The data were transformed –log (x+1) to meet the assumption of normal distribution and homogeneity. If the results were significant, then it investigated further the data. Then it was assessed further by using non-metrical dimensional scaling on Bray Curtis similarity (Clarke and Warwick, 2001).

The data number of the genera also examined by using k-dominance curve to investigate the cumulative dominance of the genera from each location. Furthermore, the data were also observed using Caswell's neutral model (Caswell, 1976) to detect neutrality of hard coral communities assuming that there is no biological interactions between species (Platt and Lambshead, 1985).

Results and Discussion

In general, percent covers of benthic communities and substrates showed different results. It turned out that hard coral covers were

by using an unplanned comparison test, Tukey method at the 95% confidence level, to find where the differences occurred.

The variation of the genera among sites analyzed using ordination methods on dissimilarity matrices in the PRIMER 7 software. The data were square root transformed to improve the spread of

significantly different among the locations (Table 1.). It also occurred likewise for other live benthos. In contrast, percent cover of DCA as well as other substrates differed significantly among the locations. Bengkulu's DCA cover was the highest among the others by 56%, while Mentawai's DCA cover was the lowest by 19.37%. In addition, Bengkulu's other substrate cover had the lowest percent cover among the other locations by 9%, while Mentawai's other substrate cover was the highest percent cover among the locations by 39.88%.

The ordination analysis indicates the corals do not distributed evenly. In this case, almost all of the corals distributed mainly in Central Tapanuli and followed by Bengkulu, making it the most diverse corals in the west coast. Mentawai and Padang Pariaman were less diverse and relatively similar as clustered together, but Padang Pariaman reefs had

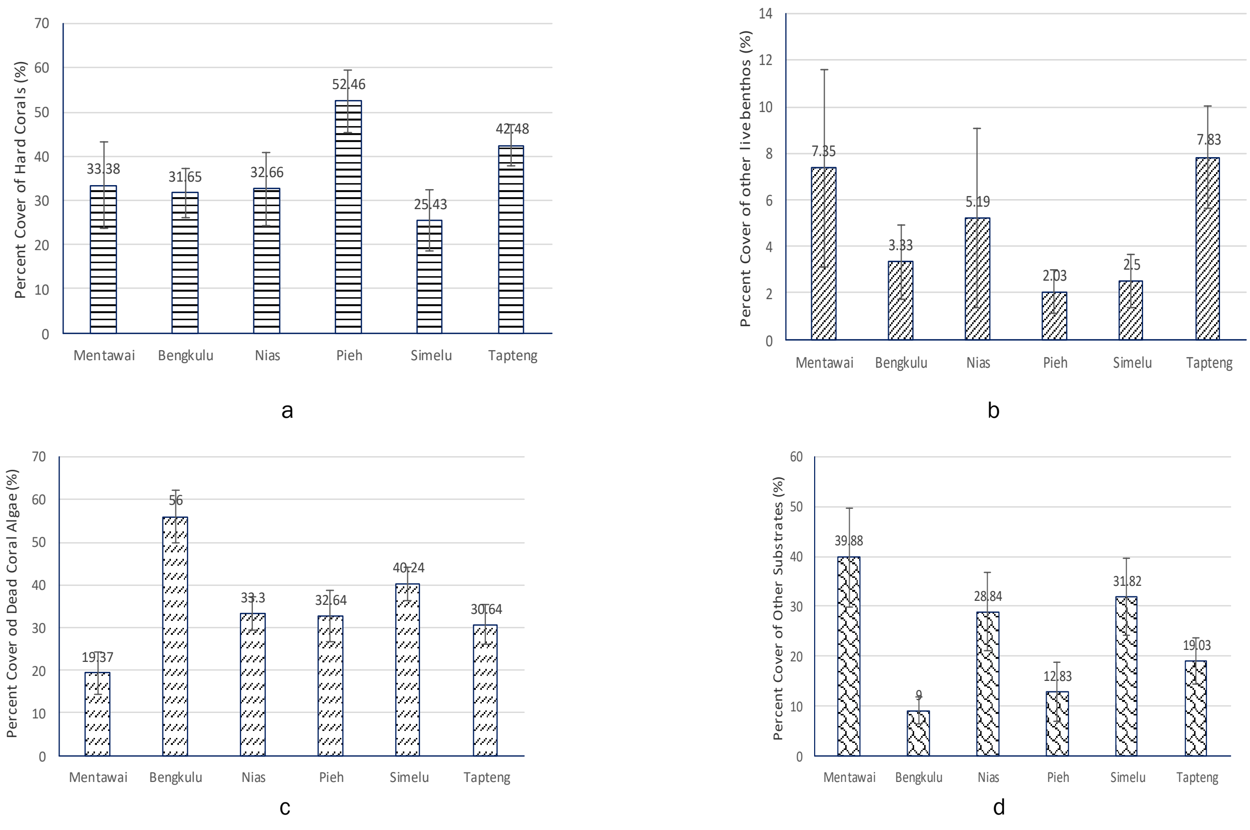

Figure 2. Percent cover of benthic and substrate categories; a) hard coral, b) other live benthos, c) dead coral with algae (DCA), d) other substrates.

Tabel 1. Anova of benthic and substrate covers with location as factor

Percent cover	Factor	Df	Sum of Square	Mean Square	F value	P value	Tukey Method
Hard corals	Location	5	4.2036	0.8407	1.7769	0.1347	-
	Residuals	50	23.6564	0.4731			
Other live benthos	Location	5	7.3415	1.4683	1.4862	0.2110	-
	Residuals	50	49.3916	0.9878			
DCA	Location	5	7.5781	1.5157	2.9132	0.02198*	B > S = N = P ≥ T > M
	Residuals	50	26.0127	0.5203			
Other substrates	Location	5	14.8223	2.9645	2.6086	0.03581*	M = S ≥ N = T ≥ P = B
	Residuals	50	56.8217	1.1364			

*: significant (M: Mentawai; B: Bengkulu; N: Niah; P: Padang Pariaman; S: Simeulue; T: Central Tapanuli)

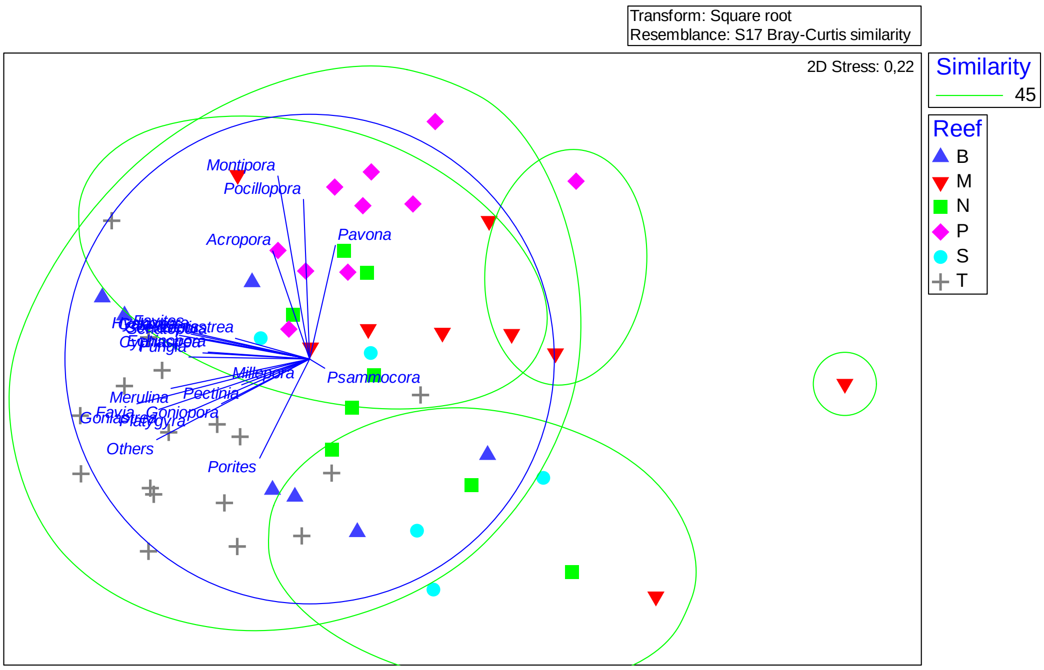

Figure 3. Non-metric Multidimensional Scaling (nMDS) of number of the genera on the six locations (B : Bengkulu, M : Mentawai, N : Nias, P : Padang Pariaman, S : Simeulue, T : Tapanuli tengah)

more *Montipora* and *Pocillopora* while Mentawai reefs is mainly featured by *Pavona* and *Psammocora*. Although Nias reefs clustered into two different clusters, the main reef features were *Porites* and *Pavona*. Simeulue reefs appeared characterized by *Porites* and *Psammocora*. Porites known as a very common genus of coral and are found in the widest area of the world's coral reefs (Veron 2000, 2009, 2014), including in Indonesian waters (Suharsono, 2008). The distribution of the the Porites genus is limited by distance, which causes genetic geographic isolation (Polato *et al.*, 2010; Baums *et al.*, 2012; Forsman *et al.*, 2015). Corals of the Porites genus show high tolerance to changes in salinity (Moberg *et al.*, 1997). The research also show a high tolerance of the Psamocora genus to changes in salinity (Bezy *et al.*, 2006) and are resistant to increased temperatures due to El Nino-Southern Oscillation (ENSO) (Jiminez and Cortes, 2001; Glynn, 2003). The diversity of Psamocora coral species and habitat variation are the inhibiting factors of adult coral recruitment and distribution (Bezy *et al.*, 2006).

The curve illustrates that the four locations (Bengkulu, Mentawai, Central Tapanuli and Nias) had higher evenness (lower dominance) than the two other locations. Bengkulu seemed to have the lowest cumulative abundance but then crossed over Central Tapanuli at the third most abundance genera. This makes Central Tapanuli hold the highest evenness afterwards. In addition, Caswell's neutral model (V) shows that Mentawai and Bengkulu had greater relative diversity than the others (positive score) (Table 2.), indicating that there were likely less stress environmental conditions occurring in those two locations. The distribution of coral genera presented in table 2 below. There were 52 genera found from six locations, eight of them distributed in all locations. Approximately 90% of which were found in Central Tapanuli (Table 3).

Study on distribution and structure of coral reef communities in several locations along the west coast of Sumatra and its outermost islands could illustrates the condition of coral reef habitat. It was found that there was no spatial variation in percent cover of hard corals and other live benthos as they not significantly different among the locations, averaging at 38.52±2.98% and 5.3±1.13% respectively. According to (Kunzmann and Efendi, 1994), high sedimentation and destructive fishing with bomb crater are the main factors of coral degradation in West Sumatra. Instead of those two factors, coral and shell mining increase the pressure to coral community within the area. In Mentawai, based on (Kunzmann and Efendi, 1994), there is a largest live reef fish trades of west Sumatra is based where fisherman practice a cyanide in order to caught fish to the middleman in the market. This lead to an endless area of coral rubble remaining. Furthermore, Jonker and Johan (1999) mentioned that coral in West Sumatra also was highly affected by the dramatic dropping of water temperature of 5-6 °C caused by the uncontrolled forest fire in 1997. The thick smoke coincides with the delayed rain and the red tide resulted in widespread coral death in West Sumatra (Jonker and Johan, 1999), which left live coral cover almost in 0% (Efendi and Indrawadi, 1998). Additionally, climatic events as Indian Ocean Dipole in 1997 also played role to stress the coral reef ecosystem. Together with wildfires and additional human disturbances, the effect was very damaging to the coral reefs (Abram *et al*., 2003).

Another possible reason is the reefs have encountered regional or global stressors from which the reef conditions declined dramatically but started
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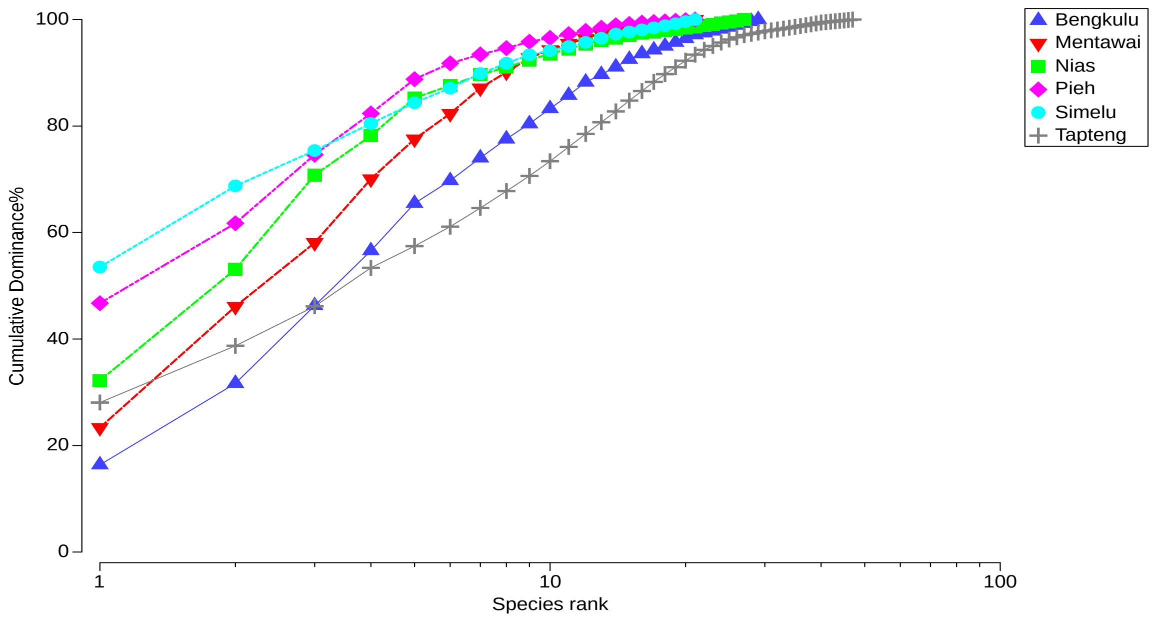

Figure 4. K-dominance curves of number of the genera from each location

Table 2. Caswell's neutral model (V) for the genera of hard corals from six locations.

Sample	N	Genera	V
Bengkulu	281	29	0,08037
Mentawai	334	21	0,01956
Nias	435	27	-1,925
Padang Pariaman	839	21	-0,9875
Simeulue	256	21	-2,567
Central Tapanuli	1229	47	-0,2292

Table 3. Distribution of hard corals in the west coast of Sumatra

No.	Genus	Bengkulu	Mentawai	Nias	Padang Pariaman	Simeulue	Central Tapanuli
1	*Acropora*	+	+	+	+	+	+
2	*Astreopora*	+	-	+	+	+	+
3	*Acanthastrea*	+	-	-	+	-	-
4	*Barabattoia*	+	-	+	-	-	+
5	*Caulastrea*	-	-	-	-	-	+
6	*Coeloseris*	-	-	+	+	-	+
7	*Ctenactis*	+	+	-	-	-	+
8	*Coscinarea*	-	+	-	-	-	+
9	*Cyphastrea*	+	+	+	+	+	+
10	*Diploastrea*	-	-	-	-	-	+
11	*Echinophyllia*	+	-	-	-	-	+
12	*Echinopora*	+	+	+	-	-	+
13	*Euphyllia*	-	-	-	-	-	+
14	*Dipsastraea*	+	+	+	+	+	+
15	*Favites*	+	-	+	+	+	+
16	*Fungia*	+	+	+	+	+	+
17	*Galaxea*	+	+	+	+	+	+
18	*Goniastrea*	+	-	+	+	+	+
19	*Goniopora*	-	-	-	-	-	+
20	*Heliopora*	+	+	+	-	-	-
21	*Hydnopora*	+	+	-	+	+	+
22	*Herpolitha*	-	-	+	-	-	+
23	*Leptastrea*	-	+	+	+	+	+
24	*Leptoseris*	-	+	+	-	-	+
25	*Lobophyllia*	-	-	+	-	+	+
26	*Litopyllon*	-	-	+	-	-	-
27	*Merulina*	+	-	-	-	-	+
28	*Millepora*	+	-	-	+	+	+
29	*Montastrea*	+	-	+	-	+	+
30	*Montipora*	+	+	+	+	+	+
31	*Mycedium*	+	-	-	-	-	+
32	*Oulophyllia*	+	-	-	-	-	+
33	*Oxypora*	+	-	-	+	-	+
34	*Pachyseris*	-	-	-	-	-	+
35	*Palauastrea*	-	-	-	-	-	+
36	*Pavona*	+	+	+	+	+	+
37	*Pectinia*	-	+	+	-	+	+
38	*Plesiastrea*	+	-	-	+	-	-
39	*Physogyra*	-	-	-	-	-	+
40	*Plerogyra*	-	-	-	-	-	+
41	*Podabacia*	-	-	-	-	-	+
42	*Polyphyllia*	-	-	-	-	-	+
43	*Pocillopora*	+	+	+	+	+	+
44	*Platygyra*	+	-	-	-	+	+
45	*Porites*	+	+	+	+	+	+
46	*Psammocora*	-	+	+	+	+	+
47	*Pseudosiderastrea*	-	-	-	-	-	+
48	*Seriatopora*	-	+	+	+	-	+
49	*Stylophora*	-	+	-	-	-	+
50	*Symphyllia*	+	-	-	-	-	+
51	*Stylocoeniela*	-	-	+	-	-	-
52	*Turbinaria*	+	+	+	-	+	+

+ : present; - : absent

to recover gradually afterwards. In this case, the region was highly impacted by the 2004 tsunami in the west coast of Sumatra and the 2010 global coral bleaching event (Rudi, 2005; Campbell *et al*., 2007; Liew *et al*., 2010; Tun *et al*., 2010; Rudi *et al*., 2012; Muttaqin *et al*., 2014). Nevertheless, the reefs did not show any indication of phase shift as the percent cover of hard corals is nearly eight times higher than other live benthos cover, indicating that the reefs might have an ecological insurance against the global and regional stressors, such as coral recruitment, substrate availability and coral diversity (Arnold and Steneck, 2011). In addition, it is necessary to gain time series data to understand the dynamic of reef benthic communities after the reefs experience severe disturbances.

The distribution of coral genera, in general, indicated a variation among the locations. In this case, the typically exposed locations (outermost islands), Mentawai, Nias and Simeulue, are characterized by mainly *Pavona*, *Psammocora* and *Porites* which are mostly found with massive and sub-massive growth form. These types of growth form are wave-tolerant, having basal area greater than wave-exposed surface area and thus enabling them to keep attaching steadily on the substratum (Massel and Done, 1993; Williams *et al*., 2013). On the other hand, the rest innermost locations, which are typically less exposed, typified by diverse of corals. Many minor genera gather in Central Tapanuli and Bengkulu, while the Padang Pariaman reefs mainly characterized by *Acropora*, *Montipora* and *Pocillopora*. Under the condition of less wave action, it gives an opportunity to many corals, including fragile-branching and foliose, to thrive and, if it continues, those corals can characterize the reefs (Done, 1982; Huston, 1985; DeVantier *et al*., 2006). Furthermore, the result also revealed that coral cumulative dominance appeared to be smaller in the leeward except Padang Pariaman, suggesting that hard corals are diverse. Hence, the coral distribution is closely related to the environment conditions, which can drive coral community structures (Eidens *et al*., 2015). Stressful environmental conditions such as dredging and eutrophication affect coral communities by reducing the relative diversity (Karlson and Hughes, 2004; Cleary *et al*., 2006). A modelling study reveals that the most stressful environment in Indian Ocean was in the north-western and some central oceanic islands, suggesting that corals in this area have high susceptibility to natural disturbances (Maina *et al*., 2008). Although the study did not mention the east region, it assumed that the north parts are likely more susceptible compared to the south parts. In this study, Simeulue, north win ward, held the lowest relative diversity (negative V-value), indicating that the environmental conditions might be more stressful than the others might. A cluster environmental analyses-based study also indicated that north and south coast of Sumatra were classified into, at least, two different clusters (Wolter, 1987). This is likely to cause the differences in relative diversity. When it moves to the south, the relative diversity becomes higher.

Benthic community cover and structure

Western Sumatra characterized by relatively open waters and directly facing the Indian Ocean. The coast consist of hilly terraces, straits, capes and small islands where coral reefs found almost in each area. Specific physical conditions and aspects of the oceanography of each location and also development and utilization of natural resource lead to the variation and certain pattern of the structure and coral reefs communities.

Live coral cover and other benthos biota do not show the difference and tend to be similar, yet the differences are seen in dead coral covered by algae and other substrate. Thus, it can be said that the distribution and cover of coral reef communities are relatively similar and do not show spatially specific patterns between sites (Eidens *et al*., 2015). Naturally, the distribution and scattering of coral and other benthic biota are strongly influenced by oceanic codes, especially current patterns, upwelling events and and their physical-chemical aspects. The oceanographic conditions of the western waters of Sumatra are relatively homogeneous and show the same pattern on a daily and seasonal basis, thus giving the same effect to the coral reef community. Besides, the form of pressure of coral exploiting and to other benthic biota is relatively similar with the development along the coast and small islands.

Dead coral algae percentage at Simeulue, Nias, Padang Pariaman and Central Tapanuli locations tends to be similar, but different percentage shown at Bengkulu and Mentawai. Those dead coral with algae were found at small islands and close to the mainland. Thus, nutrients and sedimentation from the land flew into the waters and causing in coral mortality. In Bengkulu, the high percentage of dead coral with algae occurs because the reefs are dominated by dead corals which act as the previous stage of dead coral with algae. Coastal Bengkulu is an open and direct location of Indian Ocean waters with big waves and strong current. Most of the beaches are rocky. While the benthic substrate in Mentawai waters were dominated by sand and rubble, yet the dead coral with algae is relatively low. Mentawai has a shallow waters characterized by sandy beaches and large rivers flow into the ocean causing a large number of sand and mud covering the sea base. Abrasion, sand and coral reefs mining are seen in some stations which can also increase the coverage of the sand and dead corals.

iCoral biodiversity

Waters along the west coast of Sumatra have distinctive characteristics. The character is almost similar as the characteristics of the waters along the south of Java. This similarity is emerged by the influence of the water mass from the Indian Ocean which has strong waves throughout the year. This condition characterizes the coral community structure existing along the west coast of Sumatra (Hoeksema and Putra, 2000). The result showed a total of 52 genera are found in six sites.

Hoeksema and Putra (2000), stated that the diversity of coral genera along the west coast of Sumatra is the lowest in Indonesia. West coast of Sumatra has 48 coral genera, is in the most bottom position, following the Togean Island, which has 57 coral genera. The highest number of coral genera belong to North Sulawesi (Hoeksema and Putra, 2000). Other study showed that the number of coral genera collected on the west coast of Sumatra is the lowest compared with 14 other sites in Indonesia, which is only 386 species (Veron *et al*., 2009). The highest number of species is in the bird's head of Papua, Raja Ampat Island, which has 553 species of corals (Turak and Sohouka, 2002).

The significant difference in the number of genera between the west coast of Sumatra and the central and eastern regions of Indonesia in addition to natural factors is also due to anthropogenic factors. The intensity of unsustainable fishing practices and sedimentation factors strongly contribute to the diversity of different coral genera present in each region (Edinger and Kolasa, 2000). The results of (Edinger *et al*., 1998) suggest that ground-based pollution is the primary determinant of the existence of a coral species in a region. The effect of biogeography on species diversity can be distinguished after the pollution parameters from the mainland are removed from the data set (Edinger and Kolasa, 2000). In addition, the factor that enhance the number of genera found in eastern waters of Indonesia is the presence of rare genera or species. Eastern Indonesia waters have many more rare species compared to western Indonesia (Edinger and Kolasa, 2000).

Veron *et al*. (2009) states that diversity is a result of two things, namely, the high endemism and species overlap over a vast range. Importantly, the first factor contributes only 2,5% of the diversity of coral species. However, coral diversity is almost entirely due to species overlap in the wide range that leads eastward to the Pacific Ocean and to the westward towards the Indian Ocean.

Conclusion

Coral diversity in six locations has a wide variety in distribution. The highest diversity found in Central Tapanuli followed by Bengkulu. Live coral cover and other benthic categories in all locations do not show a significant difference. Coral species found in outermost locations are dominated by encrusting species while in the innermost locations are dominated by branching species of Acropora, Pocillopora and Montipora.

Acknowledgement

Authors would like to thank to Project COREMAP under Asian Development Bank who provides fund for this research. Also thank to Prof. Dr. Suharsono for giving his best suggestion and feedback for this paper.

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