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# Change in coral reef benthic communities in the Lembeh Strait and Likupang, North Sulawesi, Indonesia

HADI Tri Aryono[1]*, SIHOUKA Jimmy[2], SHI Xiaofeng[3], BUDIYANTO Agus[1], SUHARSONO[1]*

[1] Research Center for Oceanography, Indonesian Institute of Sciences, Jakarta 14430, Indonesia

[2] Conservation Unit for Bitung Marine Life, Indonesian Institute of Sciences, Bitung 95527, Indonesia

[3] Third Institute of Oceanography, Ministry of Natural Resources, Xiamen 361005, China

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## Abstract

Anthropogenic impacts and natural disturbances have been intense recently in the global scale, affecting the composition of coral reef benthic communities from coral to algal dominated reefs. However, this condition does not always occur considering corals are able to recover when the stressors falter. This study aims to investigate the change in coral reef benthic communities and the relationship among benthic categories. The study was carried out in 2014 and 2016 at five sites, three sites in the Lembeh Strait and two sites in Likupang, North Sulawesi Province. Underwater Photo Transect (UPT) was used at depth of around 4–6 m in slope areas. The result indicated that the benthic communities were slightly changing: the percent covers of hard corals, sponges, soft corals, macroalgae and substrate categories were not significantly different between the years but category of others, particularly seasonally growing hydroid, increased significantly, occupying the available substrates and overtopping other benthos surrounding. The study also found that there was a significant relationship between the change in benthic gradient and the number of hard coral colonies: when the composition becomes less complex, the number of colony declines. In contrast, the hard coral diversity remained unchanged, suggesting the coral reefs apparently have an ecological resilience (sustainable species diversity) against the change although ecological complexity declines. In addition, the hard coral cover was significantly correlated with soft coral and sponge covers, which did not change significantly among the years. In general, the coral reefs in North Sulawesi might experience a temporary blip due to the increasing percent cover of others, and be predicted to recover as there was no indication of soft corals and sponges to increase significantly. However, it is necessary to investigate the dynamic of benthic communities in different depth gradients to gain a comprehensive understanding as the communities respond differently to the light intensity.

**Key words:** coral reef, benthic community, percent cover, Lembeh Strait, Likupang

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## 1 Introduction

Coral reefs degradation has been inevitable since anthropogenic factors became intense and continuous (De'ath et al., 2012; Knowlton and Jackson, 2008). Furthermore, natural catastrophes have caused sudden decline in coral cover and habitat complexity (Goffredo et al., 2007; Campbell et al., 2007; Kulkarni et al., 2008). Following the decline, a phase shift to algal dominated communities commonly occurs; particularly resulted from poor water quality and overfishing of herbivorous fishes (Hughes et al., 2007; Bruno and Selig, 2007; Cheal et al., 2010). However, there are evidences that coral reefs are able to recover and result in a different coral community structure (Sheppard et al., 2008; Smith et al., 2008; Gilmour et al., 2013; Ceccarelli et al., 2011). Hence, it is clear that coral reefs are dynamic and needs a good understanding at which state coral reefs are becoming at present.

Coral reefs play an important role both in ecological and socio-economic aspects. First, coral reefs provide a complex habitat which enables plenty of marine biota to settle, forage, spawn and nurture their juveniles, making it the richest marine ecosystem in the world (Moberg and Folke, 1999). Second, coral reefs boost fishery and tourism industries, providing nutritious food for people and creating many promising jobs (Brander et al., 2007; McCook et al., 2010). In Indonesia, estimated annual economic value from coral reef related to goods and services is approximately 127 million, 1.5 million and 387 million USD for tourism, fishery and shoreline protection respectively (Burke et al., 2012). These benefits are dynamic following the condition of coral reefs, making the stakeholders have to manage the reefs professionally and aware regarding the reefs' trajectory.

Coral reefs in North Sulawesi, located in the Coral Triangle Region, have been studied from some different point of views (Tomboelu et al., 2000; Souhoka, 2004; Arifin, 2007; Manembu et al., 2012; Putra and Handoyo, 2013; Hermanto, 2013). Nevertheless, the studies do not take into account the trajectory of coral reef conditions which is essential information for stakeholders to make decisions. The Lembeh Strait is well known for its exciting

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*Corresponding author, E-mail: ari_080885@yahoo.com; shar@indo.net.id

diving spots, having many long fringing reefs spanning along the strait in both of the mainland and the Lembeh Island. Along with the development of the local ports, shipping activities become frequent and may undermine the coral reef ecosystem. In Likupang, traditional fishery industry appears to be quite common, whereas, tourism sector is still rare, mainly due to lack of infrastructure. These complex conditions may influence the coral reef conditions, particularly the benthic communities, therefore monitoring is vital to understand the change of coral reef condition before feasible solutions being made. This study aims to investigate the change in coral reef benthic community condition and its relation among the categories.

## 2 Materials and methods

### 2.1 *Study area*

The research was carried out in May 2014 and August 2016 by taking five sites; three sites located in Bitung (the Lembeh Strait) and the rest occurred in Likupang (Fig. 1). The condition in the Lembeh Strait was relatively moderate in term of current with visibility, at the moment of the observation, around 10–13 m. The characteristic of the shore commonly is steep, rocky with short reef flat. In Likupang, the condition is relatively the same in term of visibility but the current is slower than in the strait. The sandy shore with long reef flat is the common characteristic of the land.

### 2.2 *Protocol*

The condition of coral reef benthic communities was quantified based on the percent covers. The method used to quantify was Underwater Photo Transect (UPT), using a 44 cm×58 cm iron frame (Giyanto et al., 2010; Giyanto, 2012a, b). The frame was put on a laying transect line, which was installed parallel to the coast line at around 4–6 m in depth, starting from 1 m to 50 m with interval of 1 m. The frame was set up and down of the transect line for odd and even numbers respectively.

### 2.3 *Data analyses*

The photo data collected from UPT method were then analyzed by using Coral Point Count with Excel extensions (CPCe) (Kohler and Gill, 2006). A 30 random point was spread on each frame (having total 1 500 points per transect); substrates and benthic categories picked by the points were identified following the given codes (Table 1). Live corals were identified further until species level by referring to Coral of the World (Veron, 2000a, b, c). The percent cover of benthos and substrate categories is automatically counted in Excel extension by the program. In addition, the number of coral colonies was also counted by calculating the total number of occurrences from the 50 photos.

To investigate the difference of coral reef conditions over time, it was used $t$-test with percent cover as a variable. Then, the change of benthic communities and substrates among the sites through the time was examined by using Principal Component Analysis (PCA) on Euclidean distance and grouped by overlying slices derived from a hierarchical cluster analysis. Beforehand, the percent cover data were transformed $\lg(x+1)$ to minimize the deviation from normality. The relation of the change was viewed from the change in gradient composition of the PCA axis (PC 1) to coral's species richness ($S$) and colony number ($N$). Furthermore, the relationship among the categories was also examined.

## 3 Results

### 3.1 *Change in benthic covers and substrates*

It appears that the benthic covers and substrates did not

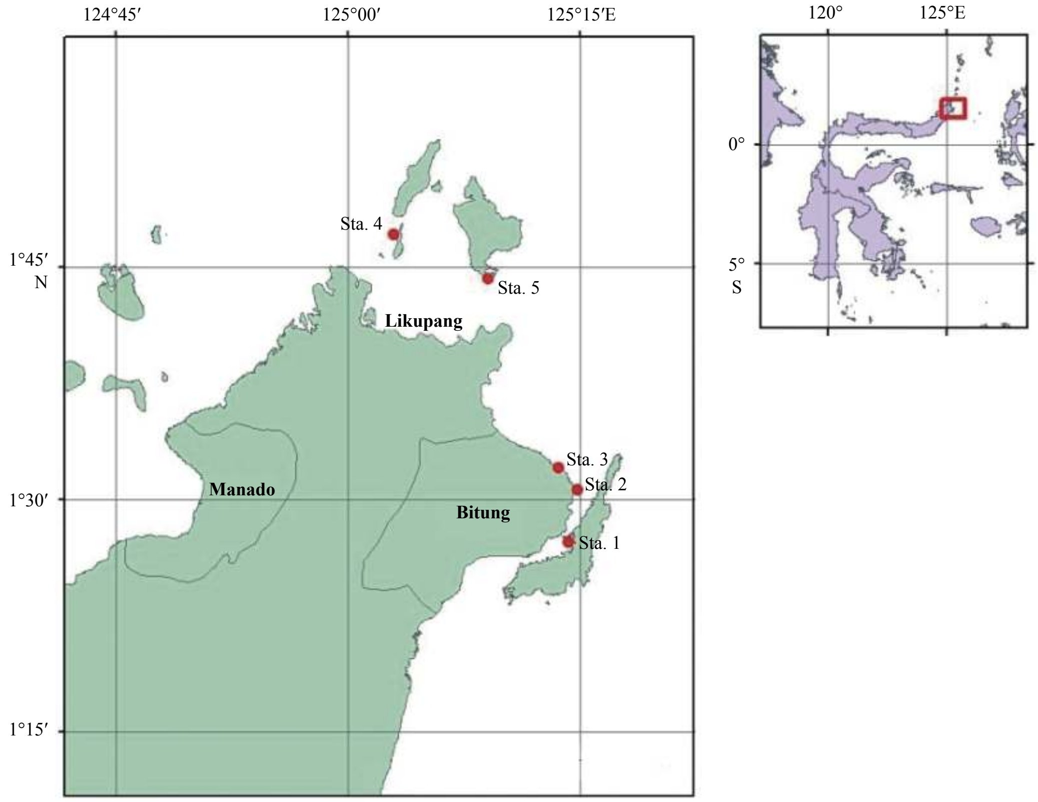

**Fig. 1.** Study sites in Bitung and Likupang, North Sulawesi, Indonesia.

**Table 1.** Codes of benthic and substrate categories

| Benthic and substrate categories | Code |
|---|---|
| Live coral | LC |
| Acropora | –AC |
| Non Acropora | –NA |
| Dead coral | DC |
| Dead coral with algae | DCA |
| TurfalgaeSoft coral | TASC |
| Sponge | SP |
| Fleshy seaweed | FS |
| Others | OT |
| Rubble | R |
| Sand | S |
| Silt | SI |
| Rock | RK |

change significantly, particularly hard corals ($p$=0.55), DCA ($p$=0.19), soft corals ($p$=0.53), fleshy seaweed ($p$=0.68) and substrates ($p$=0.11). On the other hand, sponges and others differed significantly between the year with $p$=0.03 and $p$=0.00 respectively. Although the coral cover was not significantly different, it slightly declined by 3.61% (Fig. 2). The slight decline also occurred to DCA and substrate categories by 4.68% and 3.29% respectively. In contrast, the increase occurred to four different categories, including fleshy seaweed (0.9%), sponge (1.84%), soft corals (1.99%) and others (10.47%).

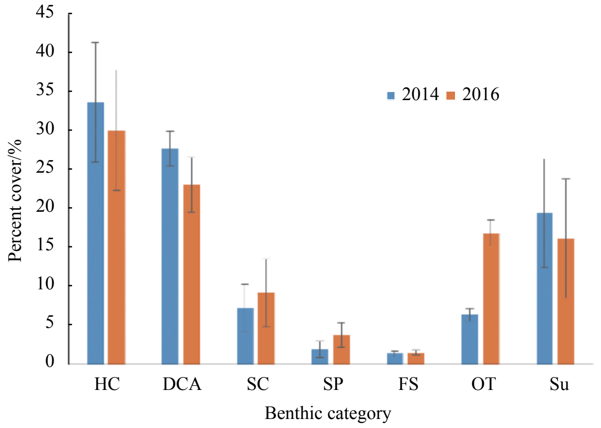

**Fig. 2.** Percent cover of benthic categories and substrates. HC represents hard coral, DCA dead corals with algae, SC soft coral, SP sponge, FS fleshy seaweed, OT others, and Su substrates (rubble and sand).

### 3.2 *Change in benthic and substrate composition*

The composition of benthos and substrates were variable from hard coral domination to soft corals and sand domination in positive and negative scores respectively (Fig. 3). The principal component 1 (PC 1), accounting for 30.2% of variation, ordinates the composition from sand in the negative scores to hard corals (Oculinidae) in the positive score. The second principal component (PC 2) differentiates Acroporidae in the positive scores to soft corals in the negative scores, having about 27.2% of variation.

It appears the composition was slightly changing during the time period and different among the sites (Fig. 3). In this case, the benthic and substrate compositions at four sites, including Stas 1, 2, 3 and 5 were not quite different between the years (indicated by the close distance), but different among the sites as grouped into three different clusters. Conversely, the composition at Sta. 4 appeared to be changing, characterized mainly by Acroporidae in 2014 to soft corals and Oculinidae in 2016.

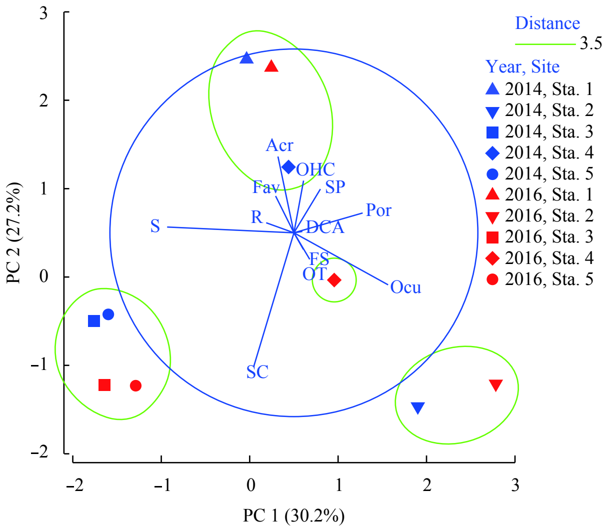

**Fig. 3.** Principal component analysis (PCA) for benthic and substrate categories from five different sites in 2014 (blue color) and 2016 (red color). Acr represents Acroporidae, Fav Faviidae, Por Poritidae, Ocu Oculinidae, OHC other hard corals, SP sponge, SC soft coral, FS fleshy seaweed, DCA dead coral with algae, OT others, S sand, and R rubble.

### 3.3 *Relationship between the gradient composition (PC 1) and species richness (S) and colony number (N) of coral; and among the benthic categories and substrate*

The number of coral species found in 2014 and 2016 were slightly different, accounting for 130 and 133 species respectively (Table A1). Whereas the average colony number was 148 and 107 colonies in 2014 and 2015 respectively. Then these data were linked to the change of the gradient composition of benthos and substrates. The change in benthic and substrate composition, from high structural complexity dominated by hard corals (Oculinidae and Poritidae) in the positive scores to low structural complexity dominated mainly by sand and soft corals, apparently brought different trends to species richness of coral and the number of colonies. In this case, species richness of coral appeared to be relatively similar ($p$=0.93, $R^2$=0.001) although the gradient composition of benthic and substrates changed (Fig. 4a). In contrast, a moderate upward trend occurred in the number of colonies ($p$=0.04, $R^2$=0.409), indicating that the lower structural complexity, the less number of colonies found (Fig. 4b).

Among the benthic and substrate categories, an insignificant relationship occurred between hard coral cover and DCA combined with fleshy seaweed ($p$=0.80), others ($p$=0.90), and rubble ($p$=0.27) (Figs 4c, d and e). In contrast, a significant relationship only occurred between hard coral cover and soft coral combined with sponge covers ($p$=0.02), suggesting that the decline in hard coral cover was likely associated with the increase of soft coral and sponge covers (Fig. 4f).

## 4 Discussion and conclusions

Coral reefs are a dynamic ecosystem in which the communities respond differently to the change of environmental condi-

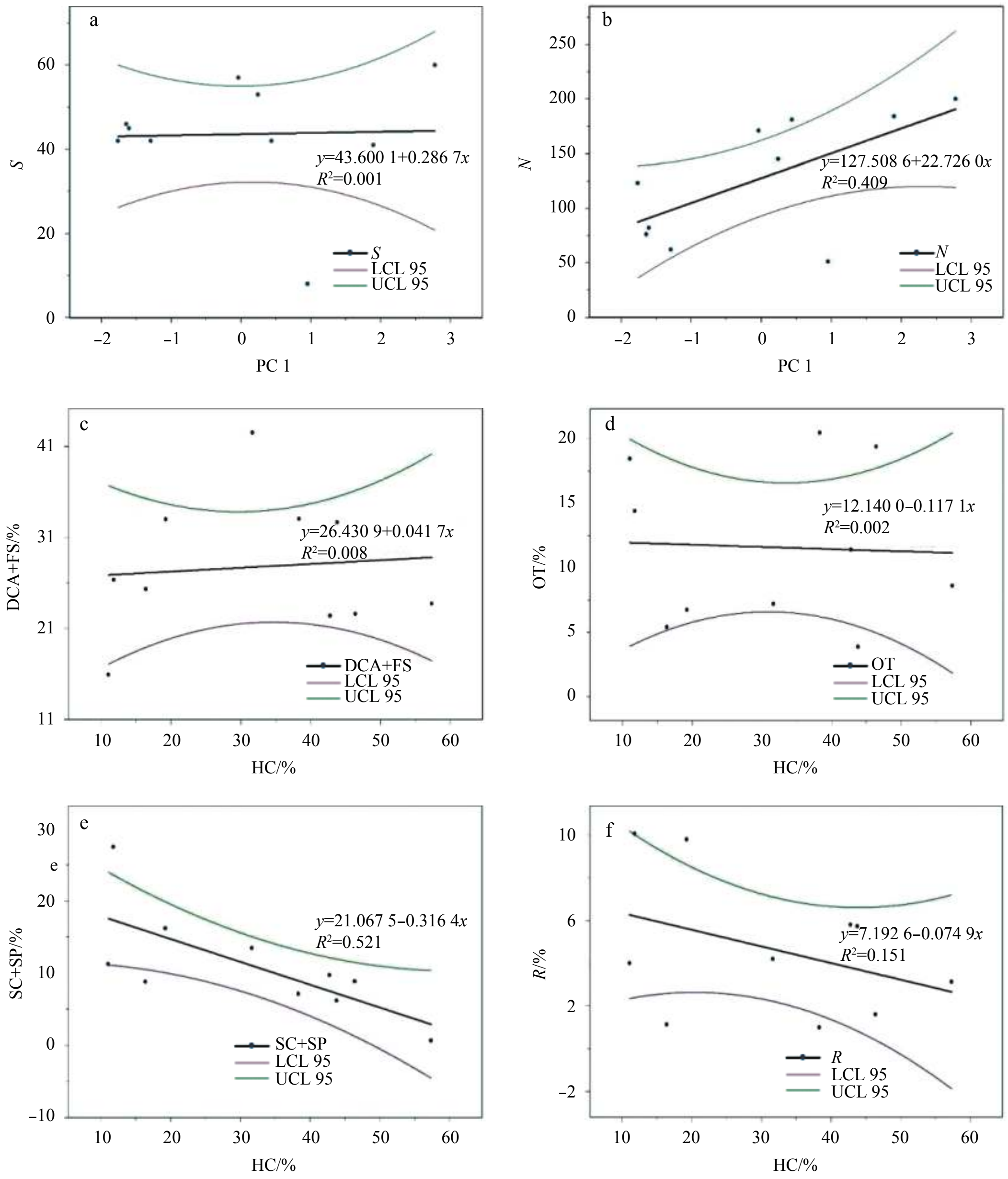

**Fig. 4.** Relationship between gradient benthic and substrate compositions and coral's species richness (*S*) (a) and colony number (*N*) (b); the relationship between hard coral cover (HC) and DCA and FS (c), others (OT) (d), SC and SP (e), and *R* (f). UCL represents upper confident limit and LCL lower confident limit.

tions (Graham et al., 2006). In this study, the benthic communities were changing differently, given that hard corals and DCA were declining while the rest of benthic communities appeared to increase. This decline in hard coral cover was also reported in some places in the mid and southeast of Indonesia's archipelago, including Kendari, Wakatobi, Raja Ampat and Lombok (Pramudji, 2016; Yosephine et al., 2016; Gerung et al., 2016; Bachtiar et al., 2016). This declining conditions might be related to the mass bleaching event occurring in 2016 (Australian Institute of Marine Science (AIMS), 2016; Ampou et al., 2017). Although it was declining, the coral cover was not significantly different to the previous year, indicating the corals might encounter a less stressful condition compared to the other areas as it is located in the north of Sulawesi and heading to the open sea of West Pacific Ocean. Furthermore, there was no bleaching event reported in this area in the recent years. The same insignificant result also occurred in Biak and Ternate which are located in the northeast of Indonesia's archipelago (Giyanto et al., 2016; Cappenberg et al., 2016). These locations may enable corals to receive continuous flow of West Pacific's mass oceanic water and therefore increase mass transfer that allow oxygen radical and their derivate to move from the cells through diffusion process, minimizing the likelihood of coral bleaching (Nakamura and Van Woesik, 2001; Monismith, 2007; Mass et al., 2010).

Another explanation of such coral decline was related to the significant increase of category of others, especially hydroid (*Aglaophenia cupressina*), which could occupy DCA, and the tufts overtopped the spaces and benthos surrounding, including live corals (Figs 5a, b). Seasonally growing hydroids were found to be abundance in reef slope in which the light and current are optim-

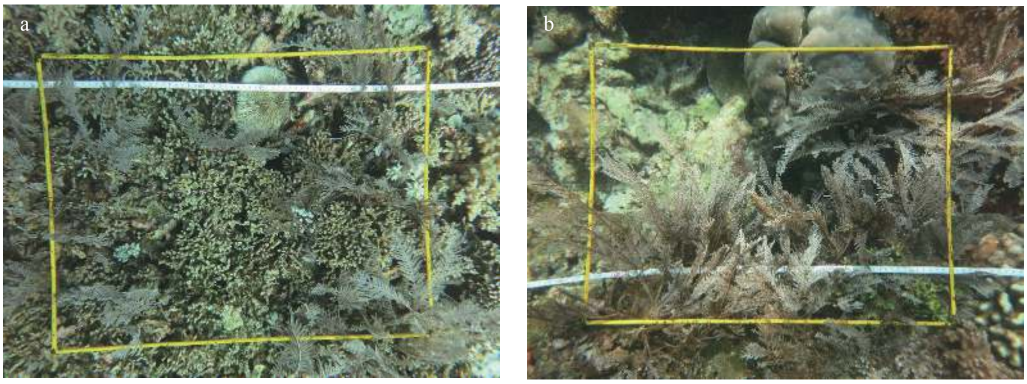

**Fig. 5.** Hydroid occupying the spaces and overtopping the benthos surrounding.

al and hard substrates are highly available (Gravier-Bonnet and Bourmaud, 2006). Furthermore, in North Sulawesi, *A. cupressina* was found to be able to compete with corals–forming very large tufts and having symbiosis with stinging zooxanthellae–and correlated positively with rainfall, which can sustain food availability (Di Camillo et al., 2008). In addition, a prolonged rainy season in the North Sulawesi for almost two years might boost the hydroid growth; May 2014 was the end of rainy season which was then followed by a transitional season prior to the dry season which ended in January 2015, and then rainy season occurred throughout the year of 2015 and 2016 which was beyond the normal condition of two seasons per year (Badan Meterorogi, Klimatologi, dan Geofisika (BMKG), 2016).

A technical issue might also contribute to the differences. Although the GPS coordinates are the same, the accuracy will not be exactly 100 percent. Therefore, the position of transect line was unlikely similar to the previous one, given there was no mark installed on the reefs. However, the 50 photos taken from the same depth range could represent the reef condition accurately compared to other methods (Giyanto et al., 2010).

In general, the benthic and substrates compositions were slightly changing, given that most of the sites were not too far from each other (between 2014 and 2016) (Fig. 4). However, Sta. 4 appeared to change dramatically from Acroporidae and other hard corals to soft corals and others dominated reef. It is likely to be related to the local environment, in this case the site is situated nearby a residential area, namely Gangga II village, which most of the villagers are fisherman. This might bring an adverse effect to the reef, particularly from waste household, boat transportation, and fishing activities. A long lasting or rapid change in a community structure can occur at local scales (small individual reefs or patches) as a result of local stressors (Nyström et al., 2008). The Acroporidae and other hard corals might be dying, providing more hard substrates available than usual for category of others to occupy. However, this result cannot be categorized as a phase shift, considering that others comprise some sorts of benthos, not a single type, and should persist for more than five years of domination (Shulman and Robertson, 1996; Ostrander et al., 2000; Ledlie et al., 2007). In addition, the study also found that the benthic and substrate compositions among the sites were heterogen, given that it was divided mainly into three big clusters (Fig. 4). The conditions might be related to the gradient environment conditions, microhabitat and complexity of interaction among biota (Karlson et al., 2004; De'ath and Fabricius, 2010; Barott and Rohwer, 2012).

The change in the benthic and substrate compositions was responded differently by the coral community structures. In this case, there was no significant relationship between the change and coral species richness. Furthermore, the number of species found between the years was nearly similar, having a difference of three species (Table A1). On the other hand, the change was significantly correlated with the number of colonies, which declined as the composition became less complex. This situation may imply the coral reefs have an ecological resilience (sustainable species diversity) against the change. When less resistant species is lost or reduced to a minor status–the state in which the number of colonies drops into the smallest number–the remaining species may be able to fill the potential gap that appears (Huston, 1985). However, it requires extra time to fill the gap than losing the coral colonies, resulting in high species diversity but poor in colony numbers. This situation would represent a severe reduction in ecological complexity (DeVantier et al., 2006).

During the study, it was found as many as 187 coral species, belonging to 54 genera. This accounts for approximately 34% of species and 60% of genera recognized from this region (Veron, 2000a; Suharsono, 2008; Veron et al., 2015). The species found was lower than the literatures as the observation took place at depth around 4–6 m using UPT method, therefore could not represent all coral species following depth gradient. Mostly, corals are found at less than 20 m in depth–the diversity increases from the surface to the depth of approximately 10 m then declines gradually–and able to survive at depth more than 20 m (Bak and Nieuwland, 1995; Bak et al., 2005; Carpenter et al., 2008; Lesser et al., 2009). Furthermore, it took place at five stations in a local scale in which the general conditions and habitat availability in the location may not be able to sustain all corals to exist, therefore need a wide range area of observation to collect more data. Compared to other studies in this region, the number of species found is fairly similar to Banggai and Kendari by 194 and 184 species respectively (Siringoringo et al., 2012; Siringoringo and Hadi, 2015). This may indicate that in these recent years the coral diversity in this location remains high.

This study confirms that there was a significant relationship between hard coral cover and soft coral and sponge. Although this study indicates others (especially the hydroid) appeared to increase significantly, the high percent cover of the seasonal growing hydroid may not persist for several years as they possess a seasonality in their annual life cycle; meaning their abundance is driven by the alternation of dry and rainy seasons which affect nutrient availability and turbidity (Boero, 1994). In contrast, soft corals and sponges are less vulnerable to seasonal changes, but to natural disturbances, such as cyclone and bleaching event

(Thompson and Dolman, 2010; McMurray et al., 2011), and anthropogenic factors (Fabricius et al., 2005; De Voogd and Cleary, 2008). Although such factors have the same impact to hard corals, sponges and corals apparently have different responses to changing ocean chemistry and environmental conditions, such as depth, light and current (Bell et al., 2013). In addition, soft corals and sponges have ability to compete by producing chemical compounds (allelopathic effect) and boring calcareous substrates, particularly by Clinoid sponges (Maida et al., 2001; Pawlik et al., 2007; Chaves-Fonnegra et al., 2008; Chadwick and Morrow, 2011). Previous studies also found a change in community structures from hard corals to soft corals (Dinesen, 1983; Stobart et al., 2005) and sponges (Aronson et al., 2002; Ward-Paige et al., 2005). These relationships among the categories suggest that coral reefs in the strait and Likupang may encounter a temporary blip due to increasing percent cover of a seasonally-growing hydroid. Furthermore, soft corals and sponge percent covers appeared not to increase significantly, implying that there will be a likelihood for hard corals to recover.

In general, the majority of benthic communities in North Sulawesi appeared to be slightly changing. The changing was correlated with the number of hard coral colonies, but the hard coral diversity remained stable. This can boost coral reef conditions as the other benthic competitors did not change, except the others (especially the seasonally-growing hydroid). Hence, it is very important to understand the dynamic of coral reef benthic communities to predict the trajectory of coral reef conditions. It is suggested to observe the benthic communities in different depth gradients, therefore can be obtained a comprehensive understanding the dynamic of reef benthic communities in recent changing environment.

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### References

Ampou E E, Johan O, Menkes C E, et al. 2017. Coral mortality induced by the 2015–2016 El-Niño in Indonesia: the effect of rapid sea level fall. Biogesoscience, 14(4): 817–826, doi: 10.5194/bg-14-817-2017

Arifin T. 2007. Indeks keberlanjutan ekologi-teknologi ekosistem terumbu karang di selat lembeh, Kota Bitung. Journal Oseanologi dan Limnologi di Indonesia, 33(2): 307–323

Aronson R, Precht W, Toscano M, et al. 2002. The 1998 bleaching event and its aftermath on a coral reef in Belize. Marine Biology, 141(3): 435–447, doi: 10.1007/s00227-002-0842-5

Australian Institute of Marine Science (AIMS). 2016. The facts on Great Barrier Reef coral mortality. Australia: Great Barrier Reef Marine Park Authority, 2

Bachtiar I, Karnan D, Santoso L, et al. 2016. Monitoring kesehatan terumbu karang dan ekosistem terkait di Sekotong, Lombok Barat. Jakarta: COREMAP-CTI, 95

Badan Meterorogi, Klimatologi, dan Geofisika (BMKG). 2016. Prakiraan musim hujan 2015/2016 di Indonesia. http://www.bmkg.go.id/iklim/prakiraan-musim.bmkg?p=prakiraan-musim-hujan-20152016-di-indonesia&tag=prakiraan-musim&lang=ID [2016-01-14/2018-02-16]

Bak R P M, Nieuwland G. 1995. Long-term change in coral communities along depth gradients over leeward reefs in the Netherland Antilles. Bulletin of Marine Science, 56: 609–619

Bak R P M, Nieuwland G, Meesters E H. 2005. Coral reef crisis in deep and shallow reefs: 30 years of constancy and change in reefs of Curacao and Bonaire. Coral Reefs, 24(3): 475–479, doi: 10.1007/s00338-005-0009-1

Barott K L, Rohwer F L. 2012. Unseen players shape benthic competition on coral reefs. Trends in Microbiology, 20(12): 621–628, doi: 10.1016/j.tim.2012.08.004

Bell J J, Davy S K, Jones T, et al. 2013. Could some coral reefs become sponge reefs as our climate changes?. Global Change Biology, 19(9): 2613–2624, doi: 10.1111/gcb.2013.19.issue-9

Boero F. 1994. Fluctuations and variations in coastal marine environments. Marine Ecology, 15(1): 3–25, doi: 10.1111/j.1439-0485.1994.tb00038.x

Brander L M, Van Beukering P, Cesar H S J. 2007. The recreational value of coral reefs: a meta-analysis. Ecological Economics, 63(1): 209–218, doi: 10.1016/j.ecolecon.2006.11.002

Bruno J F, Selig E R. 2007. Regional decline of coral cover in the Indo-Pacific: timing, extent, and subregional comparisons. PLoS One, 2(8): e711, doi: 10.1371/journal.pone.0000711

Burke L, Selig E, Spalding M D, et al. 2012. Reefs at Risk Revisited in the Coral Triangle. Washington: World Resources Institute, 72

Campbell S J, Pratchett M S, Anggoro A W, et al. 2007. Disturbance to coral reefs in Aceh, northern Sumatra: impacts of the Sumatra-Andaman tsunami and pre-tsunami degradation. Atoll Research Bulletin, 544: 55–78

Cappenberg S H, Manuputty A, Souhoka J, et al. 2016. Monitoring kesehatan terumbu karang dan ekosistem terkait di Pulau Ternate dan sekitarnya. Jakarta: COREMAP-CTI, 86

Carpenter K E, Abrar M, Aeby G, et al. 2008. One-third of reef-building corals face elevated extinction risk from climate change and local impacts. Science, 321(5888): 560–563, doi: 10.1126/science.1159196

Ceccarelli D M, Richards Z T, Pratchett M S, et al. 2011. Rapid increase in coral cover on an isolated coral reef, the Ashmore Reef National Nature Reserve, north-western Australia. Marine and Freshwater Research, 62(10): 1214–1220, doi: 10.1071/MF11013

Chadwick N E, Morrow K M. 2011. Competition among sessile organisms on coral reefs. In: Dubinsky Z, Stambler N, eds. Coral Reefs: An Ecosystem in Transition. Netherlands: Springer, 347–371

Chaves-Fonnegra A, Castellanos L, Zea S, et al. 2008. Clionapyrrolidine A—a metabolite from the encrusting and excavating sponge *Cliona tenuis* that kills coral tissue upon contact. Journal of Chemical Ecology, 34(12): 1565–1574, doi: 10.1007/s10886-008-9565-5

Cheal A J, MacNeil M A, Cripps E, et al. 2010. Coral–macroalgal phase shifts or reef resilience: links with diversity and functional roles of herbivorous fishes on the Great Barrier Reef. Coral Reefs, 29(4): 1005–1015, doi: 10.1007/s00338-010-0661-y

De Voogd N J, Cleary D F R. 2008. An analysis of sponge diversity and distribution at three taxonomic levels in the Thousand Islands/Jakarta Bay reef complex, West-Java, Indonesia. Marine Ecology, 29(2): 205–215, doi: 10.1111/mae.2008.29.issue-2

De'ath G, Fabricius K. 2010. Water quality as a regional driver of coral biodiversity and macroalgae on the Great Barrier Reef. Ecological Applications, 20(3): 840–850, doi: 10.1890/08-2023.1

De'ath G, Fabricius K E, Sweatman H, et al. 2012. The 27-year decline of coral cover on the Great Barrier Reef and its causes. Proceedings of the National Academy of Sciences of the United States of America, 109(44): 17995–17999, doi: 10.1073/pnas.1208909109

DeVantier L M, De'ath G, Turak E, et al. 2006. Species richness and community structure of reef-building corals on the nearshore Great Barrier Reef. Coral Reefs, 25(3): 329–340, doi: 10.1007/s00338-006-0115-8

Di Camillo C G, Bavestrello G, Valisano L, et al. 2008. Spatial and temporal distribution in a tropical hydroid assemblage. Journal of the Marine Biological Association of the United Kingdom, 88(8): 1589–1599, doi: 10.1017/S0025315408002981

Dinesen Z D. 1983. Patterns in the distribution of soft corals across the central Great Barrier Reef. Coral Reefs, 1(4): 229–236, doi: 10.1007/BF00304420

Fabricius K, De'ath G, McCook L, et al. 2005. Changes in algal, coral and fish assemblages along water quality gradients on the inshore Great Barrier Reef. Marine Pollution Bulletin, 51(1–4): 384–398

Gerung G S, Roeroe K A, Rondonuwu A B, et al. 2016. Study monitoring kesehatan terumbu karang dan ekosistem terkait lainnya di perairan Pulau Salawati dan Pulau Bantata, Kabupaten Raja Ampat, Papua Barat. Jakarta: COREMAP-CTI, 126

Gilmour J P, Smith L D, Heyward A J, et al. 2013. Recovery of an isolated coral reef system following severe disturbance. Science, 340(6128): 69–71, doi: 10.1126/science.1232310

Giyanto. 2012a. Kajian tentang panjang transek dan jarak antar pemotretan pada penggunaan metode transek foto bawah air. Oseanologi dan Limnologi di Indonesia, 38(1): 1–18

Giyanto. 2012b. Penilaian kondisi terumbu karang dengan metode transek foto bawah air. Oseanologi dan Limnologi di Indonesia, 38(3): 377–389

Giyanto, Rizki S U, Agus B, et al. 2016. Monitoring kesehatan terumbu karang dan ekosistem terkait di Kabupaten Biak Numfor. Jakarta: COREMAP-CTI, 99

Giyanto B H I, Soedharma D, Suharsono. 2010. Effisiensi dan akurasi pada proses analisis foto bawah air untuk menilai kondisi terumbu karang. Oseanologi dan Limnologi di Indonesia, 36(1): 111–130

Goffredo S, Piccinetti C, Zaccanti F. 2007. Tsunami survey expedition: preliminary investigation of Maldivian coral reefs two weeks after the event. Environmental Monitoring and Assessment, 131(1–3): 95–105

Graham N A, Wilson S K, Jennings S, et al. 2006. Dynamic fragility of oceanic coral reef ecosystems. Proceedings of the National Academy of Sciences, 103(22): 8425–8429, doi: 10.1073/pnas.0600693103

Gravier-Bonnet N, Bourmaud C A. 2006. Hydroids (Cnidaria, Hydrozoa) of coral reefs: preliminary results on community structure, species distribution and reproductive biology in Juan de Nova Island (Southwest Indian Ocean). Western Indian Ocean Journal of Marine Science, 5(2): 123–132

Hermanto B. 2013. Keragaman karang jamur (Fungiidae) di Perairan Pulau Siladen, Minahasa Utara. Jurnal Ilmiah Platax, 1(4): 158–166

Hughes T P, Rodrigues M J, Bellwood D R, et al. 2007. Phase shifts, herbivory, and the resilience of coral reefs to climate change. Current Biology, 17(4): 360–365, doi: 10.1016/j.cub.2006.12.049

Huston M A. 1985. Patterns of species diversity on coral reefs. Annual Review of Ecology and Systematics, 16: 149–177, doi: 10.1146/annurev.es.16.110185.001053

Karlson R H, Cornell H V, Hughes T P. 2004. Coral communities are regionally enriched along an oceanic biodiversity gradient. Nature, 429(6994): 867–870, doi: 10.1038/nature02685

Knowlton N, Jackson J B C. 2008. Shifting baselines, local impacts, and global change on coral reefs. PLoS Biology, 6(2): e54, doi: 10.1371/journal.pbio.0060054

Kohler K E, Gill S M. 2006. Coral Point Count with Excel extensions (CPCe): a visual basic program for the determination of coral and substrate coverage using random point count methodology. Computers & Geosciences, 32(9): 1259–1269

Kulkarni S, Patankar V, D'souza E, et al. 2008. Status of earthquake and tsunmi affected coral reefs in Andaman Nicobar Islands, India. Coral Oceans Research and Development in the Indian Ocean: Status Report 2008. Mombasa: Coastal Oceans research and Development in the Indian Ocean Cordio East Africa, 173–183

Ledlie M H, Graham N A J, Bythell J C, et al. 2007. Phase shifts and the role of herbivory in the resilience of coral reefs. Coral Reefs, 26(3): 641–653, doi: 10.1007/s00338-007-0230-1

Lesser M P, Slattery M, Leichter J J. 2009. Ecology of mesophotic coral reefs. Journal of Experimental Marine Biology and Ecology, 375(1–2): 1–8

Maida M, Sammarco P W, Coll J C. 2001. Effects of soft corals on scleractinian coral recruitment. II: Allelopathy, spat survivorship and reef community structure. Marine Ecology, 22(4): 397–414, doi: 10.1046/j.1439-0485.2001.01709.x

Manembu I, Adrianto L, Bengen D G, et al. 2012. Distribusi karang dan ikan karang di kawasan reef ball Teluk Buyat Kabupaten Minahasa Tenggara. Jurnal Perikanan dan Kelautan Tropis, 8(1): 28–32

Mass T, Genin A, Shavit U, et al. 2010. Flow enhances photosynthesis in marine benthic autotrophs by increasing the efflux of oxygen from the organism to the water. Proceedings of the National Academy of Sciences of the United States of America, 107(6): 2527–2531, doi: 10.1073/pnas.0912348107

McCook L J, Ayling T, Cappo M, et al. 2010. Adaptive management of the Great Barrier Reef: a globally significant demonstration of the benefits of networks of marine reserves. Proceedings of the National Academy of Sciences of the United States of America, 107(43): 18278–18285, doi: 10.1073/pnas.0909335107

McMurray S E, Blum J E, Leichter J J, et al. 2011. Bleaching of the giant barrel sponge Xestospongia muta in the Florida Keys. Limnology and Oceanography, 56(6): 2243–2250, doi: 10.4319/lo.2011.56.6.2243

Moberg F, Folke C. 1999. Ecological goods and services of coral reef ecosystems. Ecological Economics, 29(2): 215–233, doi: 10.1016/S0921-8009(99)00009-9

Monismith S G. 2007. Hydrodynamics of coral reefs. Annual Review of Fluid Mechanics, 39: 37–55, doi: 10.1146/annurev.fluid.38.050304.092125

Nakamura T, Van Woesik R. 2001. Water-flow rates and passive diffusion partially explain differential survival of corals during the 1998 bleaching event. Marine Ecology Progress Series, 212: 301–304, doi: 10.3354/meps212301

Nyström M, Graham N A J, Lokrantz J, et al. 2008. Capturing the cornerstones of coral reef resilience: linking theory to practice. Coral Reefs, 27(4): 795–809, doi: 10.1007/s00338-008-0426-z

Ostrander G K, Armstrong K M, Knobbe E T, et al. 2000. Rapid transition in the structure of a coral reef community: the effects of coral bleaching and physical disturbance. Proceedings of the National Academy of Sciences, 97(10): 5297–5302, doi: 10.1073/pnas.090104897

Pawlik J R, Steindler L, Henkel T P, et al. 2007. Chemical warfare on coral reefs: Sponge metabolites differentially affect coral symbiosis in situ. Limnology and Oceanography, 52(2): 907–911, doi: 10.4319/lo.2007.52.2.0907

Pramudji. 2016. Laporan monitoring kesehatan terumbu karang dan ekosistem terkait di Perairan Kendari. Jakarta: COREMAP-CTI, 77

Putra E H, Handoyo E W. 2013. Kajian teknis penggunaan citra satelit EO-1 *Hyperion* untuk pemetaan habitat terumbu karang di pesisir utara taman nasional bunaken. Info BPK Manado, 3(1): 65–78

Sheppard C R C, Harris A, Sheppard A L S. 2008. Archipelago-wide coral recovery patterns since 1998 in the Chagos Archipelago, central Indian Ocean. Marine Ecology Progress Series, 362: 109–117, doi: 10.3354/meps07436

Shulman M J, Robertson D R. 1996. Changes in the coral reefs of San Blas, Caribbean Panama: 1983 to 1990. Coral reefs, 15(4): 231–236, doi: 10.1007/BF01787457

Siringoringo R M, Hadi T A. 2015. Diversity of stony corals in Banggai Water. Marine Research in Indonesia, 38(1): 9–19, doi: 10.14203/mri.v38i1.52

Siringoringo R M, Palupi R D, Hadi T A. 2012. Biodiversitas Karang batu (scleractinia) di Perairan Kendari. Ilmu Kelautan: Indonesian Journal of Marine Sciences, 17(1): 22–30, doi: 10.14710/ik.ijms.17.1.22-30

Smith L D, Gilmour J P, Heyward A J. 2008. Resilience of coral communities on an isolated system of reefs following catastrophic mass-bleaching. Coral Reefs, 27(1): 197–205, doi: 10.1007/s00338-007-0311-1

Souhoka J. 2004. Kondisi Terumbu Karang di Perairan Selat Lembeh, Sulawesi Utara. Oseanologi dan Limnologi di Indonesia, 36: 33–50

Stobart B, Teleki K, Buckley R, et al. 2005. Coral recovery at Aldabra Atoll, Seychelles: five years after the 1998 bleaching event. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 363(1826): 251–255, doi: 10.1098/rsta.2004.1490

Suharsono. 2008. Jenis-jenis karang di Indonesia. Program COREMAP II-LIPI. Jakarta: LIPI Press, 372

Thompson A A, Dolman A M. 2010. Coral bleaching: one disturbance too many for near-shore reefs of the Great Barrier Reef. Coral Reefs, 29(3): 637–648, doi: 10.1007/s00338-009-0562-0

Tomboelu N, Bengen D, Nikijuluw V, et al. 2000. Analisis kebijakan pengelolaan sumber daya terumbu karang di kawasan bunaken dan sekitarnya. Jurnal Pesisir dan Lautan, 3(1): 51–67

Veron J E N. 2000a. Corals of the World. Vol 1. Townsville: AIMS, 463

Veron J E N. 2000b. Corals of the World. Vol 2. Townsville: AIMS, 429

Veron J E N. 2000c. Corals of the World. Vol 3. Townsville: AIMS, 490

Veron J, Stafford-Smith M, DeVantier L, et al. 2015. Overview of distribution patterns of zooxanthellate Scleractinia. Frontiers in Marine Science, 1: 81

Ward-Paige C A, Risk M J, Sherwood O A, et al. 2005. Clionid sponge surveys on the Florida Reef Tract suggest land-based nutrient inputs. Marine Pollution Bulletin, 51(5–7): 570–579

Yosephine M I, Hadi T A, Utama R S, et al. 2016. Monitoring kesehatan terumbu karang dan ekosistem terkait di Kabupaten Wakatobi. Jakarta: COREMAP-CTI, 92

# Appendix:

**Table A1.** Total number of colonies of hard coral species at five stations

| No. | Species | Number | |
|---|---|---|---|
| | | 2014 | 2016 |
| 1 | *Acanthastrea echinata* | 0 | 1 |
| 2 | *Acropora aculeus* | 1 | 0 |
| 3 | *Acropora acuminate* | 7 | 0 |
| 4 | *Acropora aspera* | 1 | 0 |
| 5 | *Acropora cerealis* | 0 | 1 |
| 6 | *Acropora cytherea* | 3 | 1 |
| 7 | *Acropora florida* | 4 | 1 |
| 8 | *Acropora formosa* | 12 | 29 |
| 9 | *Acropora granulosa* | 0 | 1 |
| 10 | *Acropora humilis* | 3 | 1 |
| 11 | *Acropora hyacinthus* | 1 | 0 |
| 12 | *Acropora latistella* | 1 | 1 |
| 13 | *Acropora loripes* | 0 | 1 |
| 14 | *Acropora microphthalma* | 1 | 1 |
| 15 | *Acropora millepora* | 2 | 0 |
| 16 | *Acropora nasuta* | 2 | 1 |
| 17 | *Acropora palifera* | 14 | 0 |
| 18 | *Acropora pulchra* | 0 | 2 |
| 19 | *Acropora secale* | 0 | 1 |
| 20 | *Acropora selago* | 1 | 0 |
| 21 | *Acropora* sp. | 4 | 4 |
| 22 | *Acropora stoddarti* | 0 | 1 |
| 23 | *Acropora striata* | 0 | 1 |
| 24 | *Acropora tenuis* | 2 | 0 |
| 25 | *Acropora valencinennesi* | 2 | 0 |
| 26 | *Alveopora spongiosa* | 0 | 2 |
| 27 | *Alveopora tizardi* | 0 | 1 |
| 28 | *Astreopora gracilis* | 2 | 0 |
| 29 | *Astreopora myriophthalma* | 1 | 1 |
| 30 | *Astreopora* sp. | 1 | 0 |
| 31 | *Barabattoia amicorum* | 2 | 0 |
| 32 | *Caulastrea curvata* | 1 | 0 |
| 33 | *Coeloseris mayeri* | 2 | 1 |
| 34 | *Coscinaraea columna* | 3 | 0 |
| 35 | *Ctenactis echinata* | 0 | 2 |
| 36 | *Cycloseris patelliformis* | 0 | 1 |
| 37 | *Cyphastrea chalcidicum* | 0 | 1 |
| 38 | *Cyphastrea microphthalma* | 0 | 1 |
| 39 | *Cyphastrea serailia* | 1 | 2 |
| 40 | *Cyphastrea* sp. | 0 | 1 |
| 41 | *Diploastrea heliopora* | 2 | 2 |
| 42 | *Echinophyllia aspera* | 3 | 0 |
| 43 | *Echinophyllia* sp. | 0 | 1 |
| 44 | *Echinopora horrida* | 0 | 2 |
| 45 | *Echinopora lamellosa* | 8 | 5 |
| 46 | *Echinopora pacificus* | 1 | 0 |
| 47 | *Euphyllia ancora* | 1 | 2 |
| 48 | *Euphyllia divisa* | 0 | 2 |
| 49 | *Euphyllia glabrescens* | 10 | 15 |
| 50 | *Euphyllia yaeyamaensis* | 1 | 0 |
| 51 | *Favia danae* | 0 | 1 |
| 52 | *Favia favus* | 2 | 0 |
| 53 | *Favia lizardensis* | 2 | 1 |
| 54 | *Favia matthaii* | 0 | 3 |
| 55 | *Favia maxima* | 0 | 2 |
| 56 | *Favia pallida* | 2 | 2 |
| 57 | *Favia rotundata* | 0 | 2 |
| 58 | *Favia* sp. | 14 | 5 |
| 59 | *Favia speciosa* | 1 | 4 |
| 60 | *Favia stelligera* | 1 | 0 |
| 61 | *Favia veroni* | 0 | 1 |
| 62 | *Favites abdita* | 10 | 6 |
| 63 | *Favites acuticollis* | 0 | 1 |
| 64 | *Favites bestae* | 0 | 1 |
| 65 | *Favites chinensis* | 0 | 1 |
| 66 | *Favites complanata* | 5 | 13 |
| 67 | *Favites flexuosa* | 0 | 3 |
| 68 | *Favites halicora* | 2 | 3 |
| 69 | *Favites micropentagona* | 0 | 1 |
| 70 | *Favites paraflexuosa* | 2 | 1 |
| 71 | *Favites russelli* | 0 | 1 |
| 72 | *Favites* sp. | 10 | 4 |
| 73 | *Fungia concinna* | 10 | 18 |
| 74 | *Fungia fungites* | 0 | 1 |
| 75 | *Fungia granulosa* | 0 | 1 |
| 76 | *Fungia horrida* | 0 | 1 |
| 77 | *Fungia klunzingeri* | 6 | 1 |
| 78 | *Fungia paumotensis* | 2 | 5 |
| 79 | *Fungia repanda* | 4 | 0 |
| 80 | *Fungia scabra* | 12 | 6 |
| 81 | *Fungia* sp. | 7 | 1 |
| 82 | *Galaxea astreata* | 8 | 24 |
| 83 | *Galaxea fascicularis* | 36 | 33 |
| 84 | *Gardineroseris planulata* | 4 | 2 |
| 85 | *Goniastrea aspera* | 1 | 0 |
| 86 | *Goniastrea edwardsi* | 7 | 0 |
| 87 | *Goniastrea favulus* | 0 | 1 |
| 88 | *Goniastrea minuta* | 0 | 3 |
| 89 | *Goniastrea pectinata* | 1 | 4 |
| 90 | *Goniastrea retiformis* | 5 | 3 |
| 91 | *Goniastrea* sp. | 7 | 0 |
| 92 | *Goniopora columna* | 3 | 12 |
| 93 | *Goniopora fruticosa* | 0 | 1 |
| 94 | *Goniopora lobata* | 9 | 2 |
| 95 | *Goniopora minor* | 0 | 1 |
| 96 | *Goniopora* sp. | 4 | 1 |
| 97 | *Halomitra pileus* | 1 | 0 |
| 98 | *Heliopora coerulea* | 4 | 0 |
| 99 | *Herpolitha limax* | 3 | 1 |
| 100 | *Hydnophora exesa* | 0 | 4 |
| 101 | *Hydnophora microconos* | 1 | 0 |
| 102 | *Hydnophora pilosa* | 1 | 0 |
| 103 | *Hydnophora rigida* | 1 | 1 |

to be continued

Continued from Table A1

| No. | Species | Number | |
|---|---|---|---|
| | | 2014 | 2016 |
| 104 | *Leptastrea* sp. | 1 | 0 |
| 105 | *Leptoseris* sp. | 0 | 1 |
| 106 | *Lobophyllia hemprichii* | 6 | 1 |
| 107 | *Merulina scabricula* | 5 | 4 |
| 108 | *Merulina* sp. | 1 | 0 |
| 109 | *Millepora platyphylla* | 2 | 2 |
| 110 | *Millepora tenella* | 1 | 1 |
| 111 | *Montastrea curta* | 0 | 1 |
| 112 | *Montastrea maginistellata* | 2 | 0 |
| 113 | *Montastrea* sp. | 1 | 0 |
| 114 | *Montastrea valenciennesi* | 1 | 0 |
| 115 | *Montipora caliculata* | 5 | 2 |
| 116 | *Montipora crassituberculata* | 1 | 0 |
| 117 | *Montipora digitata* | 2 | 0 |
| 118 | *Montipora efflorescens* | 5 | 1 |
| 119 | *Montipora foliosa* | 3 | 4 |
| 120 | *Montipora foveolata* | 1 | 0 |
| 121 | *Montipora grisea* | 1 | 0 |
| 122 | *Montipora informis* | 7 | 4 |
| 123 | *Montipora monasteriata* | 4 | 0 |
| 124 | *Montipora peltiformis* | 2 | 0 |
| 125 | *Montipora* sp. | 26 | 13 |
| 126 | *Montipora tuberculosa* | 1 | 0 |
| 127 | *Montipora venosa* | 1 | 1 |
| 128 | *Mycedium elephantotus* | 7 | 4 |
| 129 | *Mycedium mancaoi* | 0 | 2 |
| 130 | *Mycedium robokaki* | 1 | 9 |
| 131 | *Oulophyllia bennettae* | 1 | 1 |
| 132 | *Oulophyllia crispa* | 0 | 2 |
| 133 | *Oxypora crassispinosa* | 3 | 0 |
| 134 | *Oxypora glabra* | 0 | 2 |
| 135 | *Oxypora lacera* | 5 | 2 |
| 136 | *Oxypora* sp. | 0 | 1 |
| 137 | *Pachyseris speciosa* | 2 | 0 |
| 138 | *Pavona explanulata* | 0 | 4 |
| 139 | *Pavona minuta* | 0 | 3 |
| 140 | *Pavona* sp. | 1 | 0 |
| 141 | *Pavona varians* | 3 | 0 |
| 142 | *Pavona venosa* | 3 | 2 |
| 143 | *Pectinia alcicornis* | 1 | 0 |
| 144 | *Pectinia lactuca* | 6 | 3 |
| 145 | *Physogyra lichtensteini* | 1 | 0 |
| 146 | *Platygyra daedalea* | 1 | 3 |
| 147 | *Platygyra lamellina* | 1 | 3 |
| 148 | *Platygyra pini* | 5 | 2 |
| 149 | *Platygyra ryukyuensis* | 24 | 0 |
| 150 | *Platygyra sinensis* | 6 | 1 |
| 151 | *Platygyra* sp. | 1 | 1 |
| 152 | *Plerogyra sinuosa* | 3 | 0 |
| 153 | *Plerogyra* sp. | 13 | 5 |
| 154 | *Plesiastrea versipora* | 0 | 3 |
| 155 | *Pocillopora damicornis* | 2 | 1 |
| 156 | *Pocillopora elegans* | 0 | 1 |
| 157 | *Pocillopora* sp. | 1 | 0 |
| 158 | *Pocillopora verrucosa* | 26 | 10 |

to be continued

Continued from Table A1

| No. | Species | Number | |
|---|---|---|---|
| | | 2014 | 2016 |
| 159 | *Polyphyllia talpina* | 0 | 2 |
| 160 | *Porites annae* | 1 | 0 |
| 161 | *Porites attenuata* | 11 | 1 |
| 162 | *Porites cylindrica* | 62 | 24 |
| 163 | *Porites horizontalata* | 0 | 1 |
| 164 | *Porites lichen* | 2 | 0 |
| 165 | *Porites lobata* | 5 | 1 |
| 166 | *Porites lutea* | 51 | 26 |
| 167 | *Porites monticulosa* | 0 | 1 |
| 168 | *Porites negrosensis* | 2 | 6 |
| 169 | *Porites nigrescens* | 29 | 26 |
| 170 | *Porites rus* | 28 | 21 |
| 171 | *Porites solida* | 0 | 7 |
| 172 | *Porites* sp. | 13 | 5 |
| 173 | *Porites tuberculosa* | 0 | 1 |
| 174 | *Psammocora nierstraszi* | 0 | 2 |
| 175 | *Scapophyllia cylindrica* | 1 | 0 |
| 176 | *Seriatopora caliendrum* | 0 | 4 |
| 177 | *Seriatopora hystrix* | 22 | 10 |
| 178 | *Stylophora pistillata* | 16 | 16 |
| 179 | *Symphyllia agaricia* | 4 | 1 |
| 180 | *Symphyllia radians* | 2 | 1 |
| 181 | *Symphyllia* sp. | 1 | 0 |
| 182 | *Tubastrea micrantha* | 0 | 1 |
| 183 | *Tubipora musica* | 0 | 2 |
| 184 | *Turbinaria mesenterina* | 3 | 1 |
| 185 | *Turbinaria peltata* | 3 | 0 |
| 186 | *Turbinaria reniformis* | 1 | 0 |
| 187 | *Turbinaria stellulata* | 0 | 1 |
| | Total number of colonies | 741 | 534 |