MORPHOLOGICAL AND SPECIES DIVERSITY OF SPONGES IN CORAL REEF ECOSYSTEM IN THE LEMBEH STRAIT, BITUNG

Tri Aryono Hadi[1*], Hadiyanto[1], Agus Budiyanto[1], Niu Wentao[2] and Suharsono[1]

[1]Research Center for Oceanography, Indonesian Institute of Sciences
Pasir Putih 1, Ancol Timur 14430
[2]Third Institution of Oceanography, State Oceanic Administration
Daxue Road 178, Xiamen 361005
[*]E-mail: ari_080885@yahoo.com

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ABSTRACT

Sponges are one of the most diverse benthos in coral reef ecosystem. They have many morphological characters that are specific to species, and their existence is influenced by environmental conditions. The aims of this study are to observe the relationship between morphological and species diversity of sponges in coral reef ecosystem in the Lembeh Strait and investigate the most influential environmental factor on sponge diversity. The study was carried out between April and May 2013 at nine study sites. The methods used were belt transect and line intersect transect (LIT) installed parallel to the coastline at approximately 5 meter depth. Our study supports a positive correlation between the morphological diversity and species diversity of sponges. Many of the morphological growth types were specific to sites that have particular characteristics. The percentage of live coral cover is not a critical factor for sponge diversity in the strait. Instead, dead coral with algae as a benthic category, has a significant positive correlation with the morphological and species diversity of sponges. Conversely, rubble as a substrate type has a strong tendency to affect sponge diversity negatively. To conclude, it is important to maintain healthy reefs in order to sustain benthic communities that are valuable to ecological functions and societies.

Keywords: sponges, diversity, coral reefs, Lembeh Strait

INTRODUCTION

Coral reefs across the globe are declining due to a number of factors. The biggest threat comes from human activities such as overexploitation, increased sedimentation and nutrient levels from poor land management, and habitat destruction from destructive fishing methods (Hughes, 1994; Pandolfi *et al.*, 2003). Natural phenomena (e.g. tropical cyclones, coral predation, disease, and coral bleaching) are also a major cause of habitat degradation (De'ath, 2012; Madduppa et al., 2015). A major implication of habitat degradation is the loss of reef-building corals and a subsequent reduction in physical complexity, resulting in long lasting detrimental impacts on the diversity of ecosystems and their communities (Graham *et al.*, 2006).This includes the sponge community as one of the most dominant benthic fauna in coral reef ecosystems (Hooper & Soest, 2002).

Sponges are widely distributed in many types of habitat (Diaz and Rutzler, 2001). A common habitat for sponges is coral reef ecosystem as it provides substrates to settle on and protection from extreme

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hydrodynamics. In this habitat, sponges also contribute to ecosystem functioning where sponges playroles in nutrient cycle, bio erosion, primary production facilitation, provision of microhabitat as well as substrate stabilization and consolidation (Bell, 2008). Loss of these functional roles at which sponges excel might have direct negative consequences for coral reef ecosystem (Wulff, 2006).

Several studies have pointed out varying correlations between coral reef conditions and sponge diversity. In the Seribu Islands, the condition of coral reefs is positively correlated with sponge diversity where the inshore zone that is characterized by high turbidity and low coral cover, has fewer sponge species compared to the offshore zone (de Voogd and Cleary, 2008). Conversely in the Wakatobi Marine National Park, sponges and algae became more dominant than any other groups of benthic organism at sites with low coral cover(Powell *et al.*, 2010; Powell *et al.*, 2014). Another study, in Las Perl as Archipelago, Panama,shows no evidence of a correlation between coral cover and sponge abundance and diversity (Berman, 2004). However, these studies excluded morphological adaptation of sponges which is essential for survival in a particular habitat and environment.

Sponges come with morphological variations that vary among different species, genera and even within the same species, as a response to environmental factors (i.e. hydrodynamics, light and turbidity; van Soest *et al.*, 2012). In strong current conditions, many sponge species show a limited number of morphology that are mostly dominated by massive and encrusting forms (Bell *et al.*, 2002[a]).On the other hand, tubular and branching forms are considered to be more adaptive to high turbidity environmentsby having the ability to reduce the amount of material settling from suspension per unit of surface area (Chappell, 1980; Bell *et al.*, 2002[b]). In Indonesia, variation in sponge morphology has not been extensively studied due to lack of taxonomic information andobservational challenges.

The aims of this study are to investigate the relationship between morphological and species diversity of sponges in coral reef ecosystem and observe the most influential environmental factor on sponge diversity in the Lembeh Strait.

The Lembeh Strait in the North Sulawesi Province, is situated at the heart of the Coral Triangle region that has the highest marine biodiversity in the world. The strait separates Lembeh Island from the mainland city of Bitung, and connects the Sulawesi and Moluccas Seas. The region is also along the path of a water mass flow from the Pacific to the Indian Oceans, and is rich in nutrientsfrom upwelling process that could enhance marine life. Some studies have been carried out in the Lembeh Strait particularly on its coral reefs condition (Souhoka, 2005; Arifin, 2008). However, studies that take into account the diversity of benthic organisms are still lacking.

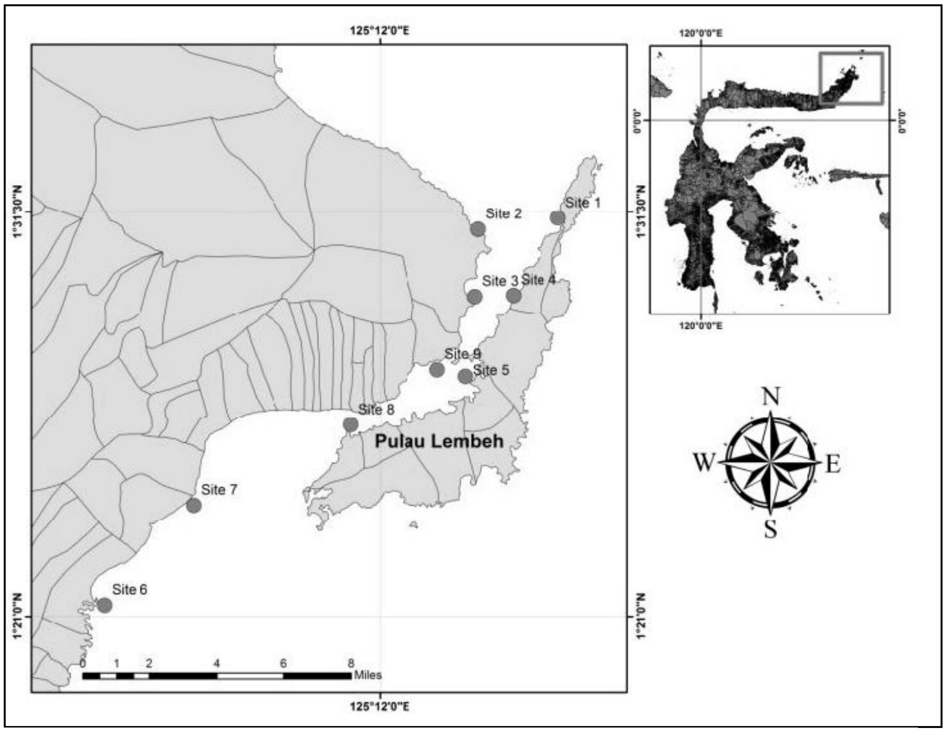

Figure 1. The study sites in the Figure 1. The study sites in the Lembeh Strait, Bitung

MATERIALS AND METHODS

Study Site

The research was carried out at nine sites along the Lembeh Strait (Figure 1). In the northern area, the current speed is relatively strong with high water visibility (more than 10 meter) and a steep slopethat sometimes creates wall-like structures. In the middle area, the visibility ranges from 5 to 7 meter with slopes between 45-60^{o}. This area is populated by residential areas, industries and ports. Whereas in the south, the current is moderate with a slope around 45^{o} and some seagrass meadow stretching along the flat. This area is less populated than the middle area.

Protocol

There were two methods used in this study: belt transect (Eleftheriou & Mclntyre, 2005) for sponges, and line intercept transect (LIT) (English *et al*., 1997) for benthic categories and types of substrates (see Table 1). These transects were installed along the same 70-mline, laid parallel to the coastline, at around 5-10 meter depth. SCUBA diving equipment was used in collecting the data.

Every individual sponge found in the area of the belt transect (2m x 70m) was listed and photographed *in situ* to record the morphology and colors. Smaller (cryptic, boring and thinly encrusting ≤ 5 cm) sponges were excluded from this study as they are highly breakable and time-consuming to collect. Sponges which were not identified in the field were collected for further identification in the laboratory at the Research Center for Oceanography. The samples were then preserved in 70% ethanol.

The data of benthic categories and substrate types were collected using LIT following English et al. (1997). Three replicates of 10m-longtransects were laid parallel to the coastline on the reef slope at approximately 5 meter depth. And each replicate transect was separated by a 20 meter distance. Thus, the LIT has a total length of 70 meter from the three10m-longtransects and the two 20mseparating distances in between. Benthic categories and substrate types beneath the tape, especially for LIT, were recorded with an accuracy up to centimeter. The conditions of the reefs were classified into four groups based on the percentage of live coral cover: poor (<24.9%), moderate (25 – 49.9%), good (50 – 74.9%) and excellent (> 75%).

Data Analysis

The relationship between the morphological diversity and species diversity of sponges was analyzed using linear regression in which Pearson's correlation was used to estimate the strength of the relationship. Pearson's correlation was also used for estimating correlation between substrate profiles (e.g. benthic categories and substrate types) and sponge morphological and species diversity.

A multivariate analysis of sponge morphological diversity, benthic categories and substrate types were evaluated using Canonical Correspondence Analysis (CCA). The data were transformed by using log (x+1) to improve spread of the data.

RESULTS

Morphological and Species Diversity

Our study finds a positive correlation between morphological diversity and species diversity of sponges at the nine study sites (r=0.94, $p<0.05$; Figure 2). Ten species of sponges with six different morphological growth formswere found at Site 7, which has the lowest diversity. Site 8has the highest species diversity as well as morphological diversity, where 17 out of 18 morphologies can be found at this site.

Habitat Quality

The habitat quality, which is viewed from the percentage of coral cover, ranges between 26.23% (St.7) and 80.73% (St.9) (Table 1). Sites 4, 6, 7 and 8 are in moderate condition with less than 49.9% coral cover, where as, Sites 1, 2 and 3are in good condition (> 50% coral cover).The rest falls under excellent condition with the percentage of live corals more than 70%.

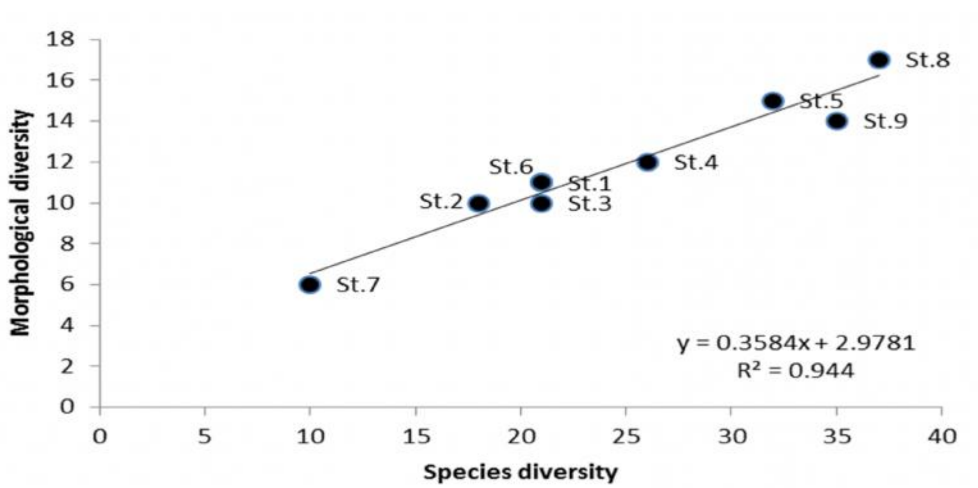

Figure 2. Linear regression of morphological and species diversity of sponges in the Lembeh Strait

Table 1. The percent cover of benthic categories and substrate types at the study sites.

	St. 1	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8	St. 9
Live Coral	50.03	65.83	51.07	42.30	74.27	29.43	26.23	40.00	80.73
Acropora	2.43	4.20	1.07	4.40	24.03	0.47	4.63	0.43	1.03
Non_Acropora	47.60	61.63	50.00	37.90	50.23	28.97	21.60	39.57	79.70
Dead Coral with Algae	3.93	10.70	5.83	9.47	12.50	8.20	2.63	15.90	5.73
Dead Coral	13.73	3.67	1.70	0.00	0.00	0.00	0.00	0.00	0.00
Soft Coral	5.97	5.50	13.83	19.50	0.23	2.73	1.57	0.00	0.00
Sponge	15.13	4.53	2.37	1.47	3.50	1.47	0.47	7.63	3.53
Turf Algae	5.33	9.60	7.80	11.70	6.87	5.07	11.73	9.03	4.70
Other Fauna	4.07	0.00	1.00	0.37	0.00	0.00	0.00	1.47	0.60
Rubble	0.77	0.17	0.00	0.43	1.17	3.23	52.17	9.13	0.00
Sand	1.03	0.00	16.40	14.77	1.47	41.63	5.20	16.83	4.70
Silt	0.00	0.00	0.00	0.00	0.00	8.23	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 2. Coefficient of Pearson's correlation withbenthic category and substrate type.

Benthic categoeries and substrate types	Sponge	
	Morphological diversity	Species diversity
Live coral	0.436779	0.50571
Acropora	0.232018	0.17729
Non-*Acropora*	0.3817	0.48108
Dead Coral with Algae	0.760551	0.64073*
Dead Coral	-0.17254	-0.24832
Soft Coral	-0.25412	-0.22666
Sponge	0.268598	0.17681
Turf Algae	-0.34798	-0.36142
Other fauna	0.121139	0.07603
Rubble	-0.57552	-0.54618
Sand	0.040868	0.00552
Silt	-0.09025	-0.15217

* = $p< 0.05$

Characters of the study sites

The multivariate analysis shows characteristics of the study sites with respect to benthic category, substrate type and sponge morphology (Figure 3). Sites 1, 5and 9 have more prevalent live corals, sponges and dead corals, where sponges at these sites are cushion-massive, columnar-massive, foliose and cup in their morphology. Meanwhile, Sites 3 and 8 are characterized by dead coral with algae, where the sponges found here are spherical, repent and busy branching. Sites 6, 2 and 7, which are characterized by turf algae, have sponges with laminar, columnar, thickly encrusting and tubular massive morphologies.

Correlation between sponges (morphological and species diversity) and the most influential environmental factors

In this study, we find a significant positive correlation between the morphological and species diversity of sponges with dead coral with algae as a benthic category (Table 2). It appears that increased percent cover of dead coral with algae is followed by species and morphological diversity (Figure 4a). On the other hand, a relatively strong negative correlation occurs between rubble with both

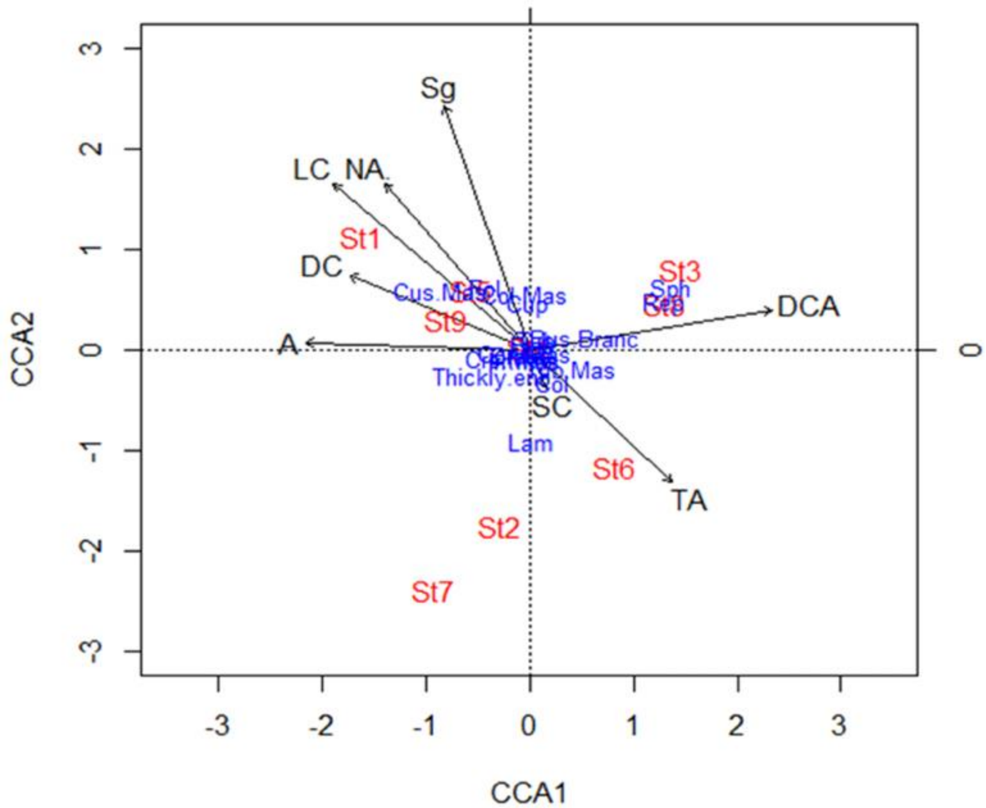

Figure 3. Multivariate analysis of sponge morphological diversity, benthic and substrate categories. Sponge morphology : Tub (tubular); Mas (massive); Irr-mas (irregular massive); Con-mas (conus massive); Tub-mas (tubular massive); Cus-mas (cushion massive); Col-mas (columnar massive); Cre-mas (creeping massive); Thickly-enc (thickly encrusting); Bus-branch (bussy branching); Branch (branching); Sph (spherical); Col (columnar); Flab (flabellate); Rep (repent); Fol (foliose); Lam (laminar). Benthic and substrate categories: LC (live coral); A (Acropora); NA (non-Acropora); TA (turf algae); SC (soft coral); DCA (dead coral with algae); DC (dead coral); Sg (Sponge).

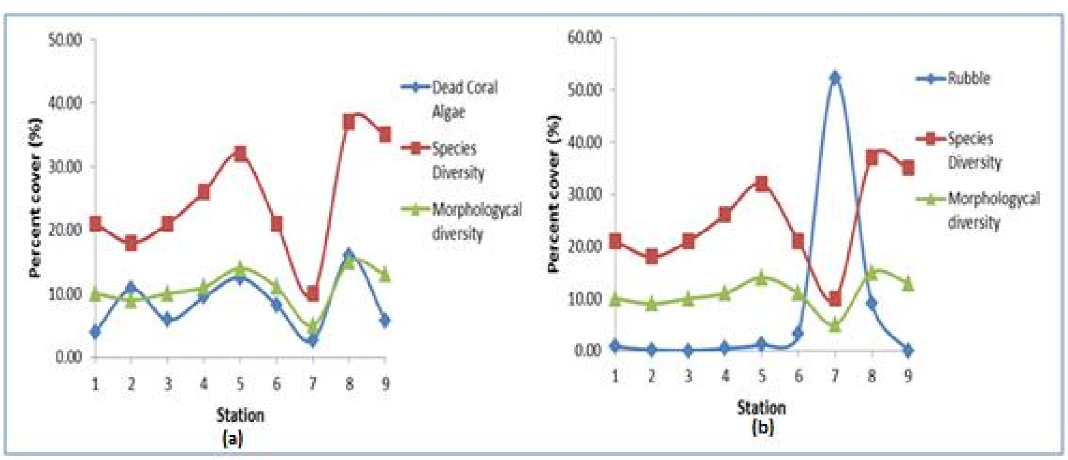

Figure 4. Scatter plots of sponge diversity with dead coral with algae (a) and rubble (b)

morphological and species diversity (Table 2). In this case when the percent cover of rubble is high, the morphological and species diversity drop especially at Site 7 (Figure 4b).

DISCUSSION

We find a positive correlation between morphological and species diversity of sponges in the Lembeh Strait. In relation to this finding, Bell & Barnes (2001)has suggested that sampling of sponge morphological diversity, which is more practical, can be used as a qualitative estimate of sponge species diversity. Environmental conditions may explain this finding. Site 8, located in the south of the Lembeh Strait that has less hydrodynamic energy, is habitable to many delicate species of sponges including highly breakable ones. Conversely, Site 7 that faces the open sea and with the highest percentage of rubble, has the fewest sponges and are mostly dominated by irregular-massive sponges (Appendix 1). In high energy environments, some complex morphologies, such as branching, tubular and flabellate, would decline as the drag force increases (Bell *et al.*, 2002[b]). It is worth remembering that sponge morphology is constrained by genetics. In other words, branching sponges cannot turn into encrusting sponges (Bell *et al.*, 2002[a]). Therefore, sponges with susceptible morphologies could disappear more easily from the ecosystem under changing environments.

Our findings are also in line with the role of space competition on sponge morphology. Sites with prevalent live corals, sponges and dead coral, are dominated by sponges that are likely to attach to the substrates with little space (e.g. cup, foliose and columnar massive). In this situation, space competition with hard corals has shaped sponge communities to settle on patchy little spaces and escape by growing upward (Rutzler, 2004; Lopez-Victoria *et al.*, 2006).

Another space competition also occurred at sites characterized by turf algae. The environment might cause sponges to have less space to attach as they have to compete with algae which grows faster than sponges. In this situation, turf algae may inhibit sponge settlement and impact all stages of development (Zea, 1993; de Caralt & Cebrian, 2013). Due to this competition, sponges in these sites have less basal attachment, such as laminar, columnar and tubular massive. However, thickly encrusting sponges can also be found here. In this case, the sponges might attach on the edge or under hard substrates first (which are less occupied by turf algae) and then grow gradually to cover a larger space. These sponges might also use chemical competitive strategies (allelophaty) to invade their surrounding areas (Wager & Blummer, 2009; Pawlik, 2011).

Sites characterized by dead coral with algae are habited by sponges that can spread (repent and spherical) or grow upward (busy branching). In this situation, environment stress may have caused hard corals to decline but the frame structures still remain. The structures could give sponges protection from strong currents, thus enabling sponges to grow upward such as branching structures. Abundant stable substrates might benefit sponges in order to spread, particularly by having a repent growth form. This is situation can be considered as an alternate state in which available spaces from abundant hard corals enable sponges to deploy morphological strategies towards expansion and resistance to damage (Wulff, 2006; Gonzales-Rivero *et al.*, 2011).

The percentage of live coral cover does not have a significant correlation with either morphological or species diversity. Although increased live coral cover provides a greater number of micro-habitats for many sponges to occupy, the correlation occurs when the live coral cover is high and available space is limited (Powell *et al.*, 2010; Aerts & van Soest, 1997). In this study, the average live coral cover was 51.1 % - indicating that there is an ample space for sponges to settle. This is followed by dead coral with algae (8.32 %), rubble (7.45 %) and dead coral(2.12 %). However, dead coral with algae (corals which have died for months to years but still have the original shape and contour patterns, and then covered by smooth algae) shows significant correlations with the morphological diversity of sponges.

Dead coral with algae as a benthic category provides a stable substrate with their massive sizes and weight. In this study, the percentage of dead coral with algae is positively correlated with the morphological and species diversity of sponges. Hard and stable substrates are a crucial environmental factor for sponges, particularly in high energy environments. In addition to stabilizing the sponges, dead coral with algae also provides a wide and safe surface for larva settle on and grow (Wulff, 2012). Although cryptic algae cam cover the substrate, sponges could grow and even out-compete them. In areas where corals are in poor conditions due to environmental stress (especially high amounts of nutrient and sediment), the number of corals appears to decrease while sponges significantly increase in number following high algae growth (Zea, 1994). In this situation, environmental conditions that cause adverse impacts on corals may not have the same effect on sponges.

Although rubble as a substrate type shows strong negative correlations with both morphological and species diversity. Rubble is considered as an unstable substrate which is light and small, making it easily moved or overturned during storms and daily wave action (Walker *et al.*, 2008). Some studies find that unstable substrates, such as gravel and rubble, are unfavorable places for sponges to settle compared to stable hard bottom substrates (Ginn*et al.*, 2000; Duckworth and Wolff, 2011; Hadi, 2013). Further more, the movement of rubble, particularly by strong currents, can damage sponges and reduce their survival rate (Trautman *et al.*, 2000). Furthermore, sites where rubbles are prevalent tend to be located lower than their adjacent rock substrates, which increases the likelihood of being damaged byfine sediments particularly during strong turbulent events. (Duckworth and Wolff, 2011).

CONCLUSION

Based on our observations, there is a positive correlation between the morphological diversity and species diversity of sponges in the Lembeh Strait. Both diversities are influenced by environmental factors, particularly other benthos and substrates. As a benthic category, dead coral with algae appears to have the highest positive correlations with the morphological and species diversity of sponges. However, rubble as an environmental setting also needs to be considered as it may reduce the diversity of sponges. To conclude, it is important to maintain healthy reefs in order to sustain benthic communities that are valuable to ecological functions and societies.

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Appendix 1. List of sponge species found in The Lembeh Strait.

Order/ Species	Morphology	Site								
		1	2	3	4	5	6	7	8	9
Calcarea										
Leucetta chagosensis	Tub	+	-	-	-	-	-	-	-	-
Agelasida										
Agelas nakamurai	Mas	+	-	-	-	+	-	-	+	+
Agelas braekmani	Col	-	+	-	+	+	-	-	-	-
Astrophorida										
Melophlus sarassinorum	Mas	-	-	+	+	-	-	-	+	+
Rhabdastrella globostellata	Mas	+	+	+	-	-	-	+	-	+
Dictyoceratida										
Carteriospongia foliascens	Lam	-	+	-	-	-	+	+	+	+
Dysidea sp.	Irr-Mas	+	-	-	+	-	-	-	-	-
Dysidea sp2.	Irr-Mas	-	-	-	+	+	-	-	-	-
Hyrtios erectus	Col	-	-	-	+	-	+	-	+	-
Ircinia sp.(encrusting)	Thickly-enc	-	+	-	-	-	-	-	-	-
Hadromerida										
Aaptos suberitoides	Irr-Mas	+	-	-	-	+	-	-	+	+
Spheciospongia sp.	Irr-Mas	-	-	+	-	-	+	+	+	+
Spheciospongia vagabunda	Con-Mas	+	-	+	+	+	+	+	+	+
Placospongia mixta	Thickly-enc	-	+	-	-	+	-	-	+	+
Halichondrida										
Achantella sp.	Bus-Branc	-	-	+	+	+	+	-	+	-
Axinyssa sp.	Irr-Mas	-	-	-	+	+	-	+	-	-
Halichondria (Halichondria) cartilagenia	Thickly-enc	-	+	-	+	-	-	+	-	-
Liosina paradoxa	Tub-Mas	-	-	-	-	-	+	-	+	-
Myrmekioderma sp.	Mas	-	-	-	+	-	-	-	+	-
Ptilocaulis spiculifera	Bus-Branc	-	-	-	+	-	-	-	-	-
Stylissa carteri	Flab	+	+	+	+	+	+	-	+	+
Homosclerophorida										
Plakortis lita	Irr-Mas	-	-	-	+	+	-	-	+	-
Haplosclerida										
Achanthostrongylphora ingens	Tub-Mas	-	+	+	+	+	+	-	+	+
Amphimedon sp. (white)	Branc	-	-	-	-	-	-	-	-	+
Amphimedon paraviridis	Col-Mas	+	-	+	+	+	-	-	+	+
Callyspongia sp. (blue encrusting)	Thickly-enc	+	+	-	-	-	-	-	-	-
Callyspongia sp. (branching)	Branc	-	-	+	+	+	-	-	+	+
Callyspongia sp. (conulosetubuler)	Tub	-	+	-	-	-	-	-	-	-
Callyspongia sp. (red)	Branc	-	+	-	-	-	-	-	-	-
Callyspongia sp. (soft tubuler)	Tub	+	+	+	+	-	+	-	+	+
Callyspongia (Callyspongia) sp. (white branching)	Branc	-	+	-	-	+	-	-	-	+
Callyspongia (Callyspongia) sp. (cushion-shaped)	Cus-Mas	+	-	-	-	-	-	-	-	-
Callyspongia (Callyspongia) sp.	Rep	-	-	-	-	-	-	-	+	-
Callyspongia (Cladochalina) aerizusa	Tub	+	-	+	+	+	+	-	+	+

Callyspongia (Euplacela) sp.	Fol	+	-	-	-	+	-	-	+	+
Callyspongia joubini	Branc	+	-	-	-	+	+	-	+	+
Dasychalina fragilis	Irr-Mas	-	-	-	-	+	-	-	-	+
Gelliodes sp.(encrusting)	Thickly-enc	+	-	-	+	+	-	-	+	+
Gelliodes sp. (white)	Thickly-enc	-	-	-	-	+	-	+	+	-
Gelliodes fibulata	Branc	-	+	-	+	-	-	-	+	+
Haliclona sp.(branching)	Branc	+	-	-	-	-	-	-	-	-
Haliclona (Gellius) amboinensis	Cus-Mas	+	-	-	+	+	-	-	-	-
Haliclona (Reniera) sp.	Cus-Mas	-	-	-	-	-	-	-	-	+
Haliclona (Reniera) fascigera	Tub	-	-	-	-	-	+	-	+	-
Neopetrosia carbonaria	Branc	-	-	-	-	+	-	-	-	+
Neopetrosia exigua	Irr-Mas	-	+	-	-	-	+	-	-	-
Niphates sp	Irr-Mas	-	-	-	-	-	+	-	-	-
Niphates sp2. (blue)	Irr-Mas	+	-	-	+	-	-	-	-	-
Niphates olemda	Tub	-	-	-	-	+	+	-	+	+
Oceanapia sp.	Mas	-	+	+	-	-	-	-	-	-
petrosia (petrosia) sp.	Mas	-	-	-	-	-	-	-	-	+
Petrosia (Petrosia) sp. (creeping-massive)	Cre-Mas	-	-	-	-	-	-	-	+	-
Petrosia (Petrosia) plana	Tub	-	-	-	-	-	-	-	-	+
Petrosia (Petrosia) hoeksemai	Cre-Mas	+	+	-	-	+	+	-	-	+
Petrosia (Petrosia) nigricans	Irr-Mas	+	+	+	+	+	+	-	+	+
Petrosia (Strongylophora) strongylata	Tub-Mas	-	-	-	-	-	+	-	-	-
Xestospongia sp.	Mas	-	-	-	-	+	+	-	-	-
Xestospongia testudinaria	Cup	-	-	-	-	+	-	-	+	+
Xestospongia vansoesti	Irr-Mas	-	-	+	+	-	-	+	-	-
'Lithistid' Demospongiae										
Theonella swinhoei	Tub	-	-	+	-	+	-	-	+	+
Theonella cylindrica	Tub	-	-	-	-	+	-	-	+	+
Poecilosclerida										
Clathria sp.	Irr-Mas	-	-	+	-	-	-	-	-	-
Clathria (Thalysias) cervicornis	Branc	-	-	-	-	+	+	-	-	-
Clathria (Thalysias) reinwardti	Branc	+	-	+	+	+	+	+	+	+
Clathria (Thalysias) vulpina	Irr-Mas	-	-	+	-	-	-	+	+	+
Biemna trirhaphis	Irr-Mas	-	-	+	-	+	-	-	-	+
Lissodendoryx fibrosa	Mas	-	-	+	-	-	-	-	-	-
Tedania (Tedania) sp.	Mas	-	-	-	-	-	-	-	+	-
Ulosa stuposa	Branc	-	-	-	-	-	-	-	+	-
Spirophorida										
Cinacyrella australiensis	Sph	-	-	+	-	-	-	-	+	-
Paratetilla sp.	Sph	-	-	-	-	-	-	-	+	-
Verongida										
Suberea sp.	Irr-Mas	-	-	-	+	-	-	-	-	+

Lam	: laminar	Cus-Mas	: Cushion massive
Flab	: Flabellate	Col-Mas	: Columnar massive
Fol	: Foliose	Con-Mas	: Conus massive
Col	: Columnar	Cre-Mas	: Creeping massive

Branch	: Branching	Irr-Mas	: Irregular massive
Bus-Br	: Bushy branching	Tub-Mas	: Tubular massive
Tub	: Tubular	Thickly-enc	: Thickly encrusting
Sph	: Spherical	Rep	: Repent
Mas	: Massive	Cup	: Cup
+	: present		
-	: absent		