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Short Communication

The Diversity and Distribution of Sponges in Three Different Islands at the Makassar Strait, Indonesia

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Abstract

Sponges are an important and dominant component of marine benthos which are threatened due to global environmental degradation. To establish appropriate conservation policies, the diversity and distribution of sponge must be understood. Meanwhile, the availability of sponge diversity and distribution especially in the Makassar Strait, is still lacking. This study aimed to investigated the diversity and distribution of the sponges composition in coral reef ecosystems on three less-explored islands in the Makassar Strait (South and West Sulawesi provinces, Indonesia). Sponge assemblages were sampled at a depth of 5 m using Underwater Photo Transect method, with a total area of 15 m2 at each site. We recorded a total of 137 morphospecies of sponges (N = 3978 individuals), 59 of which were restricted to Barrang Caddi, 39 to Gusung Toraja, and 92 to Pannikiang. Only 12 species were shared among all islands. We found ten morphological types of sponge, with the dominant type in all islands was encrusting. Our results showed that Pannikiang island represents the highest diversity and abundance of sponges, which had the largest area compared to the other islands and is surrounded by mangrove forests. There was a significant difference in species composition between Pannikiang and other islands.

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1. Introduction

Sponges are filter feeder organisms (Bell, 2008; Milanese *et al*., 2003) that can be found in all types of waters, whether marine, brackish, or freshwater (Mora *et al*., 2003). However, they are generally found in marine and can live at various depths (Cleary and de Voogd, 2007). According to Cleary and de Voogd (2007), sponges can be used as biological indicators of water because their lives depend on the physical and chemical conditions of an environment. Recent studies have shown that many sponges show higher resistance to ocean warming and particularly ocean acidification compared to corals (Duckworth *et al*., 2012; Duckworth and Peterson, 2012; Kelmo *et al*., 2013). Bioremediation using sponges is currently a productive study to examine the ability of sponges to clean the water column (Peterson *et al*., 2006). Sponges also serve as microhabitats for other small animals (Diaz and Rutzler, 2001) and can rebuild dead coral (Wulff and Buss, 1979).

As one of the most diverse sessile organisms, sponges have around 9490 valid species recorded (de Voogd *et al*., 2022), with at least 17,000 species estimated to exist worldwide in both freshwater and marine (Van Soest *et al*., 2012). Particularly in Indonesia, studies of sponges have generally focused on the eastern part of the Indonesian archipelago (Becking *et al*., 2013; Bell and Smith, 2004; Cleary and de Voogd, 2007; de Voogd *et al*., 2004, 2006; de Voogd and Cleary, 2008; van Soest, 1989). However, these studies are still lacking due to limited taxonomic information and the fact that sponges are one of the metazoans that are very difficult to identify (Hooper and Levi, 1994).

Makassar Strait is a narrow passage of the westcentral Pacific Ocean, Indonesia, which is the main pathway of the the Indonesia Throughflow (ITF) from the Pacific to the Indian Ocean (Susanto *et al*., 2012). The presence of ITF in this strait is thought to have created the 'Ocean Wallace line' for several coral reef-associated organisms (Barber *et al*., 2000). In addition, seasonal run-off from rivers, such as the Mahakam River in Kalimantan, into the Makassar Strait can influence surface water salinity and nutrient levels in this strait (Rachman *et al*., 2021). These conditions can affect the dynamics of the community of marine organisms in the water column of the Makassar Strait, including sponges. Meanwhile, coral reef ecosystems are declining on a global scale (Gaston, 2000), including in the Makassar Strait, the condition of coral reefs is seriously threatened due to anthropogenic activities (Sari *et al*., 2021). Which, if continued, could lead to changes in the structure of coral reef communities.

To determine a conservation strategy considering the importance of sponges in ecosystems and the potential for bioactive compounds that are beneficial to human life, data on the community that makes up coral reefs is needed in an area. Hence, this study aimed to investigated the diversity and distribution of the sponges composition in coral reef ecosystems on three less-explored islands in the Makassar Strait (South and West Sulawesi provinces, Indonesia).

2. Materials and Methods

2.1 Materials

This study was conducted on three different islands in the Makassar Strait, Indonesia (Figure 1). Barrang Caddi (BC) and Pannikiang (PA) in South Sulawesi, while Gusung Toraja (GT) in West Sulawesi. Those three islands have different distances from the mainland of Sulawesi, which Barrang Caddi was ±10.4 km, Gusung Toraja was ±3.2 km, and Pannikiang was 1.7 km. The location was divided into four sites on each island, which site 1, 2, 3, and 4 were located in the north, east, south, and west of the island, respectively.

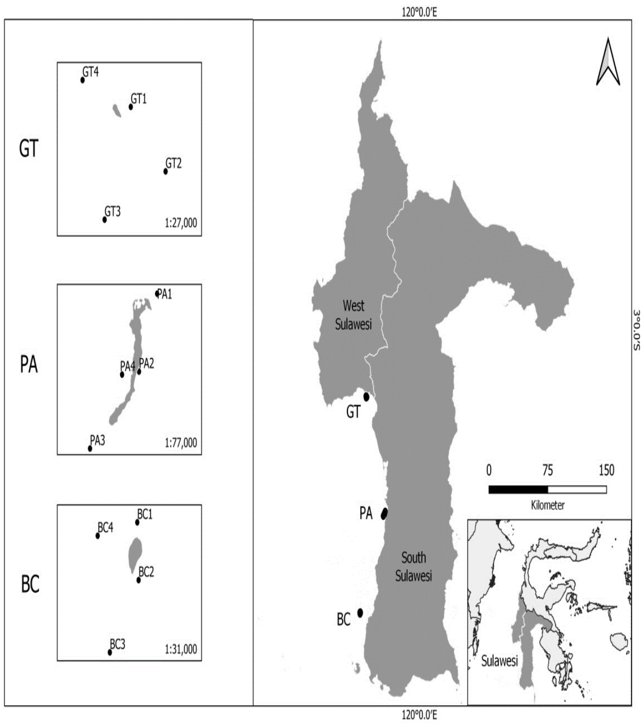

Figure 1. Map of study areas in the Makassar Strait, Indonesia (GT = Gusung Toraja; PA = Pannikiang, BC = Barrang Caddi).

2.1.1 Ethical approval

This study does not require ethical approval because it does not use experimental animals.

2.2 Methods

2.2.1 Data Collection

The sponges were collected from September 2020 to February 2021 using SCUBA diving equipment at 5 m depth. Sponge assemblages were sampled using Underwater Photo Transects (Giyanto *et al.*, 2014), with a 0.58 x 0.44 m^2 transect laid on the right and left sides of the 20 m line. This procedure was repeated three times and covered 15 m^2 at each site. These transects are also used to estimate the percentage of benthos cover (sponges, corals and other biota) and substrate. Photographs were taken for each quadrat using an Olympus TG-6 camera with housing underwater. Environmental data was collected at each station which included temperature, pH, Dissolved Oxygen (DO), and salinity.

Small pieces of sponge were collected for closer examination. The specimens were preserved in 70% alcohol and identified in the laboratory. Sponge morphology was classified according to categories described by Boury-Esnault and Rützler (1997). Sponge species were identified according to Hooper and Van Soest (2002) ; Zea *et al.* (2014), and then matched with data in the World Porifera Database (de Voogd *et al.*, 2022).

2.2.2 Analysis Data

The data were analyzed using Paleontological Statistics (PAST) v4.04 (Hammer *et al.*, 2001). Sponge species were evaluated based on abundance (number of individuals in the sampling unit), frequency (percentage of occurrence), and density (ind/m^2) at each site. At each island, analysis of species diversity (Shannon-Wienner) and Pielou evenness index (J) were also carried out. Then, we used the Hutcheson t-test to compare the diversity among sites (Hutcheson, 1970). Species richness was estimated using Chao-1 richness estimator. Shapiro-Wilk results showed that the data were significantly different from the normal distribution ($p < 0.05$), so the non-parametric tests were used throughout. The similarity analysis of the sponge composition at each of the 12 sites was compared visually using non-metric multidimensional scaling (nMDS) using the Bray-Curtis coefficient. One-way Analyses of Similarity (ANOSIM) was used to determine the statistical significance of differences among island groups based on the Bray-Curtis similarity. The taxa contributing most to the differences among assemblages were analyzed with SIMPER (Similarity Percentages, (Clarke and Warwick, 1994). Benthos and substrate coverage calculated using Coral Point Count with Excel extensions/CPCe software (Kohler and Gill, 2006), with categorization referred to Giyanto *et al.* (2014). The relationship between sponge (number of species and coverage) and corals each station were examined using linear regression analyses.

3. Results and Discussion

3.1 Sponge Assemblages and Distribution

This study is the first quantitative study of sponge diversity in coral reef ecosystems on Pannikiang and Gusung Toraja. Meanwhile Barrang Caddi, as part of the Spermonde Islands, has previously been studied by Becking *et al.* (2006) in their study. Approximately 3978 sponge individuals were collected and grouped into 137 morphospecies, with 120 of these having been identified in three classes, 17 orders, 40 families, and at least 70 genera. (Table 1). Demospongiae was the most dominant classes with 125 species, five species to Homoscleromorpha, and three species to Calcarea. The orders with the most genera were Haplosclerida (consisting of four families and twelve genera), then Poecilosclerida (consisting of eight families and ten genera). The genera with the most species were *Haliclona* (10 species) and *Dysidea* (10 species). Similar results were reported by Harris *et al.* (2019) in Barrang Lompo, Hadi *et al.* (2018) in South Coast of Java, Aulia *et al.* (2021) in Sabang (Aceh Province), and Hadi (2011) in the Kepulauan Seribu, Jakarta, Indonesia, that found the most abundant order was Haplosclerida. Reiswig (1971) stated that Poecilosclerida, Haplosclerida, and Halichondrida tend to tolerate in conditions due to sedimentation.

The highest number of species and individuals was found in Pannikiang (92 species with 2129 individuals), and the lowest was in Gusung Toraja (39 species with 351 individuals). PA4 had the highest abundance of sponges among all sites (926 individuals), then BC2 (826 individuals). Sponges were not found in the northern part of the Gusung Toraja (GT1).The most abundant and frequent species in Barrang Caddi, Gusung Toraja, and Pannikiang were *Halisarca caerulea*, *Lendenfeldia chondrodes*, and *Lamellodysidea herbacea*, respectively (Table 1), which *L. chondrodes* can be found in all islands. *Lamellodysidea herbacea* was the species with the highest abundance, with a total of 404 individuals from all the sampling sites, and the most abundant among sites was found in Pannikiang (373 individuals). In line with previous studies (Maldonado *et al*., 2016), *Lamellodysidea* was a common genus that found in Wakatobi Marine National Park, Sulawesi, where reef degradation has occurred resulting in reduced coral cover, but on the contrary, *Lamellodysidea herbacea* increased in abundance (up to 100 individual m^2) and covered more than 75% of the substrate in some locations.

Hutcheson t-test comparisons showed no significant differences in species diversity between islands ($P > 0.05$). Estimates using the Chao-1 richness estimator showed a greater number of species than we observed.

Our results show that the highest sponge diversity and abundance was found in Pannikiang. Even though it has the closest distance to the mainland, this island is surrounded by large mangrove forests throughout its coastline, which was not found in Barrang Caddi and Gusung Toraja. Mangrove are very important for coral reefs (Hermon *et al*., 2018), because they were known to reduce sediment from land, prevent coastal erosion which was beneficial for coral reefs (Jaxion-Harm and Speight, 2012), can pro-

Table 1. Most frequent and abundant species in the study areas, with their morphologies.

Species	Morphology	Occurrence (%)			Abundance (N)		
		BC	GT	PA	BC	GT	PA
Halisarca caerulea	Enc	12.82	0	0.3	192	0	2
Haliclona sp5	Enc	6.76	0	0.15	147	0	8
Lendenfeldia chondrodes	Enc	6.06	7.53	0.15	100	29	1
Terpios hoshinota	Enc	6.06	0	1.49	78	0	26
Clathria reinwardti	Br	5.59	0	3.42	77	0	38
Dysidea etheria	Co	5.13	0	0.74	134	0	15
Dragmacidon sp	Ma	4.66	4.3	0	49	16	0
Clathria sp1	Enc	3.96	0	0.59	103	0	15
Spheciospongia vagabunda	Ma	3.73	3.23	0.45	39	10	5
Dysidea sp2	Co	2.8	0	0.89	34	0	14
Phyllospongia foliascens	Fo	1.86	6.45	0	5	24	0
Phyllospongia lamellosa	Fo	0.23	5.91	1.49	1	26	19
Terpios gelatinosus	Enc	0	5.38	1.49	0	20	27
Lamellodysidea herbacea	Enc	1.63	4.84	12.93	16	15	373
Plakortis simplex	Ma	0	4.3	0	0	18	0
Dictyonella funicularis	Ma	0	3.76	0	0	10	0
Lamellodysidea sp1	Enc	2.1	3.23	0	23	10	0
Lamellodysidea chlorea	Enc	0	1.08	10.85	0	8	323
Gelliodes fibulata	Br	0	0	5.94	0	0	167
Haliclona sp2	Enc	0	0.54	3.86	0	1	69
Artemisina melana	Enc	2.33	0	3.42	50	0	56
Lamellodysidea sp2	Enc	0.7	0	3.27	14	0	113
Haliclona sp1	Enc	0.23	2.69	3.12	3	10	47
Liosina paradoxa	Ma	0	2.69	2.53	0	7	47
Diplastrella sp	Enc	0	0	2.53	0	0	38

Description: (Enc = Encrusting; Br = Branching; Co = Conulose; Ma = Massive; Fo = Foliaceous) found in Makassar Strait (BC = Barrang Caddi; GT = Gusung Toraja; PA = Pannikiang).

3.2 Species Diversity and Morphology

Species diversity and evenness of sponges in each station considerably varied (Table 2). Pairwise tect coral reefs from ocean acidification (Camp *et al*., 2016), and have stable isotopes in the transfer of dissolved inorganic nitrogen from sponges to mangroves or carbon transfer from mangroves to sponges (Ellison *et al*., 1996).

Table 2. Diversity indices for each station.

Index	Station											
	Barrang Caddi				Gusung Toraja				Pannikiang			
	BC1	BC2	BC3	BC4	GT1	GT2	GT3	GT4	PA1	PA2	PA3	PA4
Number of species (S)	27	29	14	4	0	23	17	3	36	39	30	29
Total number of individuals (N)	350	826	178	144	0	143	167	41	532	463	208	926
Shannon's diversity (H')	2.25	2.70	2.26	0.97	0	2.85	2.44	0.76	2.75	2.83	2,68	2,38
Pielou's evenness (J)	0.35	0.51	0.68	0.66	0	0.75	0.67	0.71	0.43	0.43	0,48	0,37
Chao-1 estimator	32.6	30.5	14	4	0	23.25	18	3	39.5	94	33	32

Description: BC = Barrang Caddi; GT = Gusung Toraja; PA = Pannikiang).

The sponges found were classified into ten morphological types (Figure 2). The most morphological types were found in Pannikiang (10 types). Despite the high morphological types, encrusting was dominated in all islands (38.65 – 60.75%), then massive (10.23 – 31.29%), while other morphologies ranged from 0 – 16.56%. The morphological types found in all locations other than encrusting and massive were branching, conulose, foliaceous, and papillate. Similar results were reported in several locations, such as on the south coast of Java (Hadi *et al*., 2018), Sabang (Aulia *et al*., 2021), Bengkulu (Utami *et al*., 2018) and Seribu islands (de Voogd and Cleary, 2008; Utami *et al*., 2018). Factors such as light, temperature, extreme storms, substrate type, turbulence, sedimentation, nutrient levels, and depths have been reported to influence sponge morphology (Bell and Barnes, 2000; Bell, 2004). Both encrusting and massive are resistant to high hydrodynamic forces because they have more basal area than open surfaces exposed to strong currents and high energy waves. Severe environmental stress can eliminate the other morphologies such as branching, tubular, and flabellate (Wulff, 2006).

In several sites with high pressure due to sedimentation and strong currents (such as in Pannikiang and Gusung Toraja), encrusting could be one of the morphological adaptations for several sponge species (Bell and Barnes, 2000). Moreover, habitat dominance on the reef surface, especially at the top of the reef, encrusting is also an adaptation to maximize surface area for species that depend on photosynthetic symbionts such as sponges (Cheshire and Wilkinson, 1991; Wilkinson, 1987). The low-profile morphology such as encrusting, has a greater surface area to body mass ratio than other branching or massive forms, allowing more symbionts to be exposed to light (Bell, 2007). Furthermore, the amebocyte cycle (one of the processes for capturing particles in sponges) must be slow and easily saturated for large sponges. Hence at the study site, where cloudy waters are relatively common, large sponges could have problems with this system restraining their growth rate and survival.

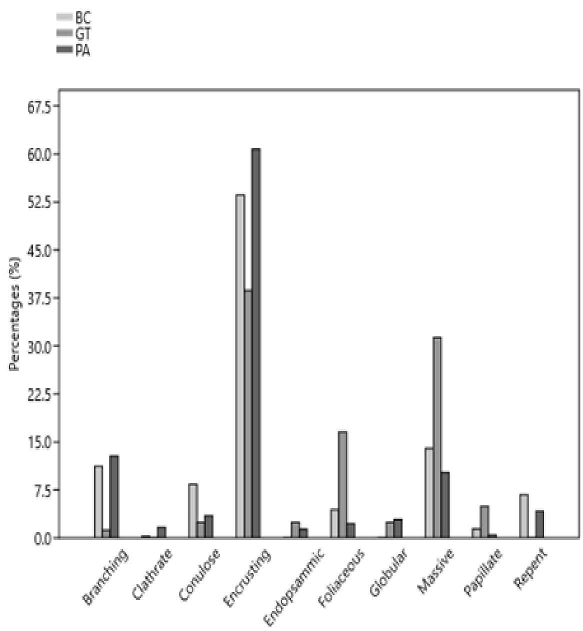

Figure 2. Proportion of sponge morphological types for each island in Makassar Strait (BC = Barrang Caddi, GT = Gusung Toraja, PA = Pannikiang).

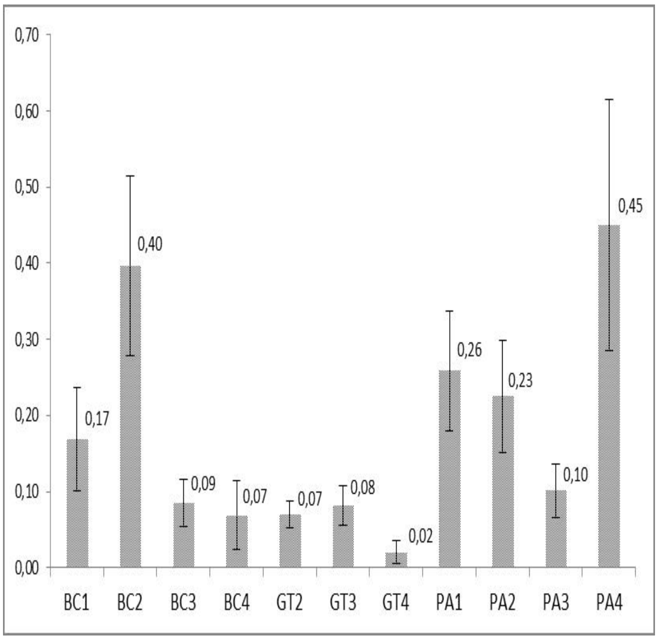

Figure 3. Average ± standard error values of sponge density across the twelve sites (BC = Barrang Caddi, GT = Gusung Toraja, PA = Pannikiang; 1 = North, 2 = East, 3 = South, 4 = West side of island).

were dominated by sediment (sand and silt). In general, sponges live in hard bottom communities and only a few sponges have adapted to soft bottom habitats such as habitats with high sedimentation (Ilan and Abelson, 1995). Supported by the results obtained in Gusung Toraja, which had the lowest sponge cover, especially on the north side (no sponges were found). In the west side, only three species found that were *Coelocarteria singaporensis*, *Amphimedon paraviridis*, and *Phyllospongia papyracea*. Similar results were also reported by de Voogd *et al*. (2009) in the Derawan Islands, and Powell *et al*. (2010) in Wakatobi Marine National Park, which had very low live coral cover due to environmental stresses, but allows other taxa (such as sponges and other filter-feeding organisms) to thrive. Sediment flowing from the surface may alter local habitats and negatively impact sponge assemblages, which can inhibit sponge growth because it requires a lot of energy to clear clogged channels and tissues (Reiswig, 1971).

The results of the linear regression analysis also support the results we obtained, which showed that

Table 3. The substrate and benthic coverage percentage at each island.

Substrate Categories	Coverage (%)											
	Barrang Caddi				Gusung Toraja				Pannikiang			
	BC1	BC2	BC3	BC4	GT1	GT2	GT3	GT4	PA1	PA2	PA3	PA4
Algae (AA)	1,5	21,2	2,0	0,6	0,0	0,5	12,6	0,3	14,1	5,1	3,4	2,1
Dead Coral (DC)	2,0	0,3	4,3	8,0	0,0	2,6	1,3	0,0	0,6	0,7	0,1	3,2
Coral (HC)	57,1	16,2	54,1	55,6	0,0	7,0	11,1	0,0	2,7	3,3	25,8	44,7
Other Biota (OT)	2,6	4,9	2,0	1,4	0,7	1,1	0,6	1,2	1,0	0,1	0,8	0,8
Soft Coral (SC)	0,0	0,4	1,6	0,6	0,0	0,7	1,2	0,0	0,4	0,3	1,2	7,1
Sponge (SP)	6,2	15,1	1,9	2,1	0,0	6,6	4,3	0,9	11,5	16,3	8,2	18,2
Dead Coral with Algae (DCA)	18,2	12,9	10,9	11,3	0,0	1,1	8,7	0,0	6,4	19,2	23,7	18,6
Rubble (R)	8,0	4,3	17,2	13,9	0,0	0,4	5,7	0,0	34,6	27,7	21,1	4,4
Silt (SI)	3,8	11,8	0,2	1,7	40,2	36,6	0,0	77,9	11,3	0,2	0,0	0,0
Sand (S)	0,8	12,2	1,9	1,7	59,1	39,2	46,1	19,6	17,4	26,6	15,7	0,7
Rock (RCK)	0,0	0,7	3,8	3,2	0,0	4,2	8,6	0,0	0,0	0,4	0,2	0,2

3.3 Comparison of Sponge Composition between All Islands

The highest average of sponge density was in Pannikiang, then Barrang Caddi, and the lowest in Gusung Toraja, with the largest density being located in PA4 (Figure 3). Supported by the results of benthic coverage (Table 3), the average of sponge cover in Pannikiang was the highest (13.55 ± 2.27% (SE)). No coral reefs were found in GT1 and GT4. Both stations there was a significant positive relationship between increasing sponge cover and the number of sponge species (P= 0.04, Figure 4). This analysis means that the increase in coral cover is in line with the increase in the number of sponges species found. While other regression analysis showed negative relationship, both between coral cover & sponge cover, and coral cover % the number of sponge species, although analysis of variance for both showed insignificant results

(P> 0.05, Figures 5A and 5B). These results indicate that as coral cover increases, sponge cover will decrease. Likewise, increasing coral cover can cause a decrease in the number of sponge species. The average of environmental parameters on each island can be seen in Table 4. From the three regression analyzes that we carried out, the results obtained were similar with the results of previous study in Sabang (Aulia *et al*., 2021). several studies have shown that sponges are the main competitors of corals in reef habitats (Chaves-Fonnegra and Zea, 2011; Brandt *et al*., 2019).

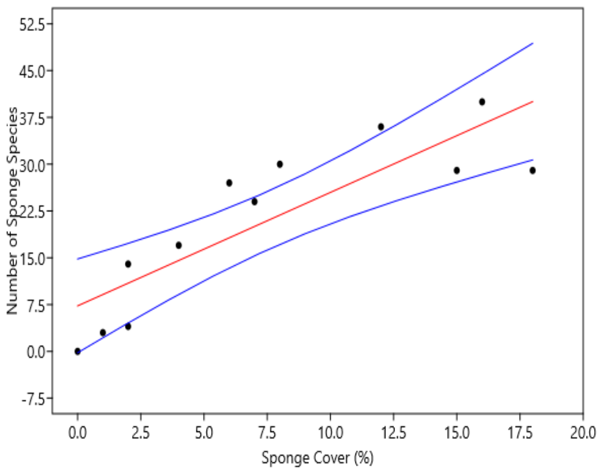

Figure 4. Relationship between sponge cover and the number of sponge species (r = 0.85506, p = 0.0004).

Table 4. Average of environmental parameter for each island

Variable	BC	GT	PA
Temperature	29.75 ± 0.5	29.5 ± 0.57	30.25 ± 0.5
Salinity	34.5 ± 1.3	31 ± 1.15	32.25 ± 0.96
Dissolved oxygen (mg/L)	4.22 ± 1.55	7.6 ± 1.14	4.4 ± 1.3
pH	7.4 ± 1.1	7.55 ± 2.1	8.3 ± 0.12

Description: BC = Barrang Caddi; GT = Gusung Toraja; PA = Pannikiang).

The results of the linear regression analysis also support the results we obtained, which showed that there was a significant positive relationship between increasing sponge cover and the number of sponge species (P= 0.04, Figure 3A). This analysis means that the increase in coral cover is in line with the increase in the number of sponges species found. While other regression analysis showed negative relationship, both between coral cover & sponge cover, and coral cover % the number of sponge species, although analysis of variance for both showed insignificant results (P> 0.05, Figures 5A and 5B). These results indicate that as coral cover increases, sponge cover will decrease. Likewise, increasing coral cover can cause a decrease in the number of sponge species. The average of environmental parameters on each island can be seen in Table 4. From the three regression analyzes that we carried out, the results obtained were similar with the results of previous study in Sabang (Aulia *et al*., 2021). several studies have shown that sponges are the main competitors of corals in reef habitats (Chaves-Fonnegra and Zea, 2011; Brandt *et al*., 2019).

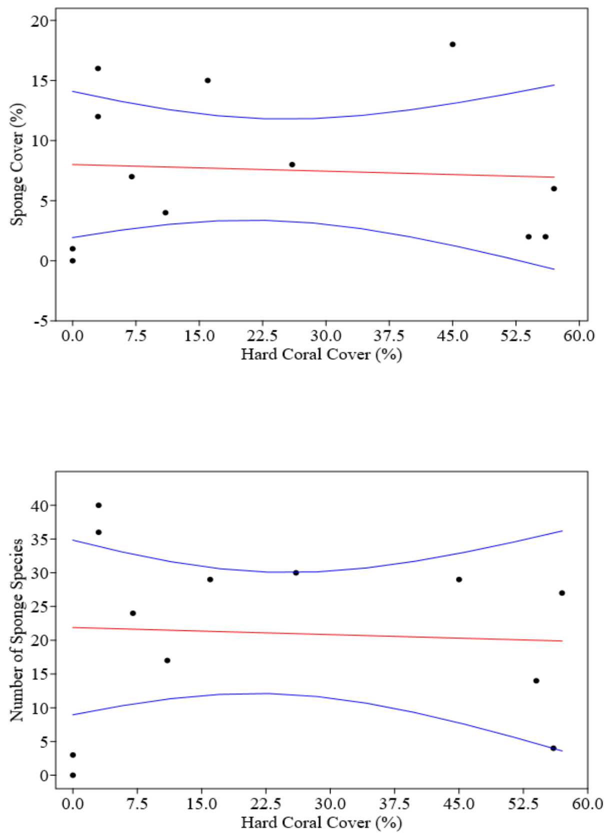

Figure 5. Relationship between A. Sponge cover & Hard Coral cover (r = -0.0689, p = 0.831), B. Number of sponge species & Hard coral cover (r = -0.0612, p = 0.8499.

The nMDS analysis indicated differences in species composition between Pannikiang and the other islands (Figure 4). This result was confirmed by ANOSIM that Pannikiang had a significant difference with Barrang Caddi (p = 0.02) and Gusung Toraja (p = 0.02). Sponges composition in Barrang Caddi and Gusung Toraja had no significant difference (p = 0.35).

Based on SIMPER analysis, species that contributed the most to differences in sponge composition were *Lamellodysidea herbacea* (7.8%), *Lamellodysidea chlorea* (6.2%), *Gelliodes fibulata* (4.9%), *Halisarca caerulea* (4.4%), and *Lendenfeldia chondrodes* (4.3%).

competitive interactions also play an important role in population dynamics and sponge size structure on coral reefs (Aerts and van Soest, 1997).

Unique species found in PA were 56 species (41%) of the total species recorded (Figure 5). There were 81 species found only at one site, and 24 species

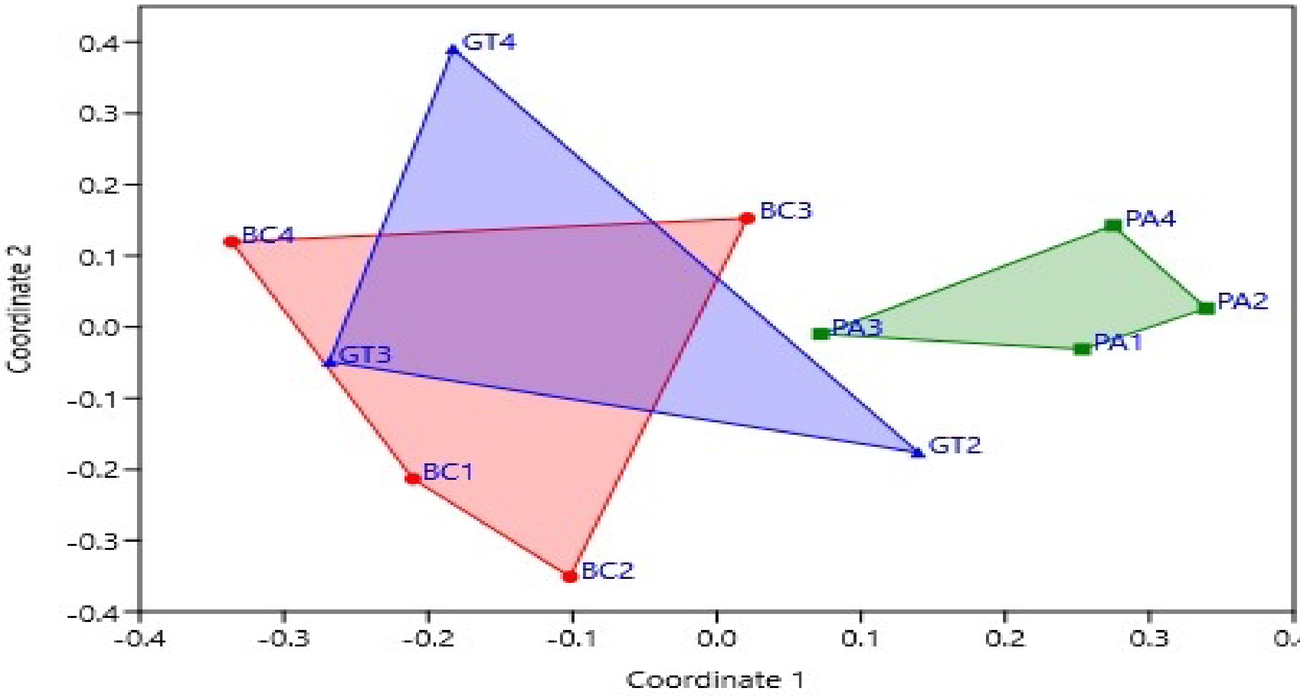

Figure 6. non-metric Multidimensional Scaling (nMDS) plot of sponge assemblages at BC, GT, and PA (GT = Gusung Toraja; PA = Pannikiang, BC = Barrang Caddi), based on Bray-Curtis similarity index (stress of configuration = 0.2757).

The distance between islands did not affect the similarity of sponges composition in this study. Based on the results of nMDS and ANOSIM, Pannikiang, which is located between Pannikiang and Gusung Toraja, actually had a significant difference. This result was similar to previous studies (de Voogd *et al*., 1999; Hooper *et al*., 1999; Hooper and Kennedy, 2002; Zea, 2001; Prabowo *et al*., 2023), which showed that the distribution of sponges was far from homogeneous. Spatially, this heterogeneity was closely related to deterministic (environmental) processes (de Voogd *et al*., 2006). A similar study by Pandolfi (2003) showed a high variance in estimates of community similarity on Caribbean coral reefs, indicating that distance alone does not affect community patterns. These data confirm previous studies that the heterogeneity of sponge distribution, especially in coral reef ecosystems, is partly caused by differences in geomorphology between reefs (Hooper, 1994), and by biogeographic factors influencing sponge composition (Hooper *et al*., 1999). Biotic processes such as predation and found only one individual in one transect. Moreover, there were 12 species commonly found on the three islands: *Xestospongia muta*, *Spheciospongia vagabunda*, *Pseudoceratina* sp., *Phyllospongia lamellosa*, *Phyllospongia papyracea*, *Lamellodysidea herbacea*, *Lendenfeldia chondrodes*, *Aaptos suberitoides*, *Amphimedon paraviridis*, *Dysidea* sp1, *Haliclona* (*Gellius*) *amboinensis*, and *Haliclona* sp1. It can be assumed that these species were common species found in the Makassar Strait. The high number of unique species found (especially in PA) and a high number (24 species) of singletons may indicate an apparent endemic of sponges at Makassar Strait, and the actual diversity is higher than recorded. According to van Soest (1989), different Indo-West Pacific geographic areas have some endemic but are very similar to their common species. Species endemism was seen to be largely a function of the biogeographic isolation or proximity to other regional faunas and ecological factors such as the possession of unique habitat types (Hooper *et al*., 1999).

3.4 Spatial Variation and Conservation Implications.

The nMDS analysis revealed clear spatial separation of sponge assemblages among the islands, underscoring the ecological uniqueness of each site. SIMPER analysis identified key species contributing to these differences, such as Lamellodysidea chlorea and Gelliodes fibulata, which were predominantly found in Pannikiang. These results emphasize the need for location-specific conservation strategies to protect sponge biodiversity, particularly in areas with high anthropogenic pressures. Globally, the findings contribute to understanding how sponge communities adapt to varying environmental conditions, offering insights for the management of coral reef ecosystems under climate change scenarios

4. Conclusion

Sponges in the Makassar Strait were diverse. They showed significant differences based on individual abundance data, with the greatest abundance and diversity found in Pannikiang and the lowest found in Gusung Toraja. The sponge composition of the three islands indicated that neighboring islands do not guarantee high similarity. Further research is recommended to improve the collection of environmental data, both biotic and abiotic, to increase understanding of the factors that influence sponge diversity.

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Conflict of Interest

The authors declare that they have no competing interests.

Declaration of Artificial Intelligence (AI)

The author(s) affirm that no artificial intelligence (AI) tools, services, or technologies were employed in the creation, editing, or refinement of this manuscript. All content presented is the result of the independent intellectual efforts of the author(s), ensuring originality and integrity.

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