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Biodiversity of hard coral (Scleractinia) and relation to environmental factors turbid waters in Spermonde Islands, South Sulawesi, Indonesia

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Abstract. *Parenden D, Jompa J, Rani C, Renema W, Tuhumena JR. 2023. Biodiversity of hard coral (Scleractinia) and relation to environmental factors turbid waters in Spermonde Island, South Sulawesi, Indonesia s. Biodiversitas 24: 4635-4643.* Water turbidity has an impact on coral growth and the diversity of coral species in the waters. Calculation of coral cover, coral diversity and environmental parameters need to be done to determine the effect of environmental parameters on growth. This research was conducted in July 2020-February 2021 in the Spermonde Islands, South Sulawesi, Indonesia, which focused on the inner zone area with high turbidity levels. The research was conducted at four observation locations, namely Kayangan Island, Samalona Island, Gusung Tallang and Lae-Lae Island. Primary data in the form of coral cover using the Underwater Photo Transect method, diversity data using the quadrant transect method and environmental parameters measured in-situ and ex-situ. The results of this study showed (1) the percentage of coral cover at each research location was classified as poor because it was in the range of 3-15%, (2) coral diversity on Samalona Island was classified as high (H'=3.2) while on Kayangan Island, Laelae Island and Gusung Tallang was classified as medium with values ranging from 2.21-2.83; and (3) environmental parameters such as turbidity, Total Suspended Solid (TSS), Total Dissolved Solid (TDS), nitrate, and phosphate and based on the results of regression analysis has a negative effect on coral cover, while turbidity and Total Suspended Solid (TSS) parameters have a significant effect on coral cover ($p<0.05$). These results have the potential to determine the composition of hard corals (*Acropora* sp.) in turbid areas and potentially serve as transplant fragments to mitigate coral damage.

Keywords: Coral cover, principal component analysis, turbid waters, underwater photo transect

INTRODUCTION

Coral reefs, one of the coastal ecosystems, are inhabited by a variety of biota that are beneficial to humans but vulnerable to environmental factors caused by human activities both in aquatic and terrestrial areas. According to Veron (2000) found that 590 species of corals belonging to 80 genera exist in Indonesia, especially in Eastern Indonesia, so Indonesia is referred to as one of the mega biodiversity countries and is the center of the world's coral triangle. However, there has been degradation due to natural factors and human activities. The coral area in the Spermonde Islands is 1,556.97 Ha, which consists of 64 genera from 16 families (Sari et al. 2021). Research by Yusuf et al. (2021) states that there are as many as 310 species from 62 genera in the Spermonde Islands. Based on monitoring conducted by the Research Center for Oceanography, National Research and Innovation Agency in 2021, coral cover increased in the 2018-2021 time frame by 0.59% and coral diversity in waters near the city of Makassar was lower than in areas far from the mainland of Makassar City. The island adjacent to the mainland of Makassar City is widely used as a beach tourist destination. This has led to an increase in damage due to tourism activities.

Coral reef life is influenced by aquatic environmental factors such as salinity, temperature, sedimentation, nutrients and others. There are also biota that prey on corals (Mitchell and Harborne 2020) and also activities in coastal areas such as development, but certain types of corals can still adapt to the changes that occur. However, over-utilization makes changes to coral ecology (Bartley et al. 2014) such as destructive fishing activities (El-Nagar 2021) and coastal development (Soares et al. 2021; Mahatir et al. 2022) or upland activities (nutrient and sediment inputs) influence the growth of macroalgae, thus inhibiting coral growth (D'Angelo and Wiedenmann 2014; Loiola et al. 2019), tourist behavior (snorkeling and diving) stepping on or touching corals so that there are many coral fractures (Abidin and Mohamed 2014; Cerutti-Pereyra et al. 2022; Massiseng et al. 2022) and global warming is causing sea surface temperatures to rise, leading to coral bleaching (Pratchett et al. 2013; Lafratta et al. 2017; Morgan et al. 2020). These factors directly or indirectly affect coral life

in the water. Coral reefs that are close to land tend to experience sedimentation and reduce the function of coastal ecosystems, one of which is coral reefs (Bégin et al. 2016; Limmon and Marasabessy 2019; Tebbett et al. 2021). Sedimentation can cover coral polyps, which inhibits the photosynthesis process, leading to coral mortality. However, there are also coral species that can survive in turbid water conditions, such as *Porites* spp. (Travaglione et al. 2023) and boulder type (Mcleod et al. 2019).

Yusuf et al. (2021) found that coral cover on Spermonde Island ranged from 32.1-33.5%. Meanwhile, research by Parenden et al. (2021) found coral cover on Kayangan Island at 4.95%, Samalona Island at 14.08%, and Lae-Lae Island at 9.53% obtained from the coral reef health monitoring report in Makassar City (Sari et al. 2017). Meanwhile, data on hard coral cover and distribution of hard coral species on islands close to the mainland of Makassar city with turbid waters are still very much needed, in this case represented by Kayangan Island, Gusung Tallang, Lae-Lae Island, and Samalona Island. The diversity and presence of hard corals on this island are strongly influenced by the environmental parameters of turbid waters, so it is necessary to know the condition and types of hard corals in turbid waters and their environmental parameters so that the research conducted is the biodiversity of hard corals (Scleractinia) and their relationship with environmental factors of turbid waters in the Spermonde Islands. This study aims to analyze the condition of coral reefs (coral cover), the distribution of coral reef types in murky waters and their relationship with environmental factors in the murky waters of the Spermonde Islands.

MATERIALS AND METHODS

Study area

The research was conducted from July 2020 to February 2021. The research site in the Spermonde Islands is in 4 (four) locations: Kayangan Island, Gusung Tallang, Lae-Lae Island and Samalona Island (Figure 1). This study focused on observing the condition of coral reefs in the turbid waters of the Spermonde islands in the inner zone or the area bordering the mainland of the city, which is directly affected by the dense activities on land and beaches that cause high turbidity of waters in this zone, the four research locations are in the inner zone of the Spermonde islands.

Procedures

Benthic hard coral data collection

Benthic data were collected using the Underwater Photo Transect (UPT) method with SCUBA equipment, taking pictures using underwater cameras and frames measuring 58 x 44 cm and analyzed using CPCe (Coral Point Count with Excell Extension) software version 4.1 (Giyanto et al. 2017). Data collection using the UPT method was carried out using SCUBA diving techniques, using a Canon Powershot G16 camera equipped with a compatible housing for diving activities and a square-shaped iron frame that was given a striking color, which is a combination of red and yellow. Transect lines were positioned parallel to the shoreline at depths where corals are commonly found, at a depth of about 5-10 meters. When the meter tape was placed, the mainland position of the island was on the left. After the meter tape was placed, photographing was carried out along the transect line starting from the 1st meter to 50 meters with a distance of 1 m between photos. Shooting at the 1st meter (frame 1), 3rd meter (frame 3) and subsequent odd-numbered frames was conducted to the right of the transect line, while even-numbered frames (frame 2, frame 4, and so on) were conducted to the left of the transect line (Figure 2). Photographing was done at a distance of about 60 cm from the bottom of the substrate so that the area of each shooting frame was about 2500 m^2. Photographs were then analyzed using CPCe 4.1 (Giyanto et al. 2017). A total of 30 random point samples were selected for each photo frame, and each point was coded according to the code of each category and the biota and substrate located at the random point. To identify the growth form, refer to the Survey Manual for Tropical Marine Resources and monitoring guidelines by the Indonesian Institute of Sciences (LIPI).

Hard coral diversity

Diversity data were collected using the quadrat transect method (Irwan 2023). Where using a 50 meter long meters drawn parallel to the shoreline and 2 x 2 quadrants places on the meters. The quadrant used is 2 x 2 meters placed on the meter to see the coral genera in the quadrant. Researchers took data on the presence of corals at 1 meter left and right of the transect line. The interval between one quadrat and another quadrat is 5 meters, so in one line transect there are 10 quadrats (Figure 3). Data collection for coral diversity was conducted after coral cover collection. Identification of coral species was done visually using a magnifying glass and Coral Finder guidebook and Coral of the World identification book (Veron 2000) and coral species in Indonesia.

Water quality parameters

Measurement and data collection of water quality parameters were carried out in situ (parameters, pH, DO, conductivity, turbidity, temperature, salinity, Total Dissolved Solid (TDS)), chlorophyll-a using WQC (Water Quality Checker) type TOA DKK WQC-24. Total Suspended Solid (TSS), nitrate, and phosphate data using Spectrophotometer are ex-situ by sampling and then examined at the Faculty of Marine Science and Fisheries Laboratory, Hasanuddin University Makassar.

Data analysis

Hard coral condition analysis

Percentage hard coral cover quantitative using CPCe software (Giyanto et al. 2017) and random point sample selection for each photo frame was calculated and analyzed using the formula:

$$\text{Coverage percentage} = \frac{\text{Number of points category}}{\text{number of random facts}} x\ 100\%$$

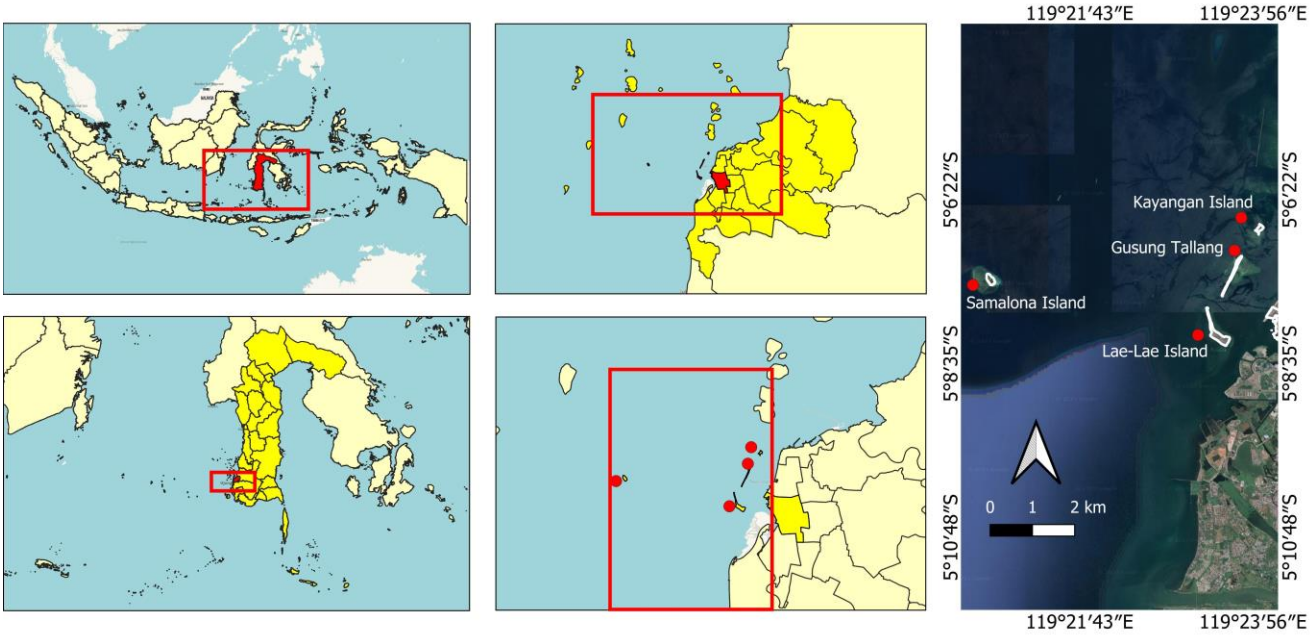

Figure 1. Research locations in Kayangan Island (5°6'42.74" S 119°23'47.34" E), Gusung Tallang (5°7'07.9" S 119°23'42.2" E), Lae-Lae Island (5°8'12.7" S 119°23'14.1" E), and Samalona Island (5°7'34.32" S 119°20'21.22" E) Spermonde Islands, South Sulawesi, Indonesia

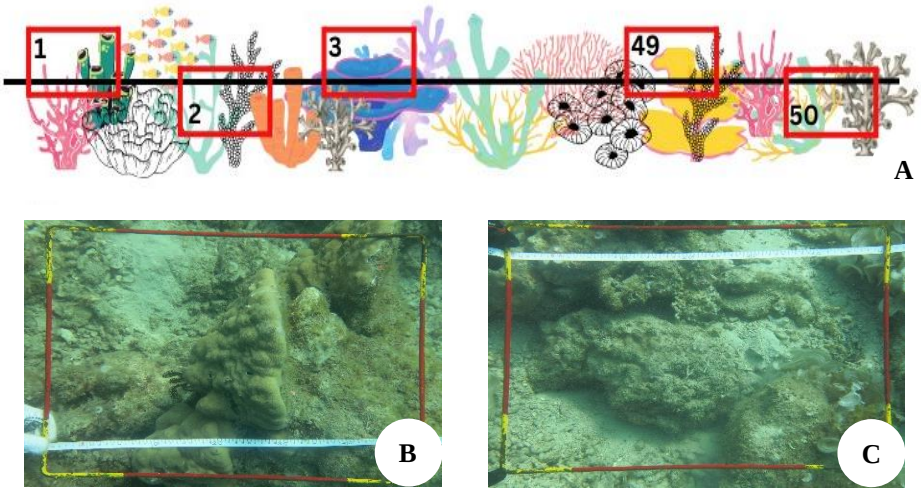

Figure 2. Coral data collection using Underwater Photo Transect (UPT). A. Illustration of transect line placement over coral and intermittent frame placement over the transect, B. Example of frame placement on odd-numbered transect lines/roll meters, and C. Example of frame placement on even numbered transect lines/roll meters

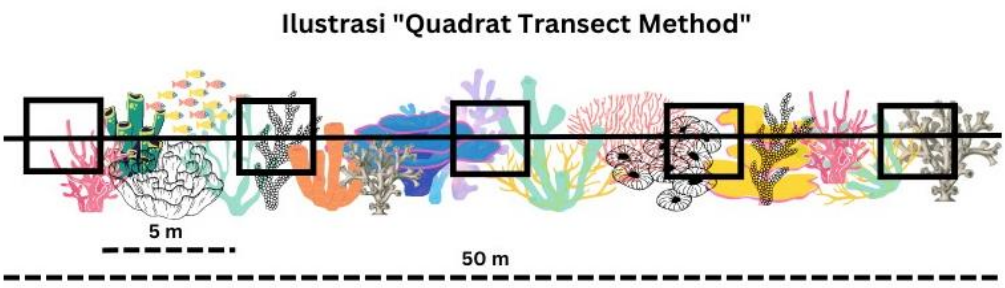

Figure 3. Coral diversity data collection using quadrant transects

Table 1. Coral cover assessment category

Live coral cover (%)	Assessment category
75-100	Excellent
50-74.9	Good
25-49.9	Medium
0-24.9	Poor

To determine the comparison of coral reef base cover data, grouping was done according to the observation location (island) and analyzed descriptively with the help of graphs. The condition of coral reefs is determined based on the category of coral life with reference to the Decree of the Minister of Environment, 2001 (Table 1) and the results are displayed in the table.

Hard coral diversity

Complex coral diversity was calculated using the Shannon-Wiener formula with the following equation:

$$H' = -\sum\left(\frac{n}{N}\ln\frac{ni}{N}\right)$$

where:
H' : Diversity Index
ni : Number of individuals in the I-th species
N : total Number of individuals

Diversity Index criteria:
H'<1: Low diversity, 1<H'<3: Medium diversity, H'>3: High diversity

To compare hard coral diversity data, grouping was done according to the observation location (island) and analyzed descriptively by displaying data on graphs.

Relation between water quality and percentage coral cover

Analyze the relationship between water quality and coral cover condition using the PCA (Principal Component Analysis) XLSTAT method. PCA analysis is used to extract structure from a set of data with many dimensions. In addition, to see the functional relationship between one variable and another variable using regression analysis, which is to determine the linear functional relationship between one response variable and one predictor variable with a value of p=0.05 using Excel software.

RESULTS AND DISCUSSION

Percentage of coral cover in turbid waters

The percentage of live coral cover on Samalona Island was 15±19.96, Kayangan Island was 5.53±7.52, Gusung Tallang was 3±5.52, and Lae-Lae Island was 7.67±13.29 (Figure 4). Based on this data, the condition of corals in the four research locations is categorized as poor.

In Figure 4, it can be seen that the cover of DCA (Dead Coral with Algae), R (Rubble), S (Sand) and Si (Silt) is higher than the cover of live corals. Research conducted by (Parenden et al. 2021) found that the live coral cover of Kayangan Island was 4.95% and Samalona Island was 14.08%. Based on the monitoring results of the Indonesian Institute of Sciences in 2016, coral cover on Lae-Lae Island was 9.53% (Sari et al. 2017). The increase in coral cover is due to the decline in tourist activities on Samalona and Kayangan Islands. Based on observations in the field, there are no tourist activities on Kayangan Island.

The decrease in coral cover in Kayangan Island, Gusung Tallang, and Lae-Lae Island waters is due to these areas being closer to the mainland of Makassar City. Those areas closer to the mainland are potentially exposed to sedimentation (Bégin et al. 2016; Limmon and Marasabessy 2019; Tebbett et al. 2021). Activities in coastal areas have a direct impact on coral ecosystems (Loiola et al. 2019; Mahatir et al. 2022) or upland activities such as nutrient inputs to waters (D'Angelo and Wiedenmann 2014; Faizal et al. 2020). Ismail et al. (2022) added that environmental pressures that occur continuously while coral recovery is slower cause coral death.

Gusung Tallang waters have lower cover because this area is a shipping lane for ships in and out of Makassar City, so it is suspected that sediment stirring occurs, which causes the closure of coral polyps. This is reinforced by research (Dharmawan et al. 2020), which states a decrease in low coral cover due to the presence of docks and high ship mobility. In addition, Gusung Tallang is a tourist area, so according to (Abidin and Mohamed 2014; Cerutti-Pereyra et al. 2022) the behavior of tourists snorkeling and diving causes coral damage. The influx of excessive nutrients into the water through river flow is one of the problems for coral reef ecosystems (Baird et al. 2021) and affects coral cover.

Hard coral diversity in turbid waters

Calculation of the diversity index shows that Kayangan Island, Lae-Lae Island and Gusung Tallang waters are included in the medium category, each having a value of 2.5; 2.83; 2.21 and while Samalona Island waters are classified as high diversity with a value of 3.2 (Figure 5). Coral species found in Samalona Island Waters amounted to 28 genera from 16 families, higher than other research locations (Table 2). Coral variation in an area can affect coral diversity in the area. In Kayangan Island waters consisted of 13 genera, Gusung Tallang waters amounted to 9 genera and Lae-Lae Island waters amounted to 18 genera (Figure 6), all coral species included in 15 families.

Environmental parameters affecting coral community structure in aquatic areas. The research location is close to the mainland of Makassar City, so it is suspected that it gets a greater influence from the mainland area. Reefs that are close to land tend to experience sedimentation and reduce their function (Bégin et al. 2016; Limmon and Marasabessy 2019; Tebbett et al. 2021). Research Yusuf et al. (2021), there are as many as 62 genera in the Spermonde Islands. The higher activities carried out in coastal areas, especially development, contribute to sediment in the waters, in addition to river flow. Enrichment of waters with nutrients (D'Angelo and Wiedenmann 2014) marine tourism and can also be caused by marine tourism (Abidin and Mohamed 2014; Cerutti-Pereyra et al. 2022; Massiseng et al. 2022), sedimentation (Lafratta et al. 2017; Morgan et al. 2020) and global

warming (Pratchett et al. 2013; Lafratta et al. 2017; Morgan et al. 2020) which has an impact on coral reef damage, so that the coral genera becomes reduced. *Acropora* coral species are found in all locations, as many as 17 individuals and in the waters of Samalona Island, this type is found a lot. This is because the waters of Samalona Island are located further from the mainland of Makassar City, so it is suspected that the sedimentation process and excess nutrients in this area do not exceed the quality standards for coral biota life. Research Parenden et al. (2021) found that the types of corals found in Kayangan Island waters are *Porites* and *Faviidae* species, Samalona Island waters of *Acropora* and *Fungiidae* species.

Analysis of the relation between turbid waters environment and hard coral cover

Aquatic environmental parameters are one of the determining factors in the life of corals in the waters. The parameters of the aquatic environment were analyzed to see the characteristics of each location using PCA and an analysis was also carried out to see the effect of several parameters of the turbid water environment on coral cover using regression analysis. Based on the results of PCA analysis, it can be seen that the angle formed 90° means not correlated. Figure 7 shows that all environmental parameters and coral cover have a correlation with one another.

It is also seen that Samalona Island waters are characterized by high Chlorophyll-a and pH parameters, Kayangan Island waters are characterized by low nitrate and phosphate, Gusung Tallang waters are characterized by low conductivity, turbidity, TDS, and TSS, and Lae-Lae Island is characterized by high temperature and salinity parameters, but low DO parameters. For the coral cover, HC, DC, DCA, and FS are high characteristics of Samalona Island. Soft coral is characterized by low Lae-Lae Island, and high Kayangan Island characterizes SP and OT. It is assumed that each station's low and high characterization can be seen from the location of these parameters in positive (+) or negative (-) quadrants.

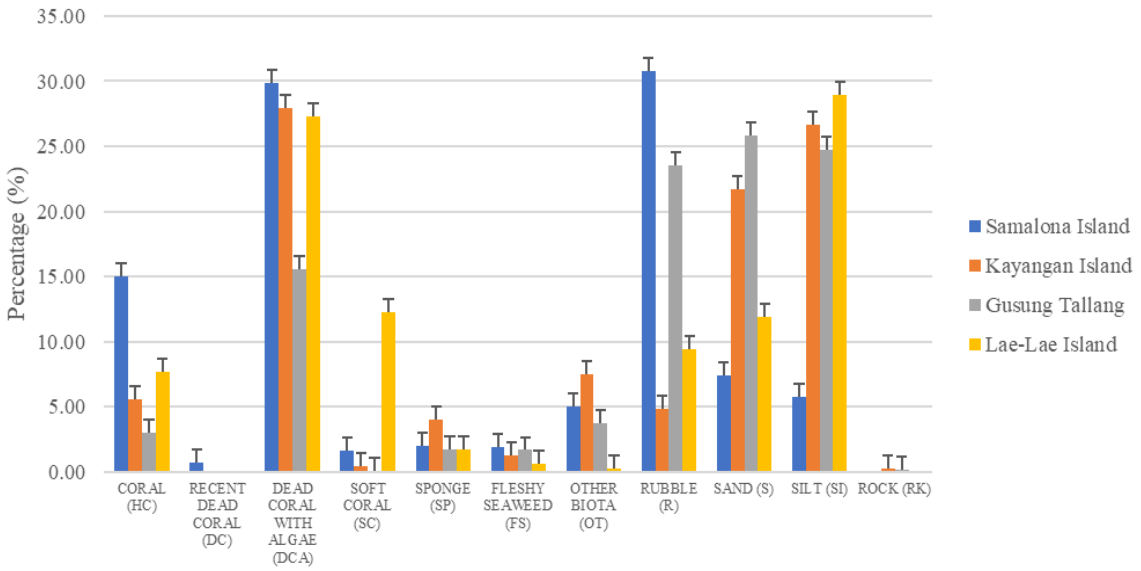

Figure 4. Graph of percentage coral cover in research location

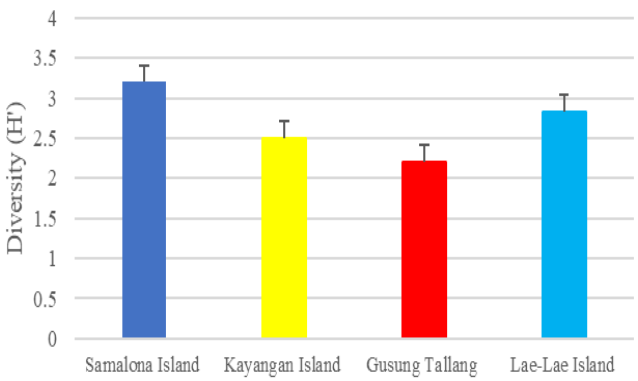

Figure 5. Diversity Index of hard coral genera

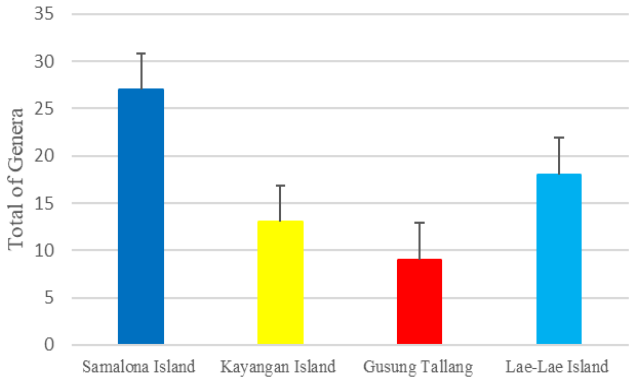

Figure 6. Total genera of hard coral

Table 2. Number of individuals corals found in the research location

Category	Family	Genera	Research location			
			Salamola Island	Kayangan Island	Gusung Tallang	Lae-Lae Island
Scleractinia coral	Acroporidae	*Acropora*	9	2	4	2
		Montipora	3	-	-	2
		Isopora	2	-	-	-
	Agaricidae	*Gardinoseris*	1	-	-	-
		Pavona	-	-	-	2
		Pachyseris	2	-	-	-
	Astrocoeniidae	*Stylocoeniella*	2	-	-	-
	Dendrophylliidae	*Turbinaria*	-	2	2	3
	Euphyllidae	*Physogyra*	4	-	-	-
	Faviidae	*Cyphastrea*	3	-	-	-
		Echinopora	-	-	-	1
		Favia	4	4	4	5
		Favites	3	3	3	3
		Montastrea	-	-	-	1
		Platygyra	1	1	-	1
	Fungiidae	*Fungia*	7	2	1	3
		Heliofungia	2	-	-	-
		Polyphyllia	2	-	-	-
	Merulinidae	*Hydnopora*	1	-	-	-
		Merulina	2	-	-	-
	Mussidae	*Lobophyllia*	4	1	1	2
		Symphyllia	2	1	2	2
	Oculinidae	*Galaxea*	1	1	-	2
	Pectinidae	*Echinophyllia*	2	-	-	-
		Pectinia	2	-	-	1
	Pocilloporidae	*Pocillopora*	3	3	2	2
		Seriatopora	3	2	-	1
		Stylopora	2	-	-	-
	Poritidae	*Goniopora*	1	-	-	-
		Porites	5	5	3	3
Non Scleractinia coral	Merulinidae	*Millepora*	2	-	-	-
	Helioporidae	*Heliopora*	-	1	-	1
Total Individual			78	31	24	39

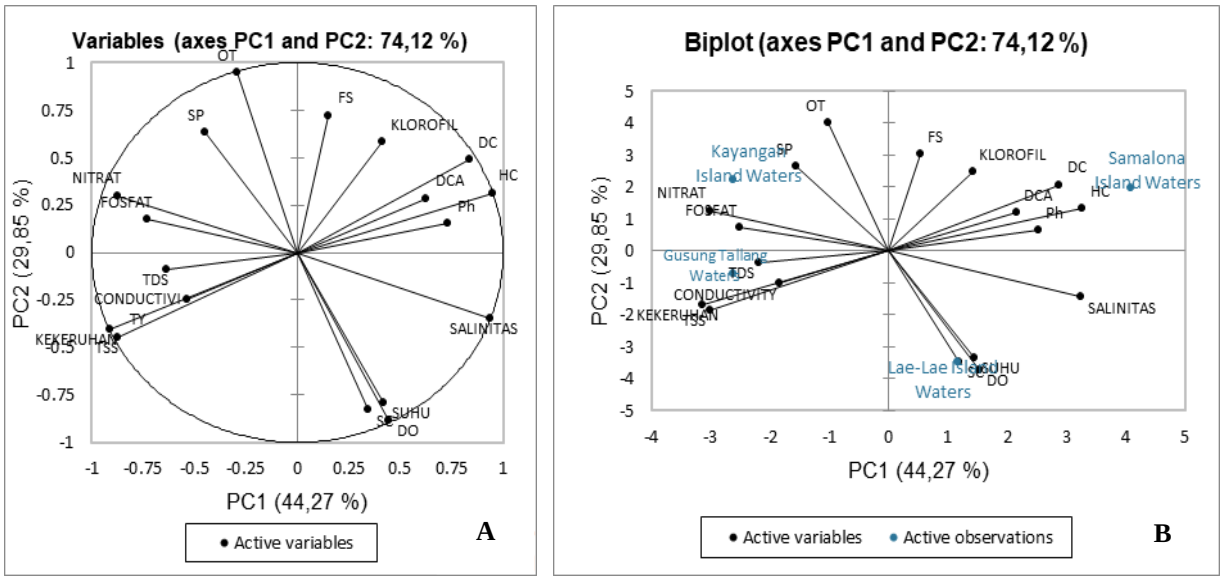

Figure 7. Graph biplot of PCA analysis. A. Environmental factors and coral cover, B. Environmental factors, coral cover in research location

Turbidity, TSS and TDS correlate because they form a small angle, nitrate and phosphate, each characteristic of Gusung Tallang and Kayangan Island waters. Gusung Tallang waters have higher turbidity levels and TDS and TSS content (Table 3), which affect the photosynthesis process of *Zooxanthellae*.

All water quality parameters temperature is still in the normal range because corals can tolerate temperatures 25-33°C (Ellis et al. 2019). Corals can live in a salinity range of 30-35‰ (Attamimi and Saraswati 2019; Chuang and Mitarai 2020). However, the river's flow is thought to affect the salinity level in the waters of Kayangan Island and Gusung Tallang waters. Turbidity, TSS, and nitrate parameters exceeded the quality standards set at all study sites, while phosphate content in Gusung Tallang waters exceeded the quality standards. Turbidity caused by increasing TSS content in the waters can be caused by the influx of river water that carries material or small particles into the waters.

According to Sully and van Woesik (2020) low hard coral cover occurs in areas that have high levels of turbidity. In addition, it can cause low levels of new coral recruitment (Wakwella et al. 2020). The presence of river estuaries impacts the influx of sediment and nutrients into the waters (Baird et al. 2021). In addition, nutrient content in the water affects genera composition (Putro et al. 2022) and nutrient content affects changes in water quality (Baird et al. 2021), so coral animals must adapt to the changes that occur.

Based on the results of the regression analysis in Figure 8 above, it can be seen that the 5 (five) environmental parameters analyzed negatively affect coral cover. However, the parameters TDS, phosphate and nitrate did not have a significant effect R^2 value or the relationship between turbidity, TDS, and nitrate. Phosphate and TSS to coral cover are 97%, 70%, 81%, 74%, and 100% respectively. The results of the regression analysis also found ANOVA results to see whether or not these parameters have a real effect on coral cover. In the ANOVA table, it can be seen that environmental parameters, namely turbidity and TSS, have a significant effect on coral cover ($p<0.05$). According to Sholihin et al. (2021), the higher the TDS value, the higher the water's turbidity value. If the turbidity is high, the oxygen content will decrease. The flow of rivers carrying nutrients to coral reef areas influences the nitrate and phosphate content in the waters (Mwachireya et al. 2015; Gordon et al. 2020). According to (Rizka et al. 2020), the higher the TSS content, the lower the density of *Zooxanthellae* in coral tissue. The increasing development activities influence the TSS content in the waters in coastal areas, thus contributing soluble and insoluble materials that cause increased water turbidity. Natural events that occur continuously make corals adapt to survive. However, human activities carried out in the waters and land have a chronic impact on coral reef damage. Turbidity levels affect coral growth both vertically due to dependence on sunlight for photosynthesis (Morgan et al. 2020). Coral diversity can be affected by human activities such as environmentally unfriendly fishing and sedimentation (El-Nagar 2021), development in coastal areas (Mahatir et al. 2022), growth in coastal areas and contributions from river flows that carry sediment into coastal areas (Rani et al. 2014).

Table 3. Water quality parameters in research location

Environmental parameters	Research location				Quality standard	Range	Average	SE
	Samalona Island	Gusung Tallang	Kayangan Island	Lae-Lae Island				
pH	8.42	8.25	7.8	8.34	7-8.5	7.8-8.42	8.20	0.139
DO (mg/L)	7.89	7.42	7.8	8.8	>5	7.42-8.8	7.98	0.292
Conductivity	4.24	4.26	7.8	4.51	-	4.24-7.8	5.20	0.868
Turbidity (NTU)	2.9	12.4	11.3	10.3	<5	2.9-12.4	9.23	2.152
Temperature (°C)	30.1	29.8	29.7	31.6	28-30	29.7-31.6	30.3	0.442
Salinity (‰)	30.2	28.2	28.5	30.1	33-34	28.2-30.2	29.25	0.524
TDS (mg/L)	46.3	50.4	47.6	49	-	46.3-50.4	48.33	0.884
TSS (mg/L)	62.8	239.5	233.5	189.7	20	62.8-239.5	181.38	41.05
Chlorophyll-a	47.9	48,9	31.4	41	-	31.4-47.9	42.3	4.035
Nitrate (mg/L)	0.0193	0.0395	0.0295	0.0241	0.008	0.0193-0.0395	0.0281	0.004
Phosphate (mg/L)	0.0102	0.0201	0.0133	0.0142	0.015	0.0102-0.0201	0.0145	0.002

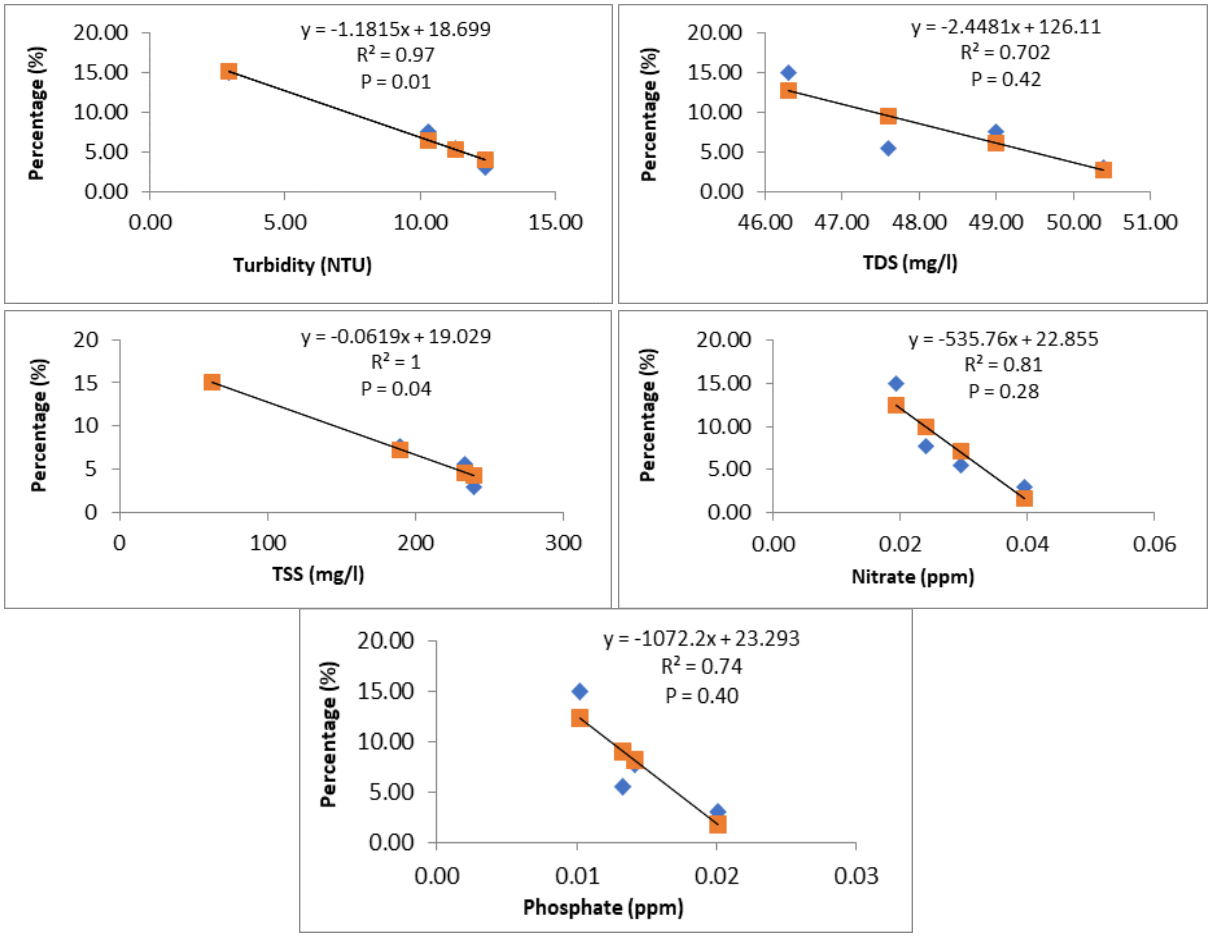

Figure 8. Graph of linear regression of the relationship between environmental parameters (turbidity, TDS, TSS, nitrate and phosphate) and percentage of live coral cover

In this study, it can be concluded that hard coral cover in 4 (four) research locations is in the poor category because it is 0-24.9%. The diversity of coral species in the waters of Kayangan Island, Gusung Tallang, and Lae-Lae Island is in the medium category. In contrast, the diversity in the waters of Samalona Island is high because it has more coral species found than other areas. Based on the results of PCA analysis, Chlorophyll and pH are characteristic of high Samalona Island, nitrate and phosphate are characteristic of low Kayangan Island, conductivity, turbidity, TDS and TSS are characteristic of low Gusung Tallang, and Temperature and Salinity are characteristic of high Lae-Lae Island. For the results of linear regression analysis, it can be concluded that environmental parameters such as turbidity (R^2=0.97), TDS (R^2=0.702), TSS (R^2=1), nitrate (R^2=0.81), and phosphate (R^2=0.74), so it can be concluded that the higher the content in the water, the more coral cover decreases. However, when viewed from the ANOVA table on regression analysis states that environmental parameters, namely turbidity and TSS, have a significant effect on coral cover. So, it is necessary to conduct further research or experiments to see the types of hard corals that can live in turbid waters, especially in Gusung Tallang waters, by transplanting corals.

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