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Community structure and diversity of coral reefs in Tapanuli Tengah marine protected area, Indonesia

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ABSTRACT

Coral reefs are essential ecosystems, providing ecological and socioeconomic benefits globally, including habitat for marine life, coastal protection, and support for fisheries and tourism. However, these reefs face significant threats due to overfishing, destructive fishing practices, pollution, sedimentation, and the effects of climate change. In response to these threats, the establishment of marine protected areas (MPAs), particularly no-take zones, has become a key strategy to conserve biodiversity and support reef recovery. This study evaluates the coral reef community structure within a no-take zone of the Tapanuli Tengah marine protected area, located in north Sumatra, Indonesia. Through underwater photo transects, the study assessed coral coverage, diversity, and spatial variation across three sites within the protected area. The results indicate significant differences in coral community composition and condition between sites, with Site 3 showing the highest diversity but lower coral cover, potentially due to environmental stressors. In contrast, Site 2 exhibited lower diversity and higher dominance by specific genera, suggesting the presence of ecological stress or degradation. These findings underscore the importance of understanding community structure within MPAs for effective conservation management and highlight the varying levels of ecological health across different reef sites. The research provides the first detailed assessment of coral community structure within the no-take zone of the Tapanuli Tengah marine protected area. Unlike previous studies, which primarily focused on fish populations or general coral biodiversity in the region, this study presents spatial variations in coral coverage, diversity, and community composition across different sites within the MPA. These findings offer new insights into the spatial heterogeneity of coral ecosystems in protected areas, an aspect that has been underexplored in this context.

Keywords: biodiversity indices, coral genera, no-take zone, reef resilience.

INTRODUCTION

Coral reefs are among the most biologically diverse and productive ecosystems on Earth, providing essential ecological functions and socioeconomic benefits to millions of coastal communities (Hughes et al., 2017; Kaiser et al., 2020). They serve as critical habitats for reef-associated fishes and invertebrates, contribute to fisheries production, protect coastlines from wave energy, and support tourism and cultural values (Woodhead et al., 2019). However, coral reef ecosystems are increasingly threatened by a combination of local and global stressors, including overfishing, destructive fishing practices, sedimentation, pollution, and the impacts of climate change, such as coral bleaching and ocean acidification (Edwards et al., 2024). These pressures have led to widespread degradation of reef structure and a decline in biodiversity, which in turn undermines ecosystem resilience and the services reefs provide. In response to these threats, the establishment of marine protected areas (MPAs) has emerged as a crucial management strategy to conserve biodiversity and promote the recovery of degraded reef ecosystems.

The community structure of coral reefs refers to the composition, abundance, and diversity of the species that play a key role in determining ecosystem health and resilience. This structure is influenced by both biotic factors, such as species interactions, and abiotic factors, including environmental conditions like temperature, salinity, and water quality (Abrar et al., 2024). Coral reefs in no-take zones often exhibit higher species richness, increased coral cover, and improved reef health compared to adjacent fished areas, although these benefits can vary depending on the size, age, and management of the MPA (Bonaldo et al., 2017).

Coral reefs in marine protected areas, especially in no-take zones, have been subject to various studies, but most have focused on fish populations or general biodiversity (Hernández-Andreu et al., 2024; Mellin et al., 2016). Despite this, there has been limited research assessing the spatial variability of coral community structure, diversity, and the ecological health of reefs within these protected zones. A specific knowledge gap exists in understanding how environmental gradients such as temperature, salinity, and water quality influence the distribution of coral communities and their resilience in MPA contexts (Hieu et al., 2025).

This study aims to fill this gap by providing a comprehensive analysis of coral community composition, coral cover, and biodiversity indices across different sites within the Tapanuli Tengah marine protected area. By focusing on the no-take zones, this study examines how the protection of these areas influences coral diversity and community structure, offering insights into the potential for recovery and conservation in similar ecosystems. The research specifically investigates whether no-take zones lead to higher coral diversity and improved coral health compared to more disturbed or fished sites (Edwards et al., 2024; Bonaldo et al., 2017).

MATERIALS AND METHODS

Study area

This study was conducted in the no-take zone of the Tapanuli Tengah MPA, located in north Sumatra, Indonesia. The MPA is ecologically significant due to its diverse coral reef ecosystems, which support a variety of marine species. Coral community observations and the collection of physicochemical water parameters were carried out in May 2024. The observations were made at three dive stations: ST1 (98°32’27.625” E; 1°39’25.07” N), ST2 (98°35’1.516” E; 1°39’56.523” N), and ST3 (98°29’31.269” E; 1°41’38.742” N), as shown in Figure 1. The sites were chosen to represent a range of coral reef conditions in the no-take zone, as they are protected from the threat of damage, thus enabling a comprehensive assessment of the ecological health of the Tapanuli Tengah MPA.

Data collection

Coral reef

In recent decades, advances in underwater survey techniques have provided new opportunities for assessing coral reef community structure with higher accuracy and reproducibility. One method that has gained increasing application is the underwater photo transect (UPT), in which standardized photographs are taken along fixed transects to capture benthic composition and reef-associated organisms (Adji et al., 2016). Data collection was conducted by deploying a 50-meter transect tape along the seafloor at each observation station. Substrate photos were systematically taken using an underwater camera (Canon EOS 4000D) with the assistance of a metal frame measuring 58 × 44 cm, placed every one meter along the transect. Photographs were alternately taken on the left and right sides of the transect (odd meters on the left, even meters on the right) to ensure spatial representation across the entire transect. The distance between the camera and the substrate was maintained at approximately 60 cm, with the camera positioned at a right angle to the substrate to avoid perspective distortion, as outlined by Giyanto (2013). An illustration of the underwater photo transect method can be seen in Figure 2a.

Environmental parameters

To assess the potential impacts of environmental factors on coral health, a series of in situ measurements was conducted at each of the three study sites. These parameters included salinity, temperature, dissolved oxygen (DO), pH, and water transparency, as these factors are known to influence coral growth and resilience (Guan et al., 2015). Salinity was measured using a refractometer. The temperature was recorded with a calibrated thermometer. DO was measured with a DO probe. pH was measured with a handheld pH meter. Finally, water transparency was assessed using a Secchi disk, which provides an estimate of water clarity by recording the maximum depth at which the disk remains visible. All water quality measurements were performed on board the ship, and the results were recorded manually on paper (Figure 2b) to ensure accuracy in field conditions. To minimize diurnal

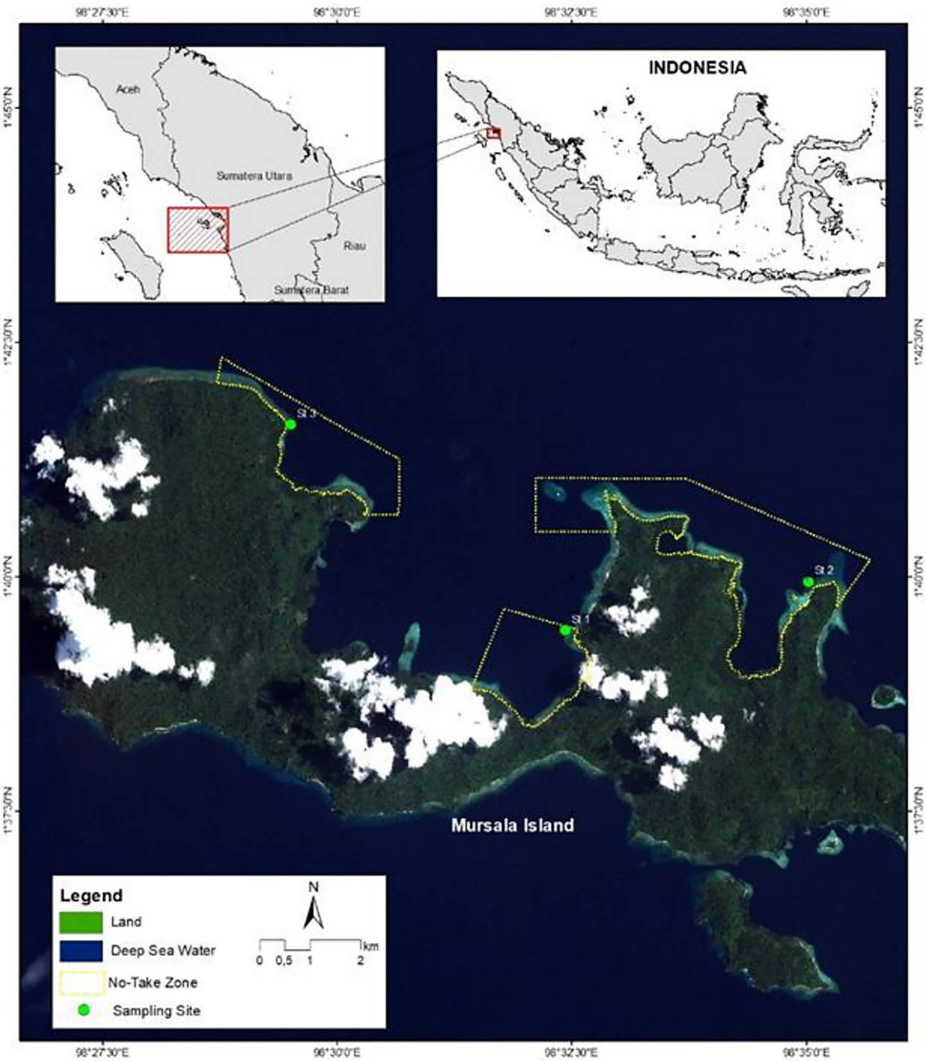


Figure 1. Sampling site of the coral reef and water quality in NTZ, Tapanuli Tengah MPA

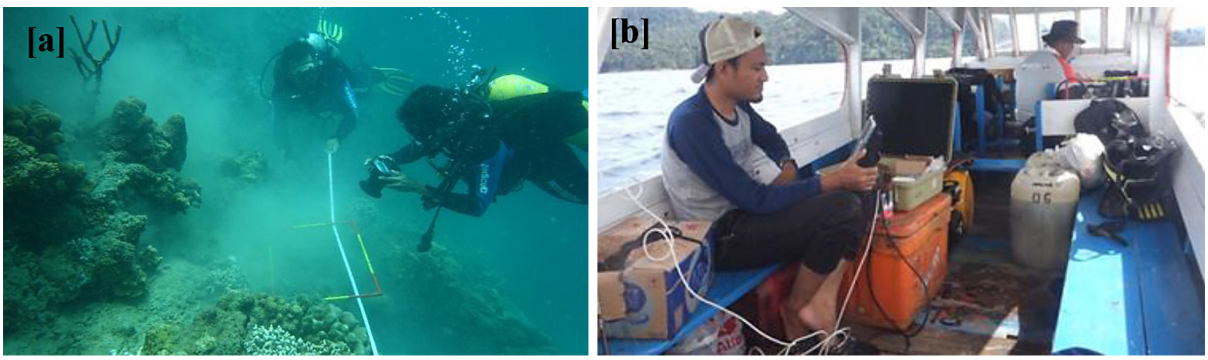


Figure 2. Sampling method: (a) underwater photos transect (UPT), (b) water quality

fluctuations, these water quality measurements were taken during daylight hours. In addition to the real-time measurements, water samples were also collected at each site for further analysis in the laboratory. This additional step helped confirm the accuracy of the field measurements and provided a more detailed understanding of the water quality at each sampling site.

Data analysis

The photographic documentation obtained from observations using the UPT method was analyzed using the coral point count with excel extensions (CPCe) software, employing a random point count approach with 30 to 100 points per photo. Each point was classified into substrate categories. The substrate cover percentage was calculated based on the proportion of points assigned to each category relative to the total number of points. Coral cover analysis was conducted to assess the status of coral reef coverage based on live coral extent (Giyanto et al., 2023)

$$N_i = \frac{L_i}{N} \times 100\% \tag{1}$$

where: N_i – percent cover (%); L_i – total length of category; N – Length of transect.

The average live coral cover per station was calculated from the percentage values of each photo, which were then used to determine the ecological status of the coral reef.

The coral condition was indicated by the percentage of live corals (Madduppa and Zamani, 2014). This was categorized as excellent (100–75% live coral), good (74.9–50% live coral), fair (49.9–25% live coral), and poor (< 24.9% live coral).

Biodiversity indices

Shannon-Wiener diversity index (H')

The diversity index is a method used to analyze the condition of an organism population by evaluating the number of individuals of each species within a community. The Shannon-Wiener Diversity Index formula, as described by (Rodríguez-Villalobos et al., 2014), is as follows:

$$H' = \sum_{i=1}^{n} P_i \ln P_i \tag{2}$$

where: H' is the index of species diversity and P_i is the relative abundance of species (n_i is the number of i-the species).

According to (Gress and Rosenberg, 2024), the higher the value of H', the greater the species diversity within the community. Conversely, the lower the value of H', the lower the species diversity in the community.

Evennes index (E)

The evenness index is used to describe the distribution of individuals among species within a community. If the distribution of individuals among species is more even, the value of the evenness index will be higher, indicating an increase in the balance of the ecosystem (Fedor and Zvaríková, 2019). The evenness index can be calculated using the following Evenness formula:

$$E = \frac{H'}{\ln S} \tag{3}$$

where: H' is the Shannon index of species diversity, and S is the species richness

Simpson's diversity index (D)

This index measures the probability that two randomly selected individuals from a sample will belong to the same species. It focuses more on species dominance (Krebs, 2017).

$$D = \sum_{i=1}^{S} p_i^2 \tag{4}$$

where: p_i is the proportion of individuals belonging to the species *i,* and S is the total number of species.

Bray-Curtis similarity index

The Bray-Curtis index is used to assess the degree of similarity within communities, whether it pertains to taxonomic species or individual organisms (Hardersen and La Porta, 2023). The results of the Bray-Curtis index calculation range between 1 and 0, and the visualization is typically represented by a dendrogram. A lower value closer to 0 indicates that the two locations have low or even no similarity in composition, whereas a value closer to 1 indicates a higher similarity. The formula for the Bray-Curtis similarity index, as described in (Rodríguez-Villalobos et al., 2014), is as follows:

$$B = \frac{\sum_{i=1}^{n}\left|X_{ij} - X_{ik}\right|}{\sum_{i}^{n}\left|X_{ij} + X_{ik}\right|} \tag{5}$$

RESULT AND DISCUSSION

Physicochemical parameters

The environmental parameters provided in Table 1 are directly related to the health and sustainability of coral reef ecosystems, as these parameters influence various physiological processes in coral species and other marine organisms. Salinity, temperature, DO, pH, and water transparency all play crucial roles in determining coral reef health, and changes in these factors can lead to coral stress, bleaching, or even death.

Salinity is a critical factor for coral survival, with fluctuations outside the normal range potentially leading to coral bleaching or death (Patthanasiri et al., 2022). Corals generally thrive in waters with stable salinity levels, as large variations can affect coral calcification and reproductive success (Vega Thurber et al., 2014). The uniform salinity value of 29 ppm across all sites in the Tapanuli Tengah marine protected area suggests stable conditions favourable for coral growth.

Temperature is another vital factor for coral health, with even minor increases leading to coral bleaching, where corals expel the symbiotic algae (zooxanthellae) responsible for their vibrant colors and energy production (Berkelmans and Oliver, 1999). As seen in the table, Site 2 has a temperature of 31.31 °C, which is on the higher end of the typical temperature range for coral reefs. Prolonged exposure to elevated temperatures has been linked to coral bleaching events (Hughes et al., 2017), suggesting that elevated temperatures could pose a threat to coral health in this area.

Dissolved oxygen (DO) is essential for the respiration of marine organisms, including corals, which rely on oxygen for metabolic processes. Low DO levels can stress corals, reducing their ability to feed and respire effectively. The DO levels at all three sites (ranging from 7.5 to 8.1 mg/l) are within acceptable ranges for healthy coral ecosystems. Adequate DO concentrations promote coral growth and reproduction, while hypoxic conditions can lead to coral mortality (McLeod et al., 2011).

The pH of seawater influences coral calcification, with ocean acidification (lowering pH) negatively affecting the ability of corals to build their calcium carbonate skeletons (Albright et al., 2013). The pH values in the Tapanuli Tengah marine protected area, ranging from 8 to 8.3, are within the optimal range for coral health, suggesting minimal risk from acidification in this area.

Water transparency is another important environmental factor affecting coral reef health. Clear water allows more sunlight to penetrate, enabling photosynthesis by the symbiotic algae within corals. Low water transparency due to increased suspended particles or pollution can limit light availability and reduce coral growth (Kojis and Quinn, 2001). The high transparency values (10 m and above) recorded in the table suggest favourable conditions for coral photosynthesis and overall reef health.

Scleractinian coral genera

Quantitative data on the average percentage cover of scleractinian coral genera observed in the no-take zone of the Tapanuli Tengah marine protected area (Table 2), based on surveys conducted across three sampling stations: ST1, ST2, and ST3. Among the genera recorded, *Acropora* sp. (family: Acroporidae) was the most prominent and was found consistently across all three sampling sites. It percent cover varied notably, ranging from 4.54% at ST02 to 15.56% at ST03, with a moderate 10.84% at ST01. The overall mean cover was 10.31%, with a standard deviation of 4.52%, indicating spatial variability in its distribution. Given that *Acropora* is a fast-growing, reef-building genus commonly associated with healthy and structurally complex reef systems, its relatively high and widespread presence suggests favorable reef conditions in parts

Table 1. Environmental parameters of Tapanuli Tengah marine protected area

Site	X	Y	Salinity (ppm)	Temperature (°C)	DO (mg/l)	pH	Transparency (m)
ST 1	98.54062	1.6571	29	30	8.1	8.3	10
ST 2	98.58382	1.665733	29	31.31	7.8	8.1	8.4
ST 3	98.49183	1.69365	25	29	7.5	8	12.2

Table 2. Average percentage of scleractinian coral genera in the no-take zone of Tapanuli Tengah MPA

No	Family	Genus	ST01	ST02	ST03	Mean±SD
1	Acroporidae	*Acropora* sp.	10.84	4.54	15.56	10.31±4.52
2	Poritidae	*Alveopora* sp.	8.05			8.05±0.00
3	Acroporidae	*Astreopora* sp.	0.41	0.19	2.00	0.87±081
4	Faviidae	*Caulastrea* sp.			0.15	0.15±0.00
5	Faviidae	*Coeloseris* sp.		0.39	0.62	0.50±0.12
6	Faviidae	*Coscinaraea* sp.	2.89	0.87	1.69	1.82±0.83
7	Fungiidae	*Ctenactis* sp.	0.31		0.46	0.39±0.08
8	Fungiidae	*Cycloseris* sp.		0.10		0.10±0.00
9	Faviidae	*Cyphastrea* sp.	0.83	1.54	0.62	1.00±0.40
10	Faviidae	*Echinophyllia* sp.	0.72	1.35	0.15	0.74±0.49
11	Faviidae	*Echinopora* sp.	3.72			3.72±0.00
12	Euphyllidae	*Euphyllia* sp.		0.10	1.08	0.59±0.49
13	Faviidae	*Favia* sp.	3.82	0.10	2.47	2.13±1.54
14	Faviidae	*Favites* sp.	1.34	1.54	2.47	1.78±0.49
15	Fungiidae	*Fungia* sp.	1.14	0.68	1.23	1.01±0.24
16	Oculinidae	*Galaxea* sp.		0.77	3.39	2.08±1.31
17	Gardidae	*Gardineroseris* sp.	2.79	1.16	6.01	3.32±2.02
18	Goniidae	*Goniastrea* sp.	0.21	0.19		0.20±0.01
19	Haloidae	*Halomitra* sp.		0.19		0.19±0.00
20	Merulinidae	*Hydnophora* sp.	0.62		1.85	1.23±0.61
21	Isopidae	*Isopora* sp.	0.21	4.05	3.54	2.60±1.71
22	Fungiidae	*Leptoria* sp.		0.77		0.77±0.00
23	Agarciidae	*Leptoseris* sp.			0.77	0.77±0.00
24	Mussidae	*Lobophyllia* sp.	0.41		0.77	0.59±0.18
25	Merulinidae	*Merulina* sp.	1.24	0.58	0.92	0.91±0.27
26	Fungiidae	*Montastrea* sp.	2.58	0.87	3.85	2.43±1.22
27	Acroporidae	*Montipora* sp.	2.58	6.37	2.93	3.96±1.71
28	Faviidae	*Mycedium* sp.	0.31	0.29		0.30±0.01
29	Oculinidae	*Oulophyllia* sp.	1.55		2.31	1.93±0.38
30	Faviidae	*Pachyseris* sp.	2.58	3.67	1.08	2.44±1.06
31	Agarciidae	*Pavona* sp.		0.87	1.85	1.36±0.49
32	Pectiniidae	*Pectinia* sp.	0.62	0.29	1.23	0.71±0.39
33	Mussidae	*Physogyra* sp.		0.10		0.10±0.00
34	Pocilloporidae	*Pocillopora* sp.	0.62		0.77	0.69±0.08
35	Fungiidae	*Podabacia* sp.		0.39		0.39±0.00
36	Poritidae	*Porites* sp.	49.54	67.95	39.91	52.47±11.64
37	Pocilloporidae	*Seriatopora* sp.		0.10		0.10±0.00
38	Pocilloporidae	*Stylophora* sp.	0.10		0.31	0.21±0.10
Taxa			26	28	28	
H			2.03	1.48	2.34	
E			0.63	0.44	0.70	
D			0.27	0.47	0.20	

of the MPA (Pellitier, 2021). This is consistent with global observations where Acropora dominance is considered a positive indicator of reef resilience and biodiversity potential (Becking et al., 2024).

In contrast, *Alveopora* sp. (family: Poritidae) was only observed at ST01, where it recorded a substantial 8.05% cover. However, the absence of this genus at ST02 and ST03 suggests a more localized distribution, potentially reflecting specific habitat preferences or environmental conditions at ST01. Some species of *Alveopora* are known to thrive in deeper or more turbid environments and may be sensitive to physical disturbance (Kang et al., 2020). Similarly, *Astreopora* sp. (also Acroporidae) was found at all three sites but in much lower percentages, ranging from 0.19% at ST02 to 2.00% at ST03, with an overall mean of 0.87%. The relatively high standard deviation (0.81%) for this genus further highlights inconsistent spatial distribution, possibly due to niche microhabitats or differential stress tolerances, a pattern noted in prior studies on coral spatial heterogeneity (Kim et al., 2022).

Caulastrea sp. (family: Faviidae) had the lowest representation, appearing only at ST03 with a minimal cover of 0.15%, indicating that this genus may be rare or occur in isolated patches within the MPA. Species of this genus often prefer more sheltered or lagoonal habitats (Briton et al., 2018). It may not be well-represented across the surveyed stations. The limited spatial occurrence of some genera, along with missing data for certain stations, reflects a pattern of uneven coral distribution, likely influenced by environmental gradients such as water clarity, substrate composition, hydrodynamics, and possibly anthropogenic impacts (Adjeroud et al., 2019).

Biodiversity indices (diversity, equability, dominance)

Biodiversity indices for three sampling sites (ST1, ST2, and ST3) within the no-take zone of the Tapanuli Tengah marine protected area (Table 2), specifically focused on coral genera, provide a clear picture of the ecological health of these coral communities. At ST3, the Shannon-Wiener diversity index (H) is the highest at 2.34, suggesting the greatest diversity of coral genera among the three sites. This indicates that ST3 supports a wide variety of coral genera, likely contributing to a more stable and resilient reef ecosystem (Li et al., 2022). The high Evenness index (E = 0.70) further suggests that the genera present at ST3 are more equally distributed, meaning no single genus is overwhelmingly dominant. This is reflected in the low Dominance index (D = 0.20), indicating that the coral community at ST3 is not dominated by a few genera. Instead, the reef at ST3 likely hosts a balanced community with a greater number of genera contributing to the overall coral cover, aligning with healthy and ecologically complex reef systems (Donovan et al., 2018).

ST1 has a Shannon-Wiener diversity index of 2.03, indicating moderate diversity of coral genera. The Evenness index at 0.63 suggests a relatively balanced distribution of genera, though not as even as at ST3. The Dominance index (D = 0.27) is also moderate, implying that a few genera may be slightly more dominant, but the community remains relatively balanced. In this site, genera such as *Acropora* may be more abundant, but there is still a diversity of other genera contributing to the coral community.

In contrast, ST2 shows the lowest values across the indices. The Shannon-Wiener index at 1.48 reflects a less diverse community of coral genera, suggesting that fewer genera are present or that certain genera are not as abundant. The Evenness index of 0.44 indicates that the genera at ST2 are unevenly distributed, with one or a few genera likely outcompeting others. This could be due to environmental stressors that favor specific, more resilient genera over others. The Dominance index (D = 0.47) is the highest at ST2, which suggests that one or a few coral genera dominate the site, possibly due to disturbances or unfavorable conditions for other genera (Zuhry et al., 2021). The dominance of certain genera at ST2 might point to a shift in community composition, potentially indicating degraded reef health or environmental pressures that limit the survival of more diverse coral genera.

The biodiversity indices highlight that ST3 supports a diverse, well-distributed, and balanced community of coral genera, indicative of a healthier and more resilient reef (Bellwood et al., 2004). ST1 is moderately diverse but still maintains a balanced mix of genera, while ST2 shows signs of stress with low diversity, high dominance, and uneven distribution of coral genera. These findings suggest that the reef at ST3 is in the best ecological condition, while ST2 may require further investigation and management to address the possible causes of reduced coral diversity and increased dominance of certain genera (Edinger et al., 2000).

Coral condition

The coral condition in the no-take zone of Tapanuli Tengah MPA varies between sites, with ST2 exhibiting the healthiest coral community, followed by ST1, which also maintains relatively good conditions. ST3 (Table 4). However, shows signs of significant stress, with lower live coral cover and higher levels of dead coral and abiotic coverage.

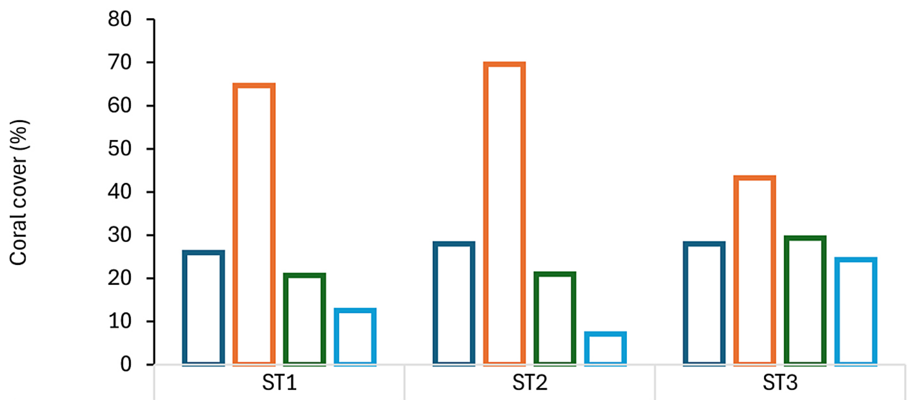
At ST1, 64.64% of the coral cover consisted of live coral, indicating a relatively healthy coral community. The percentage of dead coral at this site was 20.68%, which suggests moderate coral mortality, but not to an extent that would significantly threaten the coral ecosystem. The abiotic factors (e.g., rubble, sand) covered 12.54% of the benthic habitat, which is relatively low, allowing ample space for coral growth. The coral condition at ST1 was rated as ”good,” reflecting the balanced proportions of live and dead coral. This site appears to support a relatively stable coral community, with moderate stress from coral mortality but a strong presence of live coral. The coral condition at ST2 was also rated as ”good,” with the combination of high live coral cover and low abiotic factors contributing to a thriving reef ecosystem. It demonstrates optimal coral conditions, suggesting minimal anthropogenic disturbance and suitable environmental conditions for coral survival.

Conversely, ST3 showed a marked decline in coral health. Only 43.3% of the coral cover at this site was live coral, the lowest among the sites, indicating substantial degradation of the coral community. Dead coral covered 29.35% of the area, which is the highest of all sites, highlighting significant coral mortality. The proportion of abiotic factors was also notably higher at 24.35%, suggesting that a considerable portion of the habitat is not conducive to coral growth. As a result, the coral condition at ST3 was rated as ”fair,” indicating a stressed reef ecosystem. The low percentage of live coral, high dead coral cover, and substantial abiotic habitat reflect the compromised state of the coral community at this site, possibly due to environmental stressors such as water quality, sedimentation, or other anthropogenic impacts (Figure 3) (Saiz-M et al., 2024).

The high biodiversity observed in ST3 (Table3) reflects the presence of many coral genera, but the low coral cover (Figure 3) suggests that these genera are either sparsely distributed or subject to environmental stressors that prevent them from forming large, dense colonies. This discrepancy can be attributed to factors such as environmental disturbances, competition, or abiotic conditions that limit coral growth, despite the availability of ecological niches for a diverse range of genera. The findings highlight that coral diversity and coral cover are distinct ecological aspects and that a diverse community does not necessarily indicate a healthy or thriving reef. Biodiversity does not necessarily

Table 3. Biodiversity indices of coral genera

Parameter	ST1	ST2	ST3
Taxa	26	28	28
H	2.03	1.48	2.34
E	0.63	0.44	0.47
D	0.27	0.47	0.20



	ST1	ST2	ST3
Genera	26	28	28
Live coral	64,64	69,56	43,3
Dead coral	20,68	20,96	29,35
Abiotics	12,54	7,08	24,35

Figure 3. Benthic habitat, coral condition, and the number of genera in NTZ, Tapanuli Tengah MPA

correlate directly with the cover of live coral; it only reflects the presence and distribution of different genera, which could be sparse or fragmented across the site (Oh et al., 2024; Richards and Hobbs, 2014).

Bray-curtis similarity index

The dendrogram presented (Figure 4) illustrates the results of hierarchical clustering analysis based on the Bray-Curtis similarity index, which was used to assess the compositional similarity of coral cover percentage across three sites (ST1, ST2, and ST3). The Bray-Curtis index quantifies the similarity between two sites, with values ranging from 0 (completely dissimilar) to 1 (completely similar). The dendrogram reveals that sites ST1 and ST2 exhibit a high degree of similarity in their coral cover percentages, as evidenced by the merging of their branches at a similarity value of approximately 0.92. In contrast, site ST3 is more distantly related, with its branch merging with ST1 and ST2 only at a lower similarity level of around 0.77. This indicates that ST3 has a distinct coral cover profile compared to the other two sites. The clustering pattern underscores the significant differences between ST3 and the other sites, highlighting the variability in coral cover among the sampled sites.

The dendrogram (Figure 5) shown represents the hierarchical clustering of coral genera composition across three sampling sites. This index measures the degree of similarity between sites based on species composition and abundance, ranging from 0 (no similarity) to 1 (complete similarity). In this analysis, sites ST1 and ST3 cluster together first at a similarity level of approximately 0.72, indicating that they share relatively similar coral genera compositions. In contrast, site ST2 is more distinct and joins the ST1-ST3 cluster at a lower similarity level of around 0.67. This suggests that ST2 has the most divergent coral genus composition among the three sites.

The clustering pattern highlights a closer taxonomic resemblance between ST1 and ST3 in terms of coral genera, while ST2 exhibits greater ecological or compositional differences from the other two. These results may reflect localized environmental conditions, disturbance levels, or habitat heterogeneity influencing coral community structure at the respective sites. This is

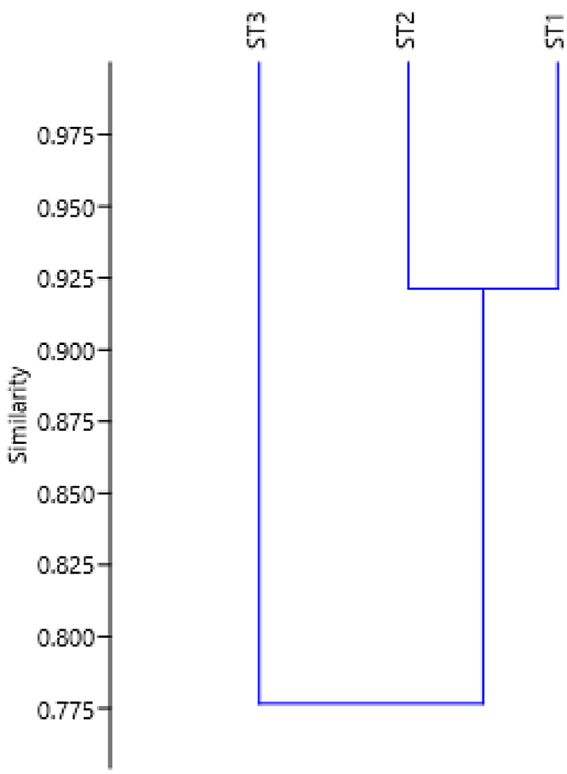


Figure 4. Dendrogram of similarity index based on the lifeform coral cover

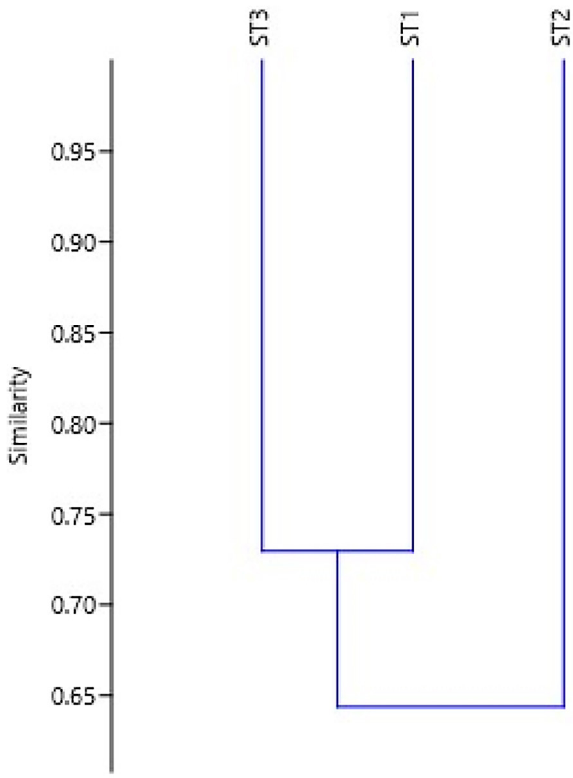


Figure 5. Dendrogram of similarity index based on coral reef genera

consistent with the findings of (Chen et al., 2020), which demonstrate that local environmental factors, disturbances, and habitat heterogeneity significantly influence the structure of coral reef communities in diverse ways.

CONCLUSIONS

This study aimed to assess the coral community structure, diversity, and ecological health within the no-take zones of the Tapanuli Tengah MPA and evaluate the effectiveness of these zones in conserving coral biodiversity. The findings indicate that ST3, although displaying the highest coral diversity, showed lower coral cover, suggesting the presence of environmental stressors. Site 2 demonstrated lower diversity and higher dominance by certain genera, which may indicate ecological stress or degradation. Site one (ST1), on the other hand, maintained a relatively balanced and healthy coral community.

The biodiversity indices, particularly the Shannon-Wiener diversity index, suggest that no-take zones can provide favorable conditions for coral diversity, especially at Site 3, where species richness was high. The study highlights that while no-take zones play an essential role in conserving coral biodiversity, their effectiveness in promoting coral health varies based on local environmental factors. These findings support the need for continued monitoring and adaptive management strategies to enhance coral reef resilience and ensure the success of MPA conservation efforts. Therefore, the study contributes valuable insights into the role of no-take zones in coral reef conservation, emphasizing their potential for preserving biodiversity and ecosystem function in protected areas.

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