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Distribution of Coral Cover and Benthic Substrate Composition in the GITA NADA Marine Protected Area, West Lombok

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ABSTRACT: Coral reefs in Indonesia are under increasing pressure from natural and anthropogenic disturbances, requiring detailed spatial assessments to support effective management. This study assessed coral cover condition and benthic substrate composition across management zones of the Gili Tangkong-Gili Nanggu-Gili Sudak (GITA NADA) Marine Protected Area (MPA), West Lombok, Indonesia. We conducted surveys from October 2023 to August 2024 across 46 stations using the Underwater Photo Transect (UPT) method. Sampling occurred in two depth categories: 44 shallow surveys at 3-5 m and 39 deep surveys at 8-10 m, as not all stations included both depth zones. We analyzed benthic photographs using CPCe software to quantify coral cover and substrate categories. Mean coral cover at 3-5 m depth was 32.57% ± 20.57%, classified as fair, whereas coral cover at 8-10 m depth averaged 17.51% ± 11.90%, indicating poor reef condition. Kruskal-Wallis analysis showed a significant difference in coral cover between depths ($P < 0.05$), with shallow reefs supporting higher coral cover than deeper reefs. At shallow depths, coral cover in the Fisheries, Utilization, and Other-use Zones was generally fair, while the Core Zone was classified as poor. In contrast, coral cover at 8-10 m depth was predominantly poor across all zones. Kruskal-Wallis analysis showed no significant difference in coral cover among management zones at either depth ($P > 0.05$). Substrate composition at 3-5 m depth was dominated by hard coral and rubble, whereas deeper reefs were characterized by high proportions of rubble and silt, reflecting habitat degradation and limited reef resilience. This study represents one of the first comprehensive UPT-based assessments of coral cover and benthic substrate composition across management zones within the GITA NADA MPA. These results indicate widespread coral reef degradation in the GITA NADA MPA, particularly at deeper depths, highlighting the need to re-evaluate zoning effectiveness, strengthen enforcement, and implement targeted reef restoration and sediment management strategies.

Keywords: coral cover; GITA NADA MPA; underwater photo transect

INTRODUCTION

Coral reefs are among the most important marine ecosystems, providing essential ecological, physical, and economic functions. Ecologically, coral reef ecosystems support high levels of marine biodiversity by providing shelter, nursery grounds, and feeding habitats for numerous marine organisms (Singh, 2023). Physically, coral reefs function as natural coastal barriers that dissipate wave energy, thereby reducing coastal abrasion and shoreline erosion (Bitterwolf *et al*., 2024). Economically, coral reefs contribute significantly to fisheries productivity and marine tourism, which represent major livelihood sources for many coastal communities (Witomo *et al*., 2020; Siregar *et al*., 2023).

Despite their ecological and economic importance, coral reef ecosystems in Indonesia have

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experienced significant degradation in recent decades due to a combination of natural and anthropogenic drivers. Natural stressors include global warming, ocean acidification, and extreme climatic events such as storms, which can lead to coral bleaching and physical reef damage (Wahyuningsi *et al*., 2025). In addition, anthropogenic pressures, including destructive fishing practices, coastal pollution, and unsustainable coastal development, have further accelerated coral reef degradation in many Indonesian coastal regions (Ramadhan & Yuliana, 2025).

The establishment of marine protected areas (MPAs) has been widely recognized as an effective management strategy for conserving marine biodiversity and supporting the long-term sustainability of coastal ecosystems. In Indonesia, the government has actively expanded its marine conservation network as part of its commitment to sustainable ocean management. One such conservation area is the Gili Tangkong-Gili Nanggu-Gili Sudak Marine Protected Area (GITA NADA), which was officially designated through Decree No. 93/KEPMEN-KP/2018 by the Ministry of Marine Affairs and Fisheries of the Republic of Indonesia (Ministry of Marine Affairs and Fisheries of the Republic of Indonesia, 2018). Located in West Lombok Regency, West Nusa Tenggara Province, the GITA NADA Marine Tourism Park covers approximately 1,279 ha of coral reef habitat (Witomo *et al*., 2020). The total economic value of its coral reef ecosystem is estimated to reach IDR 147.98 billion per year (Hilyana *et al*. 2021). However, despite its ecological and economic importance, recent studies have documented continued coral reef degradation within the GITA NADA MPA, emphasizing the need for improved monitoring and management strategies (Nurdjaman *et al*. 2023).

Previous studies assessing coral reef conditions in the GITA NADA MPA have primarily used the Point Intercept Transect (PIT) and Line Intercept Transect (LIT) methods and have generally reported coral cover ranging from poor to fair conditions. For instance, coral cover using the LIT method in Gili Gede was categorised as poor, with a mean value of 21.92% (Buhari *et al*., 2021a). Similarly, low to fair coral cover, ranging from 9.2% to 26.2%, has been reported in Gili Asahan, Gili Layar, and Gili Gede (Littaqwa & Side, 2022). Candri *et al*. 2019, reported that coral cover using the PIT method in Gili Tangkong was 46%, indicating fair condition.

Although these studies provided important baseline information on coral reef condition, they were generally limited to estimating coral cover and did not comprehensively assess spatial patterns of benthic community composition across depth gradients and management zones. The Underwater Photo Transect (UPT) method offers several advantages over conventional field-based approaches, including permanent photographic records, reduced observer bias, improved data verification, and the ability to conduct detailed post-survey analyses of benthic substrates. In addition to estimating coral cover, UPT enables quantification of a wide range of substrate components, including hard corals, soft corals, algae, rubble, sand, and silt, thereby providing a more comprehensive ecological assessment of reef condition (Adji *et al*., 2016). Furthermore, the photographic datasets generated through UPT facilitate comparisons across locations and depths, making the method particularly suitable for large-scale reef assessments.

To date, no comprehensive coral reef assessment using the UPT method has been conducted within the GITA NADA MPA. Therefore, this study aims to evaluate spatial variations in coral cover and benthic substrate composition across different depth strata and management zones within the GITA NADA MPA, West Lombok. The results of this study are expected to provide updated baseline information to support coral reef monitoring and contribute to the development of more effective conservation and management strategies in the area.

MATERIAL AND METHODS

This study was conducted from October 2023 to August 2024 to assess live coral cover and benthic substrate composition, including both living and non-living components. Surveys were conducted across 46 observation stations at two depth categories: shallow (3-5 m) and deep (8-10 m). A total of 44 stations were surveyed at shallow depth and 39 stations at deep depth, as some stations contained only one suitable depth zone for assessment. The spatial distribution of survey stations is shown in Figure 1, while detailed station information by management zone and depth is provided in the Supplementary Material (Table 1).

Journal of Marine Research Vol 15, No. 3 Agustus 2026, pp. 576-590

Table 1. Distribution of observation stations by management zone and depth

Zonation	Number of Stations	Station Codes	Depth Category
Core Zone (CZ)	4	ST 24, ST 25, ST 26, ST 39	3-5 m; 8-10 m
Utilization Zone (UZ)	28	ST 2, ST 9-12, ST 14-23, ST 30-34, ST 36, ST 40-45	3-5 m; 8-10 m
Fisheries Zone (FZ)	10	ST 4-6, ST 8, ST 13, ST 27, ST 29, ST 35, ST 37, ST 46	3-5 m; 8-10 m
Other-use Zone (OZ)	4	ST 1, ST 7, ST 28, ST 38	3-5 m; 8-10 m
Depth-specific exceptions	-	ST 15, ST 30, ST 31, ST 43, ST 44 (3-5 m only); ST 25, ST 27 (8-10 m only)	As indicated

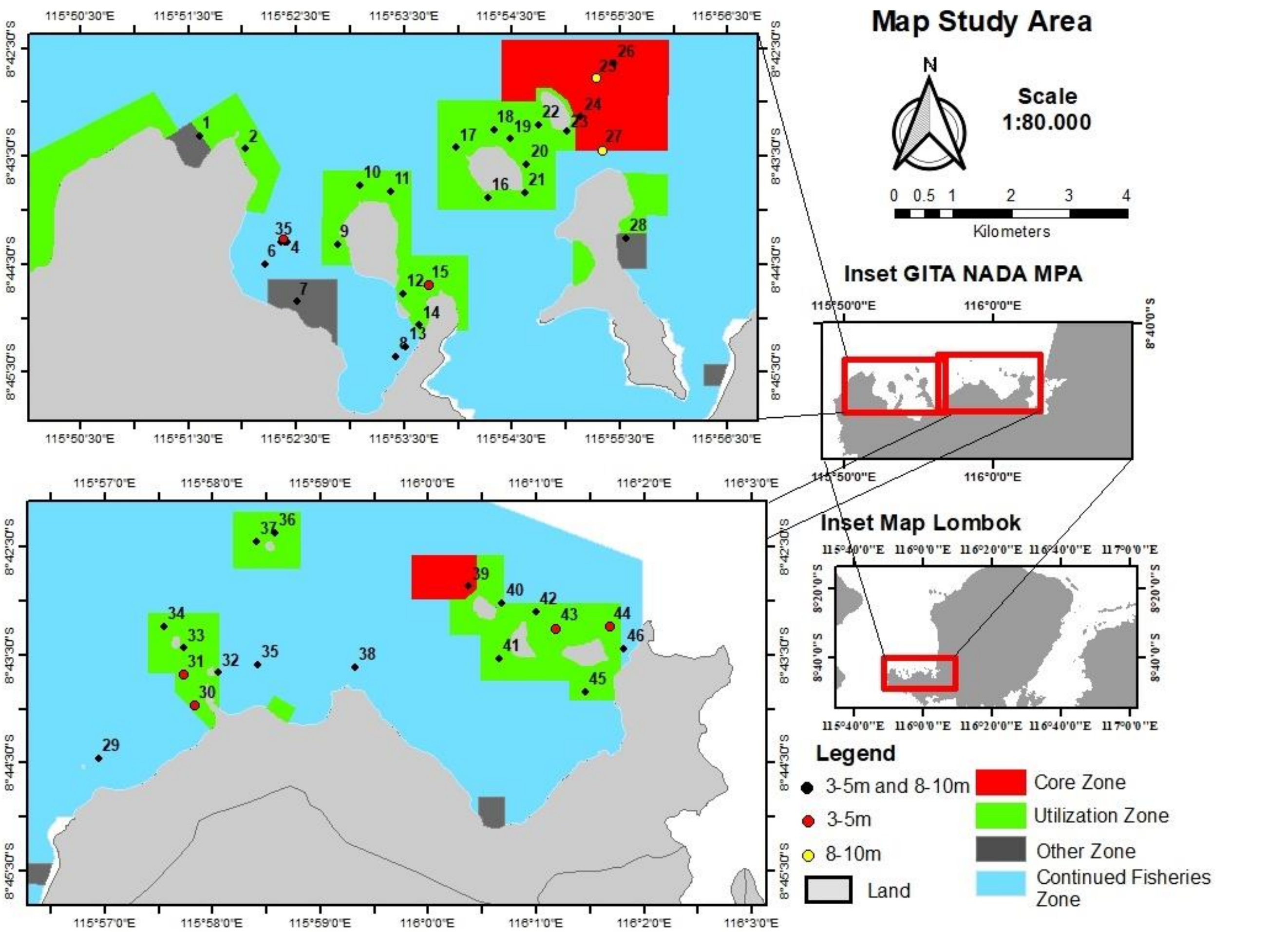

Figure 1. Map of Study Location GITA NADA MPA

Coral reef observations were conducted using the Underwater Photo Transect (UPT) method. This method involves using an underwater camera to photograph benthic conditions along a defined transect. Data collection was carried out by SCUBA diving at two depth categories: shallow waters (3-5 m) and deeper waters (8-10 m), with transects aligned parallel to the coastline.

A 150 m survey transect was established at each site, consisting of three 50 m transects separated by 5 m intervals. The transects were positioned parallel to the shoreline following the protocol described by (Giyanto *et al*., 2017a). A PVC quadrat frame measuring 58 cm × 44 cm (2,552 cm^2) was used for photographic sampling. The frame was placed at 1 m intervals along each transect. Odd-numbered frames (1, 3, 5, 7, …, 49) were positioned on the left side of the transect line (Figure 2a), while even-numbered frames (2, 4, 6, 8, …, 50) were positioned on the right side (Figure 2b).

Figure 3 illustrated the underwater photo transect setup. An Olympus TG-6 underwater camera was used to photograph each quadrat vertically from a consistent height above the substrate, ensuring complete coverage of the quadrat area and standardization of image quality among sites. A total of 50 photographs were collected along each 50 m transect, resulting in 150 photographs per site for each depth category.

Photographs obtained from each underwater survey were subsequently analyzed using CPCe (Coral Point Count with Excel Extension) software. CPCe facilitates the analysis of benthic component cover using a random point analysis method applied to quadrat photographs (Kohler & Gill 2006). The software automatically overlays 30 randomly distributed points within each image frame. To minimize observer bias during substrate classification, all image analyses were conducted using standardized CPCe procedures, following the substrate classification references of English et al. (1997) and Giyanto *et al*. (2017a). Point classifications were performed by trained observers using consistent identification criteria throughout the analysis process. Living and non-living substrate categories are shown in Table 2. Identification results from all points and transects were averaged to calculate the percentage cover for each substrate classification. The mean percentage values of all benthic categories were subsequently used as the basis for assessing coral reef condition. Monitoring was conducted from October 2023 to August 2024, with each survey location sampled twice at different time periods. Coral reef condition was assessed according to the categories shown in Table 3, based on Giyanto *et al*. (2017b).

Substrate identification was conducted using photographic data obtained with an Olympus TG-6 underwater camera. The images were subsequently analyzed using Coral Point Count with Excel extensions (CPCe) software, following the substrate classification guidelines described by English et al. (1997) and Giyanto *et al*. (2017a).

Substrate cover was assessed following the methodology described by (Giyanto *et al*., 2017a). The percentage cover of each substrate category was calculated using the following formula:

$$\text{Category Cover Percentage} = \frac{(The\ number\ of\ points\ in\ that\ category)}{(Total\ points)} \text{x}\ 100\%$$

Coral cover condition was classified according to the categories shown in Table 3, as proposed by Giyanto *et al*. (2017b).

Tabel 2. Code of each substrate category (English *et al*., 1997; Giyanto *et al*., 2017a)

Living substrate		Non-living substrate	
Code	Category	Code	Category
HC	Hard Coral	DC	Recently Dead Coral
SC	Soft Coral	DCA	Dead Coral with Algae
SP	Sponge	RB	Rubble
FS	Fleshy Seaweed	SD	Sand
OT	Other Biota	SI	Silt
		RC	Rock

The spatial distribution of coral cover categories in the GITA NADA MPA was visualized using distribution maps. These maps were generated using QGIS 4.0.3 software. Map development involved entering geographic coordinates and coral cover data into Microsoft Excel, followed by spatial visualization and layout preparation in QGIS 4.0.3.

Statistical analysis tested differences in coral cover between depth categories and among management zones. Differences in coral cover between depths (3-5 m and 8-10 m) and among zonation categories were analyzed using the Kruskal-Wallis test at a significance level of $p < 0.05$. The Kruskal-Wallis test was selected because the data were not normally distributed and the number of stations differed among depth and zonation categories. Statistical analyses were conducted using SPSS version 16 (Gio & Rosmaini 2016).

Table 3. Assessment categories for coral cover based on Giyanto *et al*. (2017b)

Cover (%)	Category
0-25	Poor
26-50	Fair
51-75	Good
76-100	Excellent

(a) (b)

Figure 2. Photographic sampling using the Underwater Photo Transect (UPT) method: (a) odd-numbered frame positioned on the left side of the transect line; (b) even-numbered frame positioned on the right side of the transect line (Giyanto *et al*, 2017a).

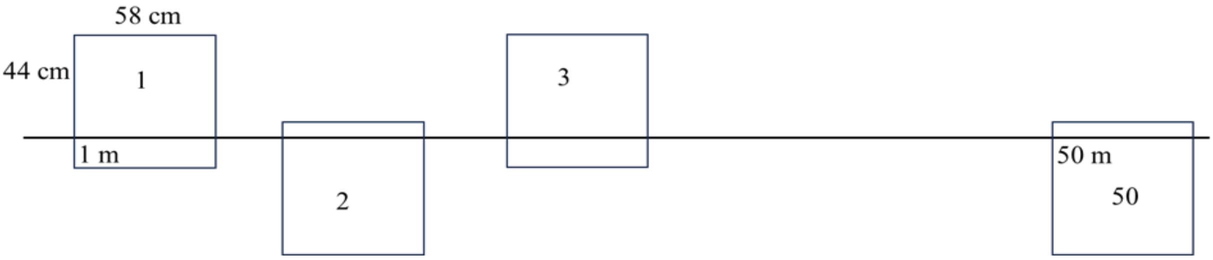

Figure 3. Illustration of the underwater photo transect data collection setup

RESULTS AND DISCUSSION

Mean coral cover across all stations at depths of 3-5 m and 8-10 m is presented in Figure 4. Coral cover at 3-5 m ranged from 0 to 74.96%, indicating conditions from poor to good. At 8-10 m, coral cover ranged from 0 to 58.55%, also indicating conditions from poor to good. Mean coral cover at 3-5 m was 32.57% ± 20.57%, which falls within the fair category, whereas mean coral cover at 8-10 m was 17.51% ± 11.90%, indicating poor overall reef condition.

Kruskal-Wallis analysis revealed a significant difference in coral cover between the two depth categories (3-5 m and 8-10 m) ($P < 0.05$), with shallow reefs supporting higher coral cover than deeper reefs. The lower coral cover observed at 8-10 m may be associated with depth-related environmental factors, particularly reduced light availability and increased sediment accumulation. Reduced light availability with increasing depth may limit the photosynthetic efficiency of symbiotic zooxanthellae, thereby constraining coral growth, calcification, and recovery processes (Tamir *et al.* 2019). In addition, deeper reef habitats may experience greater accumulation of fine sediments, which can smother consolidated substrates and reduce available coral habitat (Tuttle & Donahue, 2022). This interpretation is supported by the higher proportions of silt substrate recorded at 8-10 m stations. Isdianto *et al*. (2025), observed that areas with reduced coral cover tended to exhibit greater dominance of sand and silt substrates, indicating that elevated sedimentation may be an important factor influencing reef condition.

The highest coral cover at 3-5 m was recorded at Station 46 (74.96%), located in the eastern part of the GITA NADA MPA, indicating good condition. At 8-10 m, the highest coral cover was observed at Station 36 (58.55%) in North Gili Poh. In contrast, Station 21 exhibited no live coral cover (0%) at either depth and was dominated by sandy substrate, indicating unsuitable conditions for coral establishment and persistence. The distribution of coral cover conditions at depths of 3-5 m is presented in Figure 5. Coral cover across all stations at this depth ranged from 0 to 74.96%, indicating conditions from poor to good. The mean coral cover across the 44 survey locations was 32.57%; therefore, the overall coral cover at this depth was classified as fair. The highest coral cover was recorded at Station 46 (74.96%), indicating good coral condition. This station is located in the eastern part of the GITA NADA MPA. In contrast, Station 21 had no live coral cover (0%) and was predominantly characterized by sand substrate.

Based on the coral cover condition categories shown in Figure 5, 10 locations (22.73%) were classified as good, 15 locations (34.09%) as fair, and 19 locations (43.18%) as poor. No locations were classified as excellent (0%). Although the mean coral cover across all stations was categorized as fair, a greater proportion of individual survey locations fell within the poor category, indicating considerable spatial variation in reef condition across the study area.

This pattern likely reflects anthropogenic pressures. Fishing activities and land-based inputs have been reported as major contributing factors to the degradation of coastal ecosystem quality (Buhari *et al*., 2021a). The distribution of coral cover conditions at depths of 8-10 m is presented in Figure 6. Coral cover at this depth ranged from 0 to 58.55%, indicating conditions from poor to good. The mean coral cover across the 39 survey locations was 17.51%, indicating that the overall coral condition at this depth was classified as poor. The highest coral cover was recorded at Station 36 (58.55%), located in North Gili Poh, whereas no coral cover was observed at Station 21 (0%). Based on the coral cover condition categories shown in Figure 6, only one location (2.56%) was classified as good, five locations (12.82%) as fair, and 33 locations (84.62%) as poor. No locations were classified as excellent (0%).

These results indicate that coral cover at depths of 8–10 m in the GITA NADA MPA was predominantly in poor condition. This pattern is consistent with the depth-related interpretation described above, particularly the potential influence of reduced light availability and sediment accumulation.

Figure 7 presents coral cover based on MPA zonation at depths of 3-5 m. Coral cover in the Fisheries Zone (FZ) ranged from 4.35% to 70.30%, reflecting conditions from poor to good. Station 46 recorded the highest coral cover in the FZ and among all stations (70.30%). According to local residents, this location is considered suitable for snorkelling activities. Similar findings were reported by Durotunasha *et al*. (2023), who documented good coral cover condition in the traditional fisheries zone of Kambang Island, Karimunjawa National Park.

Coral cover in the Other-use Zone (OZ) ranged from 18.79% to 50.25%, also indicating conditions from poor to good. The highest coral cover in the OZ was observed at Station 28 (50.25%), which was classified as good. Meanwhile, coral cover in the Utilization Zone (UZ) ranged from 0.00% to 68.75%, with the highest value recorded at Station 15 (68.75%), indicating good condition. In contrast, coral cover in the Core Zone (CZ) ranged from 10.50% to 30.26%, corresponding to poor to fair conditions. The highest coral cover in the CZ was recorded at Station 39 (30.26%), which falls within the fair category.

Mean coral cover at depths of 3-5 m in the FZ, OZ, and UZ was categorized as fair, with mean values of 38.39% ± 24.36%, 37.40% ± 16.50%, and 31.24% ± 20.40%, respectively. Conversely, the CZ exhibited a mean coral cover of 20.77% ± 9.90%, which was classified as poor. These findings indicate that coral cover conditions in the FZ, OZ, and UZ were relatively better than those in the CZ.

The lower coral cover recorded in the CZ was unexpected, as core zones are intended to provide the highest level of protection. One possible explanation is that insufficient enforcement and monitoring may have limited the effectiveness of protection measures, allowing continued anthropogenic pressure or non-compliant activities to persist within the zone. This pattern is consistent with the findings of Hukom *et al*. (2019), who reported that coral reef conditions in tourism and traditional fisheries zones in Raja Ampat were relatively better than those in the core zone. Buhari *et al*. (2021b), reported that coral cover in the core zone of the Gili Matra marine conservation area, North Lombok, reached only 8%, indicating poor condition.

Kruskal-Wallis analysis showed no significant difference in coral cover among management zones at this depth (P > 0.05). Nevertheless, the comparatively poor condition of the CZ highlights the need to evaluate and revise zoning management, particularly in areas experiencing coral reef degradation. Such measures are essential to support restoration efforts aimed at improving coral reef condition.

Coral cover based on zonation at depths of 8-10 m is shown in Figure 8. Coral cover in the FZ varied between 9.54% and 41.35%, indicating poor to fair conditions. Station 46 in the FZ showed the highest coral cover, at 41.35%, which was classified as fair. Coral cover in the UZ ranged from 0.33% to 58.55%, indicating poor to good conditions. Station 36 showed the highest coral cover in the UZ, at 58.55%, which was classified as good.

Coral cover in the CZ ranged from 12.68% to 18.75%, indicating poor condition. Station 16 had the highest coral cover in the CZ, at 18.75%. Coral cover in the OZ ranged from 1.90% to 19.64%, also indicating poor condition. Station 1 had the highest coral cover in the OZ, at 19.64%.

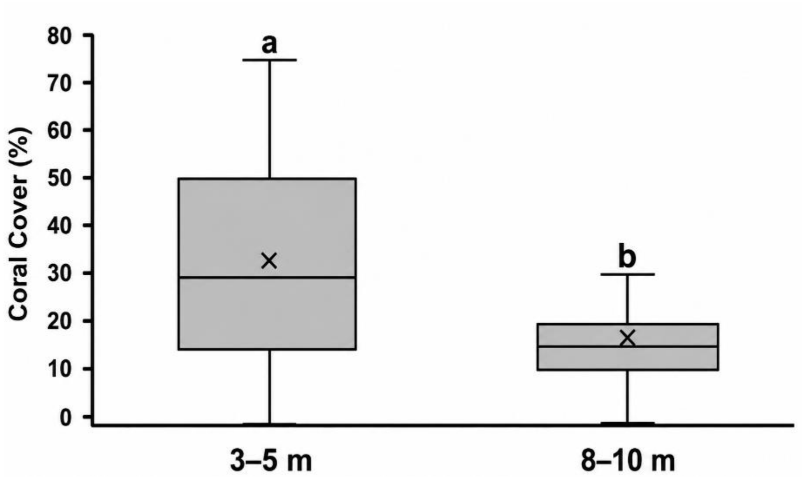

Figure 4. Mean coral cover in all stations 3-5 m and 8-10m

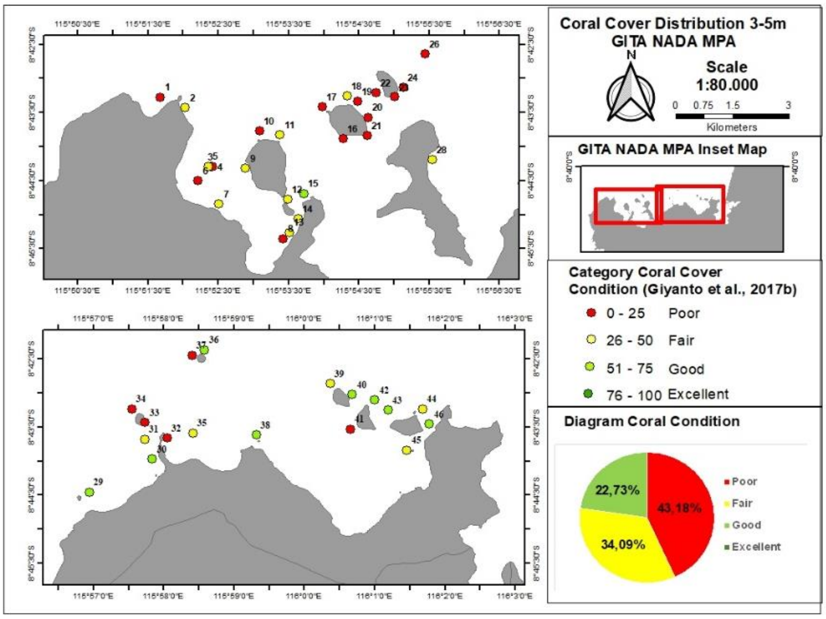

Figure 5. Map of distribution of coral cover conditions 3-5m

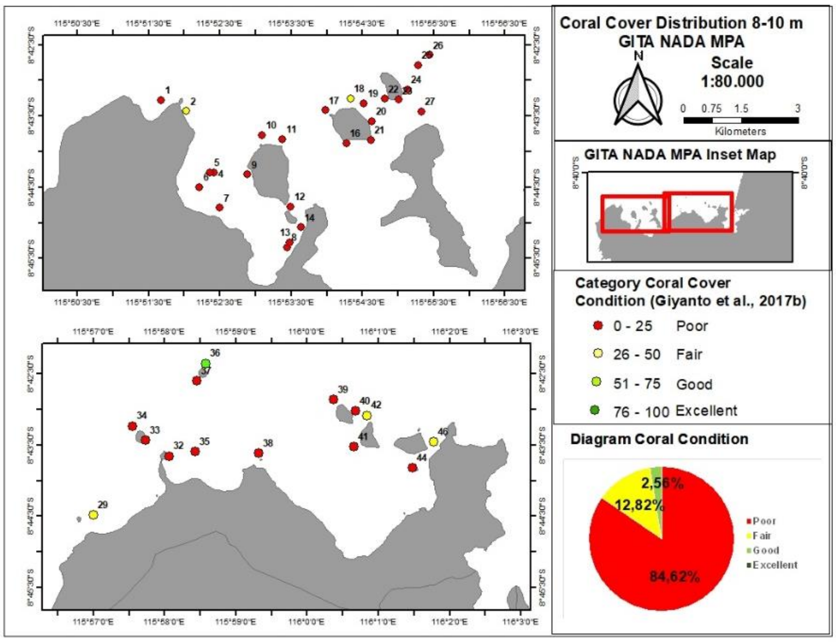

Figure 6. Condition of coral cover at 8-10 m

Mean coral cover at depths of 8-10 m in the FZ, UZ, CZ, and OZ was classified as poor, with values of 18.60% ± 10.40%, 17.88% ± 13.55%, 16.16% ± 2.82%, and 10.77% ± 12.54%, respectively. This indicates that coral cover condition at depths of 8-10 m was predominantly in the poor category across all zones. The consistently low coral cover across all zones at depths of 8-10 m indicates widespread degradation of deeper reef habitats within the GITA NADA MPA.

Although some stations, particularly in the UZ, exhibited relatively higher coral cover, the overall zonation pattern suggests that existing management measures have not effectively maintained coral reef condition at this depth. Kruskal-Wallis analysis showed no significant difference in coral cover among management zones at this depth ($P > 0.05$). These results differ from those of

Erdana *et al*. (2022),), who observed relatively good coral condition in the core zone at 10 m depth in the Koon Island Marine Conservation Area, Maluku Province. These findings highlight the need for targeted coral reef restoration interventions to enhance reef resilience and promote recovery. Similar conclusions were reported by Malik *et al*. (2023), who emphasized the importance of restoration efforts in rehabilitating degraded coral reef ecosystems. Mean coral cover among management zones at both depth categories is presented in Figure 9.

The average substrate cover at depths of 3-5 m across all stations is presented in Figure 10. Living substrate cover across all stations at 3-5 m is shown in Figure 11, while non-living substrate cover is shown in Figure 12. Among the living substrates, soft coral exhibited the highest mean cover after hard coral, with an average value of 9.95% ± 14.41%. The highest soft coral cover was recorded at Station 25 (50.85%). The mean cover of fleshy seaweed (FS) across all stations was 6.40% ± 8.41%, with the highest value observed at Station 16 (50.85%). Sponge cover averaged 3.78% ± 4.29% across all stations, with the highest cover recorded at Station 37 (19.83%). Other biota (OT) had the lowest mean cover among living substrates, averaging 1.22% ± 1.24%, with the highest value found at Station 32 (5.72%).

The relatively high cover of soft corals compared to other living substrates may indicate a shift in benthic community structure, as soft corals are often more tolerant of disturbed or sedimented environments than hard corals (Baum *et al*., 2016). Additionally, the presence of fleshy seaweed (FS) and dead coral with algae (DCA) reflects reduced reef resilience and possible competitive pressure on coral recruitment. Algal proliferation on dead coral substrates can inhibit larval settlement and slow reef recovery processes, particularly when herbivory is insufficient to control algal growth (Adam *et al*., 2022; Butler *et al*., 2024).

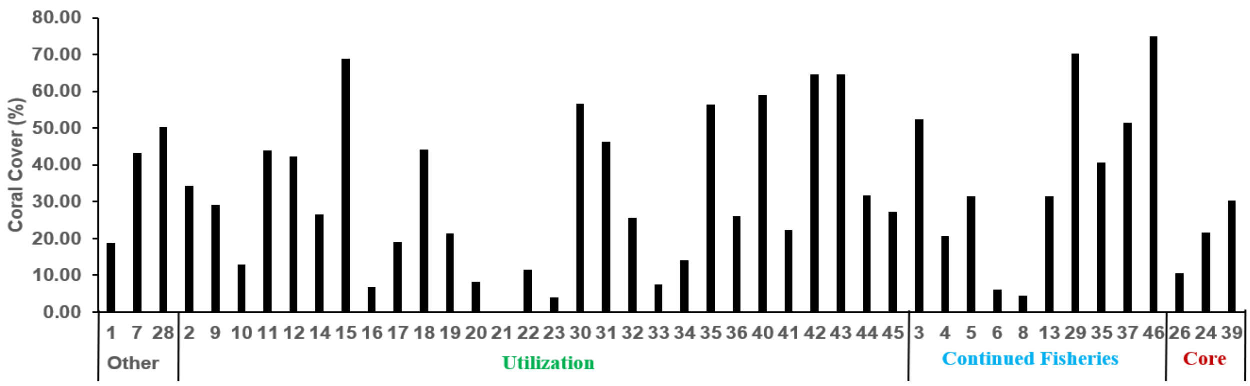

Figure 7. Coral cover by management zone at depths of 3-5 m

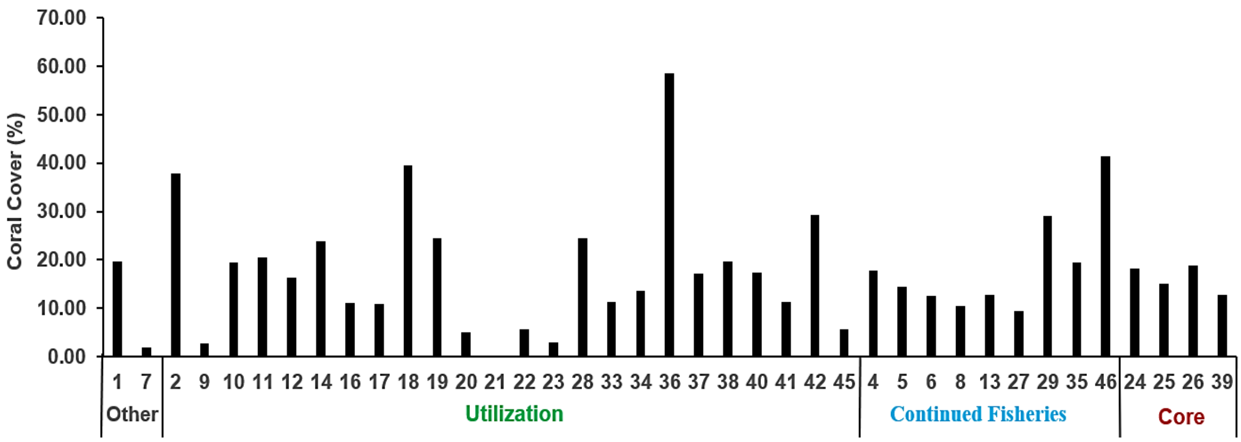

Figure 8. Coral cover by management zone at depths of 8-10 m

Within the non-living substrate group, rubble exhibited the highest mean cover at 21.61% ± 14.36%. Several stations, namely Stations 6, 10, and 20, recorded rubble cover greater than 50%. High rubble cover at several stations (>50%) suggests substantial physical degradation of reef structure. Rubble-dominated substrates may indicate severe mechanical disturbances, including storm damage and destructive fishing practices such as blast fishing, which fragment coral colonies and reduce structural complexity (WWF, 2023). Loss of structural complexity can negatively affect habitat availability for reef-associated organisms and impair ecological functions.

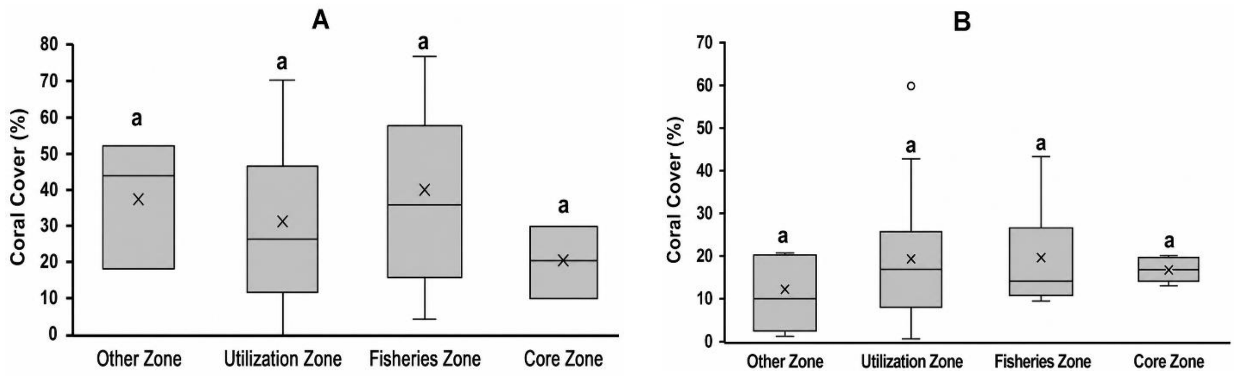

Figure 9. Mean coral cover (%) by management zone at (A) 3-5 m and (B) 8-10 m depth

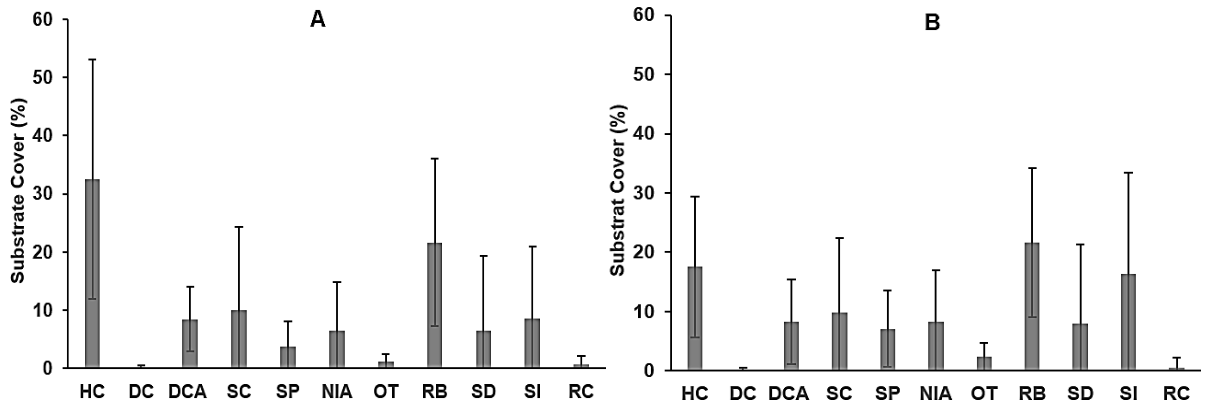

Figure 10. Mean substrate cover from all stations at (A= 3-5m and B= 8-10m)

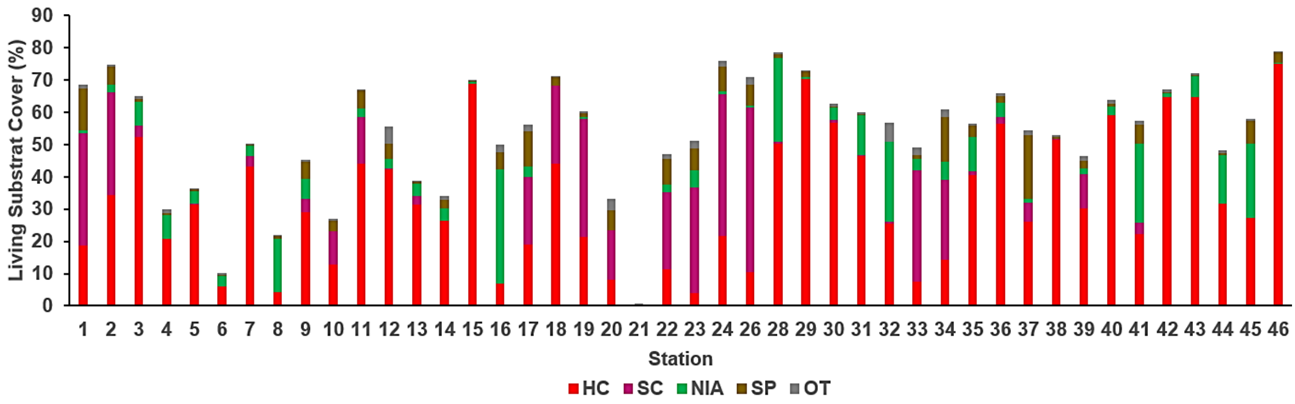

Figure 11. Living substrate cover of all stations at 3-5m

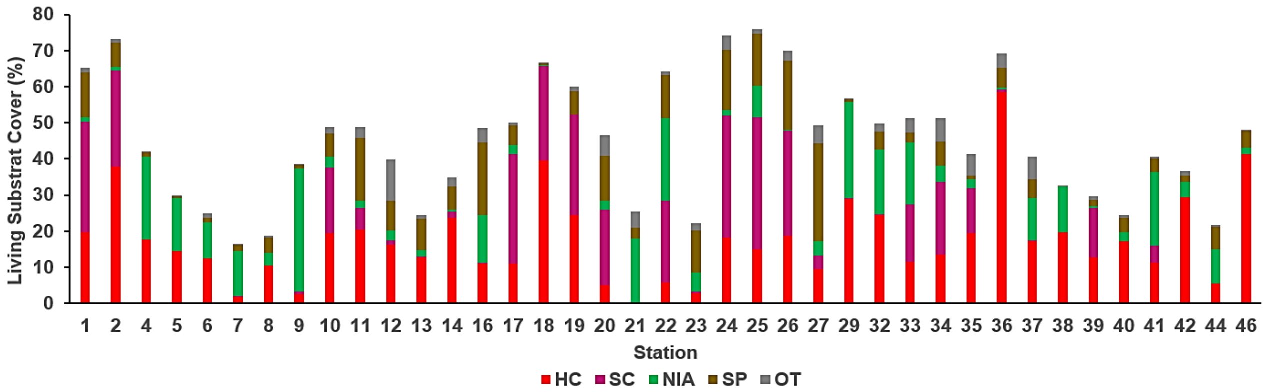

Figure 12. Living Substrate cover of all stations at 8-10m

Mean sand cover across all stations was 6.51% ± 12.78%, with the highest value recorded at Station 21 (50.85%). Meanwhile, the average cover of dead coral with algae (DCA) was 8.43% ± 5.54%, with the highest value observed at Station 39 (25.86%). Rock (RC) cover averaged 0.66% ± 1.45%, with the highest value recorded at Station 35 (5.46%). Dead coral (DC) exhibited the lowest mean cover among non-living substrates, averaging 0.22% ± 0.30%, with the highest value recorded at Station 9 (1.53%).

Overall, the substrate composition at depths of 3-5 m indicates that while some reef framework remains intact, several locations within the study area exhibit signs of degradation and altered benthic structure, emphasizing the need for continued monitoring and effective management to enhance reef resilience and recovery.

The average substrate cover at depths of 8-10 m across all stations is presented in Figure 10. Living substrate cover across all stations at 8-10 m is shown in Figure 13, while non-living substrate cover is shown in Figure 14.Among the living substrates, soft coral had a mean cover of 9.87% ± 12.48%, with the highest value recorded at Station 23 (36.44%). The mean cover of fleshy seaweed (FS) across all stations was 8.21% ± 8.71%, with the highest value observed at Station 8 (36.44%). Sponge (SP) cover averaged 7.07% ± 6.44%, with the highest cover recorded at Station 25 (27.18%). Other biota (OT) had a mean cover of 2.32% ± 2.45%, with the highest value observed at Station 11 (11.47%).The moderate dominance of soft corals, sponges, and algae among living substrates suggests a shift in benthic community composition toward more disturbance-tolerant organisms. Such shifts are commonly associated with reduced reef resilience and slower recovery potential, as non-reef-building taxa often outcompete scleractinian corals under conditions of chronic disturbance, sedimentation, or nutrient enrichment (Siagian *et al*., 2022; Nalley *et al*., 2023).

Among non-living substrates, rubble exhibited the highest mean cover, at 21.64% ± 12.59%. Two stations recorded rubble cover exceeding 50%, namely Station 33 (58.76%) and Station 4 (53.11%). The high proportion of rubble at depths of 8-10 m indicates substantial degradation of benthic habitat structure in deeper reef zones. Elevated rubble cover at Stations 33 and 4 suggests historical physical disturbances that have resulted in coral fragmentation and loss of structural complexity.Silt (SI) had a mean cover of 16.40%, with the highest values recorded at Station 7 (73.33%) and Station 6 (55.69%). The relatively high silt coverage, particularly at Stations 7 and 6, reflects increased sediment accumulation at deeper depths, which can reduce substrate stability and inhibit coral recruitment. Fine sediments may smother coral tissues and limit light penetration, thereby constraining the growth of reef-building corals.

Mean sand (SD) cover across all stations was 8.00% ± 13.24%, with the highest value recorded at Station 23 (59.56%). The average cover of dead coral with algae (DCA) was 8.27% ± 7.15%, with the highest value observed at Station 34 (31.62%). Rock (RC) cover averaged 0.58% ± 1.56%, with the highest value observed at Station 26 (7.36%). Dead coral (DC) exhibited the lowest mean cover among non-living substrates, averaging 0.19% ± 0.27%, with the highest value recorded at Station 14 (1.09%).

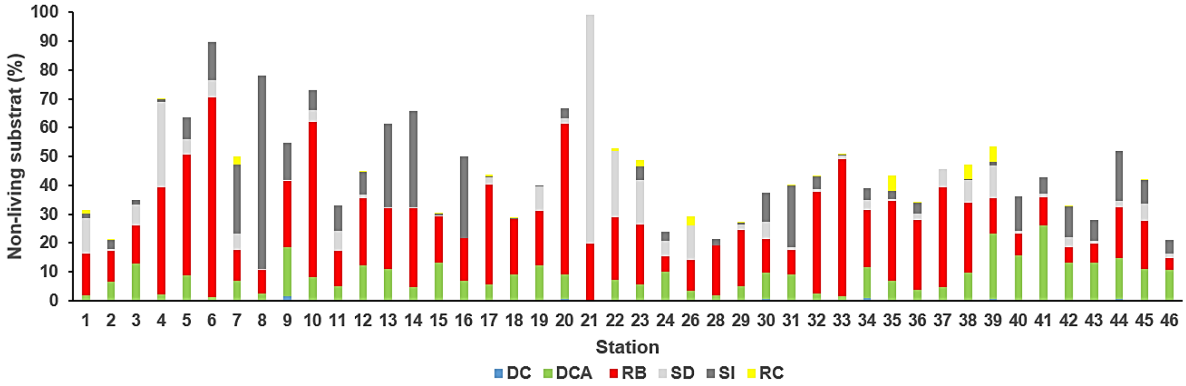

Figure 13. Non-living substrate cover of all stations at 3-5m

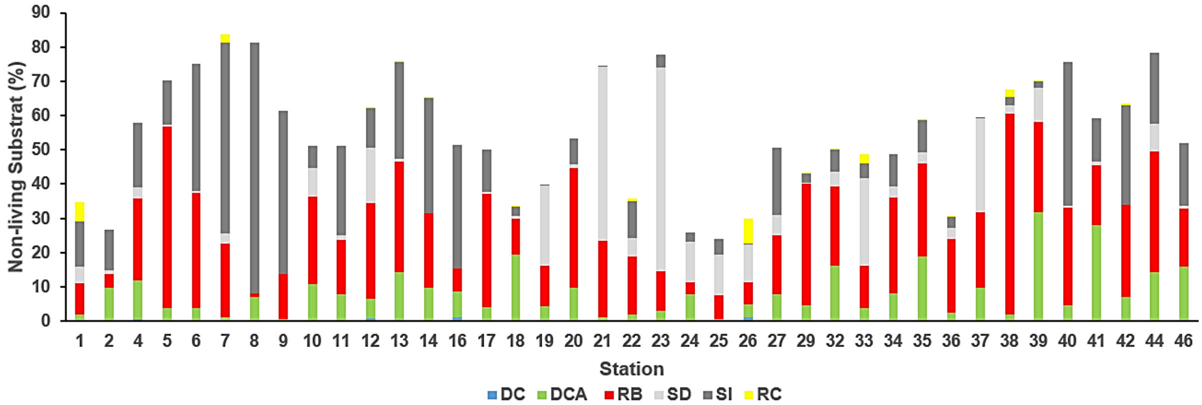

Figure 14. Non-living Substrate cover of all stations at 8-10m

Overall, the substrate composition at depths of 8-10 m indicates a high proportion of non-living substrate, particularly rubble and silt, reflecting degraded benthic habitat structure and reduced suitability for coral recruitment and recovery.

CONCLUSION

Coral reef condition exhibited clear depth-related and spatial variability, with fair coral cover at shallow depths (3-5 m) and predominantly poor coral condition at deeper reefs (8-10 m). Kruskal-Wallis analysis revealed a significant difference in coral cover between the two depth categories (3-5 m and 8-10 m) ($P < 0.05$), with shallow reefs supporting higher coral cover than deeper reefs. Zonation-based analyses revealed that mean coral cover in the FZ, OZ, and UZ at shallow depths (3-5 m) was categorised as fair, with mean values of 38.39% ± 24.36%, 37.40% ± 16.50%, and 31.24% ± 20.40%, respectively. Conversely, the CZ exhibited a mean coral cover of 20.77% ± 9.90%, which was classified as poor. At deeper depths (8-10 m), mean coral cover remained consistently low across all zones, with the FZ, UZ, CZ, and OZ classified as poor. Kruskal-Wallis analysis showed no significant difference in coral cover among management zones at either depth ($P > 0.05$). These findings suggest limitations in current management effectiveness, particularly within the Core Zone and deeper reef habitats. Living and non-living substrate cover further indicated evidence of degradation and structural alteration of reef habitats. The relatively high cover of soft corals, sponges, and fleshy seaweeds at both depths suggests a shift toward disturbance-tolerant benthic assemblages. In addition, the dominance of rubble, sand, and silt at several stations was potentially associated with destructive fishing practices, historical disturbances, and land-based sediment inputs. Taken together, the findings indicate that coral reef ecosystems within the GITA NADA Marine Protected Area are experiencing ongoing degradation, particularly in deeper reef zones and within the Core Zone. This study represents one of the first comprehensive UPT-based assessments of coral cover and benthic substrate composition across management zones within the GITA NADA MPA. The findings provide an important benchmark against which future monitoring and restoration outcomes can be evaluated and highlight the urgent need for re-evaluation of zoning effectiveness, stronger enforcement measures, targeted reef restoration, and sediment management strategies. Continued long-term monitoring using standardized methods is critical to track ecosystem recovery, assess management effectiveness, and support adaptive, ecosystem-based conservation of coral reefs in West Lombok.

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