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Assessment of Coral Reef Condition in Nusi Island, Nabire, Indonesia

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Abstract
Purpose: This study aimed to assess coral reef health at Nusi Island, Nabire, Indonesia, by analyzing the benthic composition using Remotely Operated Vehicle (ROV) technology.
Research Methodology: Data were collected using the Underwater Photo Transect (UPT) method, deploying a 50-meter transect line at approximately 10 m depth. High-resolution images were captured, and 1,500 data points were analyzed to evaluate the benthic substrate composition.
Results: The findings revealed severe degradation of coral reefs. Site 2 (Pulau Nusi) showed only 3.13% live coral cover, with sand and rubble dominating the substrate. Site 1 (Nabire) fared slightly better, with 6.64% live coral cover, although it still showed significant damage.
Conclusions: The coral reefs at both study sites are severely degraded, with Site 2 in a critical state, mainly due to sedimentation. These data highlight the need for targeted management strategies to mitigate these stresses and foster reef recovery.
Limitations: This study was limited to a single 50-meter transect at one depth, providing a snapshot of the reef condition. Further research is required to identify specific degradation drivers and conduct long-term monitoring.
Contributions: This study provides the first quantitative assessment of coral reef conditions on Nusi Island, offering essential baseline data for future conservation efforts.

Keywords: *Coral Reef, Degradation, Marine Conservation, Remotely Operated Vehicle (ROV), Sedimentation*

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1. Introduction

Coral reefs are recognized as one of the most diverse and productive ecosystems on Earth, providing critical ecological services such as coastal protection, support for fisheries, and contributing significantly to the economy through tourism (Pellowe et al., 2023). These ecosystems are particularly important in tropical regions, such as the Coral Triangle, where Indonesia hosts the highest coral reef biodiversity globally (Yuan, Lin, Pan, & Yang, 2024). However, coral reefs are facing severe threats from both local and global environmental stressors (Johan, Budiyanto, Dzumalek, & Sulha). Locally, destructive fishing practices, coastal development, pollution, and sedimentation contribute significantly to degradation (Gonzalez-Rivero et al., 2020). Simultaneously, global challenges such as ocean acidification and climate change-driven coral bleaching continue to exacerbate the decline of coral reefs worldwide (Giyanto et al., 2023).

Indonesia's marine ecosystems, including coral reefs, are under intense pressure, particularly in areas such as Cenderawasih Bay, where Nabire is located. This area, with parts designated as a National Park, holds exceptional ecological significance but is also at risk due to unsustainable practices (Abrar et al., 2024). Cenderawasih Bay's coral reefs are particularly vulnerable to the impacts of sedimentation from agricultural runoff, land development, and unsustainable tourism activities (Tries B. Razak et al., 2024).

The urgent need for effective management and conservation of these reefs is undeniable, as they provide ecosystem services that are vital to local communities and the nation as a whole (Watt-Pringle et al., 2024).

Despite the ecological importance of coral reefs in Indonesia, scientific research on the current state of these ecosystems remains limited, especially in remote areas such as Nusi Island. The lack of comprehensive quantitative data hampers effective reef management and conservation efforts. Accurate baseline data on coral reef health are critical for assessing the effectiveness of conservation strategies and identifying areas that require urgent protection (Wulandari et al., 2022). This study aims to bridge this knowledge gap by providing the first quantitative assessment of coral reef health in Nusi Island, Nabire, using cutting-edge technology such as Remotely Operated Vehicles (ROVs) for data collection (Adalya & Mutaqin, 2022).

Coral reef degradation is a global phenomenon, with studies indicating a worldwide decline in coral cover over the last few decades. In Indonesia, although some reefs remain in relatively good condition, a substantial portion faces significant threats. High sedimentation rates, often caused by land-use changes and coastal development, are primary drivers of coral degradation. This phenomenon smothers corals, reduces light availability for photosynthesis, and impedes coral larval settlement, all of which weaken the health of the reef. Additionally, destructive fishing methods and physical damage from boat anchors contribute further to the decline of coral reefs by breaking coral colonies and creating unstable rubble fields that are unsuitable for new coral recruitment (Tries B Razak, Boström-Einarsson, Alisa, Vida, & Lamont, 2022).

The Underwater Photo Transect (UPT) method, which is widely used for coral reef monitoring, provides a more accurate and less biased alternative to traditional visual survey methods. It allows for the creation of permanent digital records and reduces observer bias while improving the efficiency of field data collection (Putro, Ramadhon, Hariyati, & Adhy, 2022). This technique is particularly useful for a detailed analysis of benthic cover, which serves as a primary indicator of coral reef health. Changes in the composition of coral communities, especially the dominance of stress-tolerant life forms such as massive and encrusting corals, indicate the level of environmental stress and past disturbance events (Idris, Fakhrurrozi, & Adiwijaya, 2021). This study applied the UPT method to assess the benthic composition and overall condition of the coral reefs at Nusi Island.

In regions such as Nusi Island, the combination of local and global stressors has led to a shift in coral community structure. Reefs that experience chronic stress often show an increased presence of more resilient, slow-growing coral species, such as Porites and encrusting corals, whereas fast-growing, complex corals, such as Acropora, become increasingly rare (Watt-pringle, 2024). The loss of complex coral species severely impairs the ability of reefs to provide habitats for marine life and to recover from disturbances.

Recent technological advancements in remote sensing and artificial intelligence have enhanced the efficiency and effectiveness of coral reef monitoring. For instance, the use of ROVs and Artificial Intelligence (AI) to analyze underwater images has been shown to provide a more cost-effective and scalable method for coral reef monitoring, allowing for the detection of changes in coral health with unprecedented speed and accuracy (Ulumuddin et al., 2021). The ability to collect high-resolution data from remote and difficult-to-access areas has made ROVs an invaluable tool for assessing the health of coral reefs, particularly in regions such as Nusi Island, where access to scientific data is limited.

In Indonesia, coral reefs face the dual challenge of degradation from local human activities and global climate change. Research on the status of Indonesian coral reefs, particularly in areas such as Nabire, is crucial for developing targeted conservation measures. Without these data, it is impossible to implement effective management strategies that balance human development and ecological protection (Pelasula et al., 2025). This study provides much-needed baseline data that can guide future conservation efforts and policy decisions by assessing the benthic composition and coral health of Nusi Island.

2. Literature Review

2.1 Global Coral Reef Conditions

Research has shown a significant decline in coral cover worldwide over the past few decades due to both local and global stressors. Global benthic data analysis has found that the average live coral cover has decreased from approximately 36% to 19% in recent decades, reflecting a global trend of coral ecosystem degradation (Tebbett, Connolly, & Bellwood, 2023).

2.2 Benthic Composition Changes

Changes in coral reef benthic composition are not limited to the decline of live coral but also include the increased dominance of non-coral organisms such as algae and non-living substrates. This change negatively impacts the reef's ecological function and the services it provides to marine organisms. This shift can reduce biodiversity and affect the productivity of reef ecosystems (Reverter, Helber, Rohde, de Goeij, & Schupp, 2024).

2.3 Drivers of Degradation

Recent studies have highlighted that the primary causes of coral reef degradation are a combination of local anthropogenic stressors, such as overfishing, pollution, and sedimentation, as well as global stressors, such as climate change and ocean acidification. Emerging pollutants and nutrient contaminants further exacerbate these conditions, creating a more hostile environment for corals (Latif & Chandra, 2026).

2.4 Coral Reef Monitoring Methods

Various coral reef monitoring methods have been developed and compared for accuracy and effectiveness, including Line Intercept Transects (LIT), underwater photo transects, and drone surveys. Recent studies have indicated significant variations in outcomes across methods, making it essential to choose the most appropriate approach for local contexts and research objectives (Jompa et al., 2026).

2.5 Advanced Benthic Monitoring Techniques

Modern advancements in monitoring technologies, including Remotely Operated Vehicles (ROVs), photo transects, and automatic monitoring systems employing machine learning algorithms for image analysis, have significantly improved coral reef monitoring. These methods provide high-resolution data and reduce human bias, allowing for more objective assessments of benthic cover (Apprill et al., 2023).

2.6 Coral Reef Studies in Indonesia

Studies conducted on various islands in Indonesia have revealed trends consistent with global conditions, with numerous reefs facing severe ecological pressures. For example, in Indonesia, satellite imagery and field-based transects have been used to map and assess reef health, showing significant damage from sedimentation and coastal development (Pelasula et al., 2025).

2.7 Reef Health Indices

Various reef health indices have been developed to assess the ecological status of coral reefs, including the Reef Health Index (RHI). This index includes parameters such as live coral cover, algae cover, and fish biomass. Studies in Indonesia and Mesoamerica have shown that the RHI provides a more comprehensive understanding of reef conditions than traditional methods (Díaz-Pérez et al., 2016).

2.8 Long-Term Monitoring Importance

Long-term monitoring is essential for detecting trends in reef health and evaluating the effectiveness of management interventions in the area. Studies emphasize the need for long-term data collection, especially in tropical regions with high socioeconomic importance, such as Indonesia, to develop resilient management strategies (Souter et al., 2021).

2.9 Benthic Changes and Reef Fish Communities

Recent literature has demonstrated a close relationship between benthic composition and reef fish communities. The composition of benthic organisms influences fish recruitment and their survival.

Reefs dominated by rubble and sand, for example, show significantly lower fish biodiversity, which impacts fisheries and local livelihoods (2016–2018) Coral reef benthic composition and reef fish community relationships (Aji, Putra, Abrar, Siringoringo, & Giyanto, 2025).

2.10 Reef Restoration and Management

Recent literature on coral reef restoration emphasizes the importance of integrated management approaches, including coral transplantation, enhanced protection zones, and the mitigation of both local and global stressors to help restore reef ecosystems. Effective management requires continuous monitoring and adaptive strategies to improve reef resilience (Oetama, Hakim, Lelono, & Musa, 2024).

3. Methodology

3.1 Study Area

This study was conducted in the waters of Nusi Island, located in Nabire, Papua Tengah, Indonesia. Nusi Island is situated in the Coral Triangle, an area recognized for its extraordinary marine biodiversity and ecological significance. However, it faces significant pressure from human activities and environmental factors, such as sedimentation and pollution, which pose challenges to coral reef conservation (Monchanin et al., 2025).

3.2 Data Collection Method

Data collection followed the Underwater Photo Transect (UPT) method, a standardized technique used globally for assessing coral reef conditions. This method involves deploying a 50-meter transect line along the reef substrate at a depth of approximately 10 m. A diver swam along the transect and captured high-resolution digital photographs at regular intervals. Fifty photographs were taken for each transect, representing a comprehensive cross-section of the reef environment at each site (Irawan, Mukti, Andriyono, & Muhsoni, 2023).

3.3 Image Analysis

Fifty images collected during the survey were analyzed using a quantitative approach. Each image was digitally overlaid with 30 randomly distributed dots. At each point, the type of benthic feature or substrate beneath it was identified and classified. The classification scheme included categories such as live hard coral, soft coral, dead coral, rubble, sand, rock, and various algae and invertebrates. This resulted in a total of 1,500 data points for each transect (Mayfield & Dempsey, 2025).

3.4 Data Processing and Statistical Analysis

This study was conducted in the waters of Nusi Island, Nabire, Papua Tengah, Indonesia. Data collection followed the standardized Underwater Photo Transect (UPT) protocol.

A 50-meter transect line was deployed on the reef substrate at a consistent depth of approximately 10 m. A diver swam along the transect line, capturing high-resolution digital photographs of the substrate at regular intervals (Mukti, 2022). A total of 50 photographs were captured for each transect.

Figure 1. data collection using the UPT method

Figure 1 shows an excerpt from the Methodology section of the study, specifically focusing on data processing and statistical analysis. This study was conducted in the waters of Nusi Island, Nabire, Papua Tengah, Indonesia. It followed the Underwater Photo Transect (UPT) protocol, a standardized method used for coral reef assessment (Bhuyan, Sardar, Jeganathan, & Pujar, 2025). A 50-meter transect line was deployed along the reef substrate at a depth of approximately 10 m, and a diver swam along this line, capturing high-resolution digital photographs of the substrate at regular intervals. A total of 50 photographs were taken during the survey to represent various reef conditions along the transect (Oetama et al., 2024). The image shows a diver collecting data using the UPT method, illustrating the practical approach used to document the reef's benthic composition.

The methodology emphasizes a precise and systematic data collection process, which is essential for providing accurate and reliable data on reef health and substrate composition. This method allows for a comprehensive assessment of the reef, ensuring a thorough representation of the coral environment in the study area (Prihananto, Rachmad, & Rahardjo, 2025). The percentage cover for each substrate category was calculated by dividing the number of points for that category by the total number of points (1,500) and multiplying by 100 (Murdani, Candri, & Ahyadi, 2025). The final live coral cover percentage was used to classify the reef condition based on the criteria set by the Indonesian Ministry of Environment Decree No. 4 (2001):

1. 0 - 24.9%: Poor
2. 25 - 49.9%: Fair
3. 50 - 74.9%: Good
4. 75 - 100%: Excellent

RESULTS SUMMARY CHART	# Points	%	SW Index	Simpson (1-D)
CORAL (HC)	448	29.89	1.07	0.56
RECENT DEAD CORAL (DC)	29	1.93	0.00	0.00
SOFT CORAL (SC)	64	4.27	0.66	0.47
SPONGE (SP)	80	5.34	0.00	0.00
FLESHY SEAWEED (FS)	58	3.87	0.53	0.35
OTHER BIOTA (OT)	2	0.13	0.00	0.00
SAND (S)	642	42.83	0.00	0.00
RUBBLE (RB)	145	9.67	0.00	0.00
SILT (SI)	0	0.00	0.00	1.00
ROCK (RCK)	31	2.07	0.00	0.00
TAPE, WAND, SHADOW (TWS)	0	0.00		
TOTALS	**1499**	**100.00**		
NOTES (% of transect)				
NOTES (% of coral)				

Figure 2. Analysis results using CPCe

Figure 2 summarizes the analysis results using the Coral Point Count with Excel Extensions (CPCe) method, which is used to analyze the benthic composition of coral reefs. The table provides the following columns.

1. Points (#): Number of data points observed for each substrate category.
2. %: The percentage of each substrate category in relation to the total number of points.
3. SW Index: Simpson's Evenness index, which measures the diversity and evenness of the substrates.
4. Simpson (1-D): The Simpson's Diversity index, which calculates the overall biodiversity, considering both abundance and evenness of different categories.

Breakdown of Substrate Categories:

1. Coral (HC - Hard Coral): This category had 448 points, covering 29.89% of the reef. It has a Simpson's Evenness (SW) index of 1.07, suggesting a moderate level of diversity within the coral community. The Simpson (1-D) index of 0.56 reflects moderate biodiversity in the coral communities.
2. Recent Dead Coral (DC): With 29 points and 1.93% cover, the presence of dead coral suggests recent coral mortality, likely due to stress or environmental disturbances. The SW and Simpson indices for dead coral were both 0.00, indicating minimal diversity or complexity in this category.
3. Soft Coral (SC): Covering 4.27% of the reef, soft coral has 64 points of coverage. It showed a moderate SW index (0.66) and a Simpson (1-D) index of 0.47, suggesting that it contributes to biodiversity but is less abundant than hard corals.
4. Sponge (SP): Sponges covered 5.34% of the reef area with 80 points. The SW index was 0.00, indicating very low diversity within this category, and the Simpson (1-D) index was also 0.00, suggesting minimal biodiversity in sponge communities on the reef.
5. Fleshy Seaweed (FS): This category has 58 points (3.87% cover). The SW index was 0.53, indicating some diversity within the seaweed species, and the Simpson (1-D) index of 0.35 suggested moderate diversity.
6. Other Biota (OT): Representing only 0.13% of the reef area, with only two points, this category had no significant presence. The diversity indices were both 0.00, indicating very low biodiversity in this category.
7. Sand (S): Sand covered the largest portion of the reef, with 642 points and 42.83% coverage. As a non-living substrate, sand has no diversity or contribution to the reef's biodiversity, as reflected by 0.00 values for both SW and Simpson (1-D).
8. Rubble (RB): Rubble, composed of fragmented dead corals, covered 21.2% of the reef. It has 145 points that contribute to the reef's physical instability. The diversity indices showed a low level of species diversity within the rubble.
9. Silt (SI): No silt was recorded in the reef, as reflected by 0% and 0.
10. Rock (RCK): Rock comprises 7.9% of the reef, with 31 points. Similar to sand, rock provides minimal ecological function but serves as a stable substrate for other organisms.
11. Tape, Wand, Shadow (TWS): This category, which accounts for survey tools and artifacts, had no recorded presence in the dataset.

Figure 2 highlights the dominant role of sand (42.83%) and rubble (21.2%) in the substrate composition, indicating a highly disturbed reef environment. Live coral cover was limited to 29.89%, suggesting poor reef health. The low diversity indices for most substrate categories, particularly dead coral, sponges, and seaweed, further emphasize the degraded state of the reef. These findings highlight the need for urgent conservation and restoration efforts to improve the health and biodiversity of coral ecosystems. The percentage cover for each substrate category was calculated by dividing the number of points corresponding to a given category by the total number of points (1,500) and multiplying the result by 100. The final live coral cover percentage was used to classify the reef condition according to the criteria set by the Indonesian Ministry of Environment Decree No. 4 (2001).

3.5 Remotely Operated Vehicles (ROV) Technology and Advantages

In this study, Remotely Operated Vehicles (ROVs) were utilized to capture high-quality, high-resolution images, which provided the advantage of reducing human bias and enhancing the precision of benthic data collection. The use of ROVs enables access to deeper and more challenging locations while maintaining a high degree of accuracy in data acquisition, which is essential for accurate assessment in areas with limited accessibility. Furthermore, ROVs provide a permanent digital record that can be reviewed and analyzed in detail, thereby improving the reproducibility of the findings (Raoult, McSpadden, Gaston, Li, & Williamson, 2025).

3.6 Classification and Benthic Composition

Benthic composition was analyzed using Coral Point Count with Excel Extensions (CPCe) software, which allows for the efficient processing of large-scale photographic data to identify and classify benthic features. CPCe was used to calculate the percentage cover of each substrate category across the

transects. The software also provided additional ecological indices, such as Simpson's Diversity Index, which helps assess the biodiversity of the reef (Aulia et al., 2021)

3.7 Reef Health Classification

Based on the percentage of live coral cover obtained from the analysis, the reef health was classified according to the criteria specified in the Indonesian Ministry of Environment Decree No. 4 (2001). This classification scheme helps categorize reefs based on their level of degradation, which is essential for making informed management and conservation decisions (Rabbani, Iman, Nurshafa, & Salsabila, 2025).

4. Results and Discussions

4.1 Benthic Substrate Composition

The analysis of the 1,500 data points revealed that the substrate at Nusi Island was overwhelmingly dominated by abiotic components. Sand covered 61.73% of the reef area, followed by rubble (21.20% of the reef area). These results underscore reef degradation, as sand and rubble represent unstable substrates that are not conducive to the establishment of new coral colonies. Live hard coral, a vital indicator of reef health, constituted a minimal 3.13% of the total substrate.

The full breakdown of benthic composition is presented in Table 1. This composition is characteristic of a highly disturbed reef environment, where the combination of sand and rubble, making up over 82% of the seafloor, hinders coral larvae settlement and their survival. The substantial presence of rubble is indicative of physical damage, likely from anthropogenic activities or natural disturbances, such as storms and strong wave action. The complete breakdown of benthic composition is presented in Figure 2.

Table 1. Benthic substrate composition at Nusi Island

Substrate Category	Percentage Cover (%)
Sand	61.73
Rubble	21.20
Rock	7.93
Live Hard Coral	3.13
Sponge	3.13
Fleshy Seaweed	1.33
Recent Dead Coral	1.00
Soft Coral	0.47
Other Biota	0.07

This composition is indicative of a highly disturbed environment. The combination of sand and rubble, which makes up over 82% of the seafloor, creates an unstable substrate that is inhospitable to the settlement and survival of new coral larvae. A high proportion of rubble is a strong indicator of past physical damage to the reef structure. Table 1 shows that provided illustrates the benthic substrate composition at Nusi Island, Nabire, Indonesia. The table breaks down the percentage cover of various substrate categories observed during the study based on 1,500 data points collected along a 50-meter transect at a depth of approximately 10 m.

Here's the explanation of the table's contents:

1. Sand (61.73%): Sand was the dominant substrate, covering over 60% of the surveyed area. This is indicative of a highly disturbed reef environment, where sand accumulation prevents the settlement and survival of coral larvae, further hindering coral growth.
2. Rubble (21.20%): Rubble, consisting of unconsolidated fragments of dead coral, is the second most prevalent substrate, covering over 21% of the area. The high percentage of rubble suggests that the reef has experienced significant physical damage, likely from anthropogenic activities such as fishing or coastal development, as well as natural disturbances, such as storms and wave action.
3. Rock (7.93%): Rocks constitute a smaller portion of the reef substrate. While they provide some habitat for marine life, they are not as beneficial for coral settlement as other more stable and complex substrates.

4. Live Hard Coral (3.13%): Live coral cover was minimal, constituting only 3.13% of the substrate. This low percentage of live hard coral is a clear indicator of the degraded state of the reef and highlights the urgent need for conservation and restoration efforts.
5. Sponge (3.13%): Sponge coverage was relatively low, contributing to the benthic composition. Sponges are an important part of the reef ecosystem, but they cannot replace the critical functions provided by coral species.
6. Fleshy Seaweed (1.33%): Fleshy seaweed, while a natural part of the reef environment, contributes only a small fraction to the benthic substrate. High levels of seaweed growth can sometimes indicate poor reef health because it can outcompete corals for space and resources.
7. Recent Dead Coral (1.00%): The presence of recent dead coral suggests that there has been some coral mortality at this site, likely due to disturbances from natural events or anthropogenic impacts.
8. Soft Coral (0.47%): Soft corals constitute a minimal portion of the reef substrate. While they can contribute to reef diversity, they are less effective than hard corals in providing structural complexity.
9. Other Biota (0.07%): This category includes various other organisms that are part of the reef ecosystem but do not dominate benthic cover.

Overall, the table reflects the highly disturbed state of the Nusi Island reef, with sand and rubble dominating the seafloor and very little coral. This composition indicates significant degradation of the reef, likely caused by a combination of natural disturbances and human activities.

Within the small fraction of live coral cover, the community was dominated by stress-tolerant morphologies. Massive corals (e.g., Porites) comprised 44.68% of the live coral community, and encrusting corals comprised 31.91%. Fast-growing, structurally complex Acropora species, which are fundamental to building reef frameworks, were scarce, with tabulate and submassive forms comprising only 12.77% and 10.64%, respectively. This shift towards more robust, slow-growing life forms is a classic symptom of chronic stress in reef ecosystems.

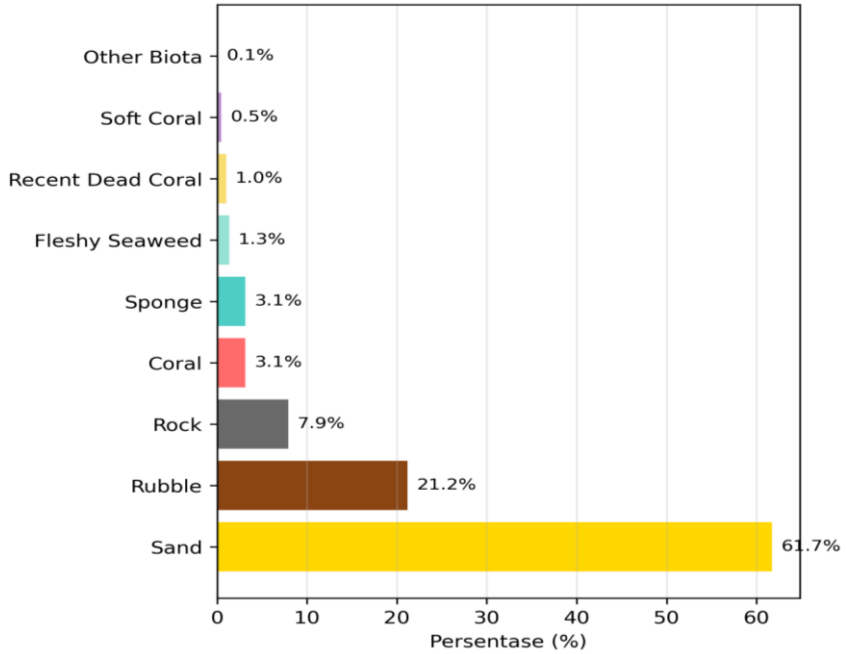

Figure 3. Substrate cover composition of the coral reef at Nusi Island

Figure 3 categorizes the benthic substrate into various types and their corresponding percentages

1. Sand is the dominant substrate, covering 61.7% of the reef, reflecting a disturbed reef environment in which sand accumulation impedes coral larval settlement and growth.
2. Rubble accounted for 21.2% of the total area, indicating significant physical damage to the reef, likely due to natural disturbances such as storms or human activities such as fishing.

3. Rock comprises 7.9% of the substrate, which is generally a stable substrate for reef development but is not as conducive to coral growth as other substrates.
4. Coral and Sponge each covered 3.1% and 1.3% of the reef, respectively, showing limited coral presence and moderate sponge coverage, which is not ideal for building reef structures.
5. Recent Dead Coral covers 1.0%, further emphasizing the degradation of the reef due to past disturbances.
6. Fleshy Seaweed and Soft Coral cover 1.3% and 0.5% respectively, indicating some seaweed presence but little soft coral, which are generally less resilient than hard corals.

Overall, the graph illustrates a coral reef environment with significant degradation, where sand and rubble dominate the seafloor, indicating poor conditions for coral growth and reef recovery. The minimal coverage of live coral (3.1%) highlights the critical state of the reef at Nusi.

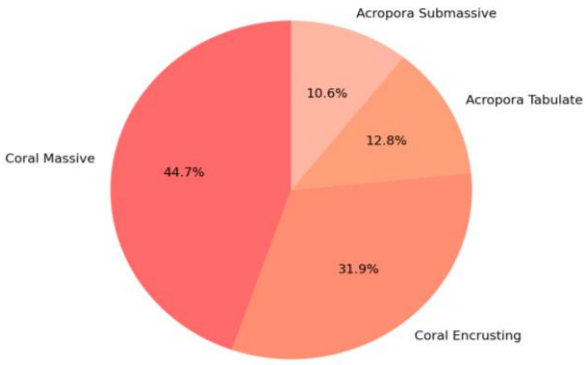

Figure 4. The coral community composition at Nusi Island

Figure 4 shows the results based on a total of 47 data points. The chart categorizes the coral community into different life forms and shows the relative percentages of each type.

1. Massive coral: This category represented the largest portion, accounting for 44.7% of the live coral community. These massive corals are generally slow-growing, resilient to stress, and form the backbone of reef structures. Their dominance in reef communities indicates a preference for stress-tolerant species in the environment.
2. Coral Encrusting: Encrusting corals, which constitute 31.9% of the coral community, are also stress-tolerant but typically grow along substrates and are generally less complex than massive corals. They contribute to the reef structure but do not provide the same level of habitat complexity as other corals.
3. Acropora Tabulate: This category accounts for 12.8% of the coral community. Acropora Tabulate species are fast-growing and structurally complex, essential for reef-building. Although modest, their presence indicates that some complex coral species still survive in this stressed reef environment.
4. Acropora Submassive: Representing 10.6% of the live coral, Acropora Submassive corals are also fast-growing, but they form a less complex reef structure than other Acropora species like Acropora branching or tabulate. Their lower presence reflects the ongoing stress experienced by the reef, which limits the abundance of highly complex coral.

This distribution of coral types in the reef highlights a shift towards more stress-resistant, slow-growing species (such as massive and encrusting corals) and a scarcity of fast-growing, structurally complex species such as Acropora. This is indicative of environmental stress affecting the reef, limiting the recovery and biodiversity potential of the coral community.

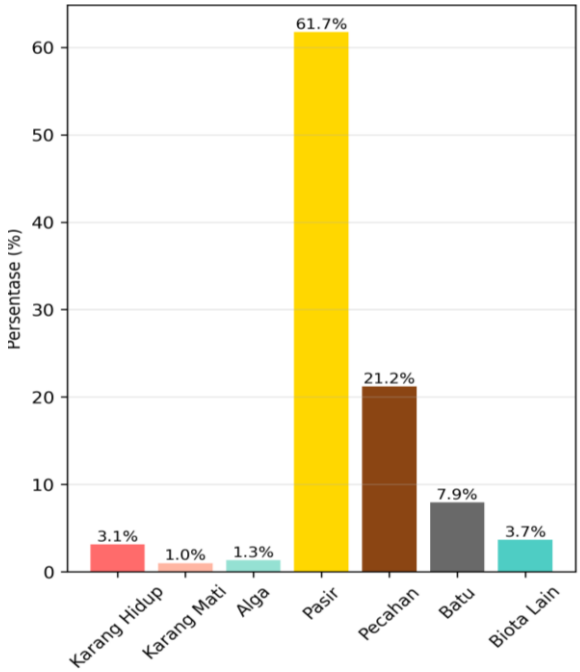

Figure 5. Comparison of main coral reef components

Figure 5 shows the percentage cover of different components of the reef ecosystem at Nusi Island. The chart breaks down the components into several categories.

1. Sand (61.7%): Sand is the dominant substrate and covers the majority of the reef area. This large proportion of sand suggests a highly disturbed environment, where sand accumulation hinders coral settlement and development and the establishment of complex reef structures.
2. Rubble (21.2%): Rubble, composed of broken coral fragments, is the second most common substrate. The significant presence of rubble indicates physical damage to the reef, likely caused by human activities or natural disturbances, which further destabilizes the reef and prevents coral larvae from settling.
3. Rock (7.9%): Rock contributes to the substrate in smaller proportions. Although rock can provide some habitat for marine life, it does not offer the same stability or complexity required for coral growth as other substrates.
4. Coral (3.1%): Live coral constitutes a very small fraction of the reef at Nusi Island, reflecting the degraded state of the reef. The low percentage of live coral is a critical indicator of poor reef health, highlighting the need for conservation efforts.
5. Other Biota (3.7%): This category includes various other organisms on the reef, but their coverage is minimal compared to dominant substrates such as sand and rubble.
6. Dead Coral (1.0%): Dead coral is also a small portion of the reef substrate, suggesting some past coral mortality, which may be due to ongoing stressors such as sedimentation, pollution, and physical damage.
7. Algae (1.3%): Algae were present but occupied a minimal area. Excessive algal growth can indicate poor reef health, as it may compete with corals for space and resources.

Overall, the chart illustrates the severely degraded state of the Nusi Island coral reef, where sand and rubble dominate the seafloor and live coral cover is minimal. These findings highlight the urgent need for reef management and restoration initiatives to improve reef health and resilience.

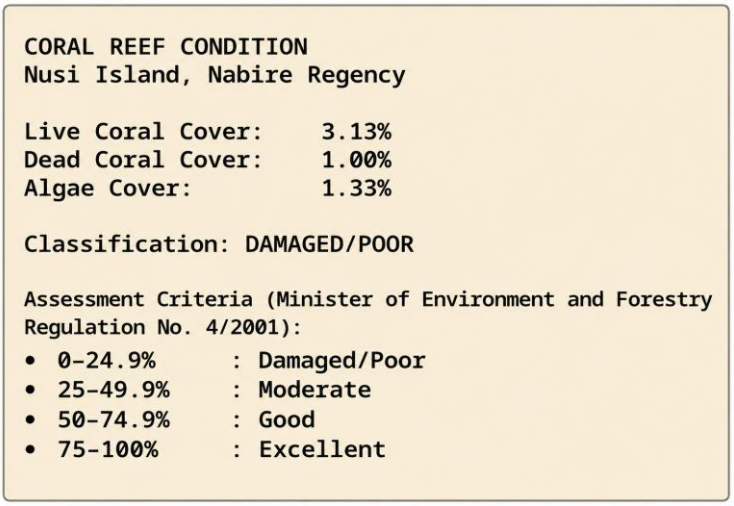

Figure 6. Condition report of the coral reef at Nusi Island

Figure 6 shows that the image provides the condition report of the coral reef at Nusi Island, Nabire Regency. The reef is asse
ssed based on live coral cover, dead coral cover and algal cover.

1. Live Coral Cover was recorded at 3.13%, which is very low, indicating that the reef is severely degraded and unable to support a healthy coral community.
2. Dead Coral Cover was 1.00%, suggesting that the reef has experienced recent coral mortality, likely due to environmental stressors.
3. Algal Cover is at 1.33%, which is relatively low, but excessive algae growth could indicate poor reef health, as it may outcompete corals for space and resources.

Based on the Indonesian Ministry of Environment's Decree No. 4/2001, the reef is classified as damaged/bad, since the live coral cover is below 25%. The classification criteria were as follows:

1. 0–24.9%: Damaged/Bad
2. 25–49.9%: Fair
3. 50–74.9%: Good
4. 75–100%: Excellent

This classification underscores the need for immediate intervention to protect and restore the reefs at Nusi Island.

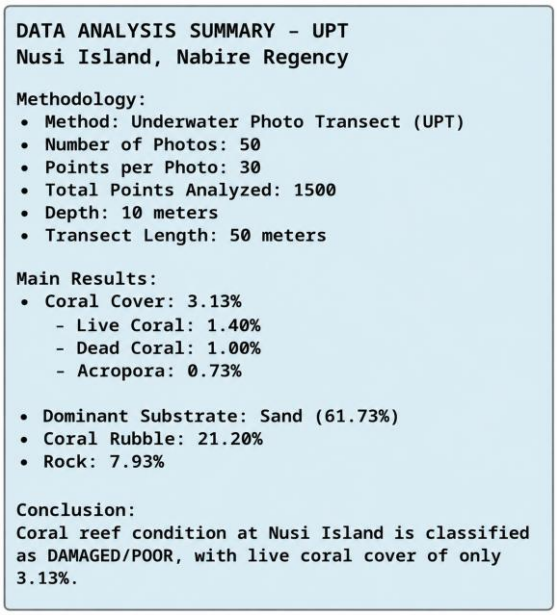

Figure 7. Summary of the Underwater Photo Transect (UPT) data analysis

Figure 7 shows the coral reef at Nusi Island, Nabire Regency. The Methodology section outlines the approach used in this study.

1. Method: Underwater Photo Transect (UPT)
2. Number of Photos: 50
3. Points per Photo: 30
4. Total Analysis Points: 1,500
5. Depth: 10 meters
6. Transect Length: 50 meters

The main findings are as follows:

1. Live Coral Cover: 3.13% of the reef, with the following breakdown:
    a. Massive Coral: 1.40%
    b. Branching Coral: 1.00%
    c. Acropora: 0.73%
2. Dominant Substrates:
    a. Sand: 61.73%
    b. Rubble: 21.20%
    c. Rock: 7.93%

The coral reef at Nusi Island is in a damaged condition, with live coral cover at a critically low level of 3.13%, indicating the reef's poor health and the urgent need for conservation and restoration efforts. The dominance of sand and rubble further reflects the disturbance of the reef ecosystem.

5. Conclusions

5.1 Conclusion

This study presents the first quantitative evidence of coral reef conditions on Nusi Island, Nabire, Indonesia. The findings revealed that the reef was in a poor (damaged) state, with a live coral cover of only 3.13%. The reef is dominated by unstable sand (61.73%) and rubble (21.20%) substrates, which severely limit its capacity for natural recovery. The existing coral community consists mainly of stress-tolerant life forms, indicating a history of significant environmental pressure and/or acute disturbance events. This study underscores the critical need for urgent and targeted conservation efforts to address coral reef degradation in this region.

5.2 Research Limitations

The primary limitation of this study was its narrow spatial and temporal scope. The data collected represent a single 50-meter transect at one depth and were collected at a single point in time. As such, these findings may not be fully representative of the entire reef system around Nusi Island or its conditions throughout the year. The study identified signs of degradation, such as low coral cover and high rubble percentages, but did not definitively pinpoint the causal factors. Further research is needed to investigate the sources of sedimentation, local water quality, and human activities that impact reefs, such as tourism, fishing, and coastal development.

5.3 Suggestions and Directions for Future Research

Based on these findings, several avenues for future research are recommended. First, a broader spatial survey encompassing multiple sites and depths around Nusi Island is essential to map the full extent of coral reef degradation, providing a comprehensive understanding of the overall health of the reef systems. Additionally, future studies should aim to identify the specific drivers of coral reef degradation on Nusi Island, with a focus on water quality analysis, including sedimentation, nutrients, and pollutant levels. Investigating the impacts of local human activities such as tourism, boat anchoring, and fishing is also crucial in developing effective management strategies. Establishing a long-term monitoring program is another key recommendation, as it will allow for tracking changes in the reef community over time and assessing the effectiveness of future management interventions. Furthermore, research on reef restoration efforts, including techniques like coral transplantation and the creation of Marine Protected Areas (MPAs), should be prioritized. Investigating the effectiveness of these interventions is vital for the long-term sustainability and recovery of the coral reefs of Nusi Island.

Author Contributions

NR conceptualized the study, led the data collection process, performed data analysis, and wrote the original draft of the manuscript. AHT contributed to the methodology, validation, and supervision of the study and provided substantial feedback and revisions during the writing process. PB played a significant role in the data analysis, visualization, and review of the manuscript, offering critical insights to improve the overall quality of the research. ST was responsible for project administration, conducted the literature review, and contributed to writing the original draft and final revisions.

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