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A Comparative Analysis of Coral Reef Degradation in Nabire Bay, Indonesia, Using ROV-Based Quantitative Assessment: A Tale of Two Sites

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Abstract

Coastal marine ecosystems in the Coral Triangle are facing unprecedented threats, yet high-resolution data to guide management remains scarce. This study presents a comparative analysis of coral reef health at two contrasting sites in Nabire Bay, Indonesia, using quantitative data from a Remotely Operated Vehicle (ROV). Site 1 (Nabire) and Site 2 (Pulau Nusi) were surveyed to assess benthic composition. The results reveal a stark picture of degradation at both locations, but driven by different ecological dynamics. Site 2 (Pulau Nusi) is in a critical state, with live coral cover at a mere 3.13% and dominated by sand (61.73%) and rubble (21.20%), indicating chronic sedimentation stress. Site 1 (Nabire) shows slightly better but still poor conditions, with live coral cover at 6.64%, but with a higher proportion of dead coral (17.27%). The comparative analysis highlights that while both sites are severely degraded, the dominant degradation driver at Pulau Nusi is likely terrestrial runoff and sedimentation, whereas Site 1 may be experiencing a combination of stressors including a recent mass mortality event. This study underscores the utility of ROV technology for rapid, cost-effective, and quantitative assessment, providing crucial, site-specific data needed to develop targeted conservation and management strategies in a high-priority marine biodiversity region.

Keywords : Coral Reef; Degradation; ROV; Comparative Analysis; Sedimentation; Nabire; Marine Conservation

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1. Introduction

The Coral Triangle, a global epicenter of marine biodiversity, is under severe threat from a combination of local anthropogenic stressors and global climate change (Hoegh-Guldberg et al., 2007; Burke et al., 2011). Effective management and conservation of these vital ecosystems, such as the expansive coral reefs in Nabire Bay, Indonesia, depend on accurate, timely, and spatially explicit data on their condition (Mumby & Steneck, 2008). However, traditional monitoring methods, which primarily rely on SCUBA-based surveys, are often constrained by cost, time, logistical complexity, and safety risks, limiting their scalability and frequency (Ginting, 2023). This creates a critical data gap, hindering the ability of managers to respond effectively to rapid environmental changes.

Recent advancements in marine robotics, particularly the development of low-cost Remotely Operated Vehicles (ROVs), offer a transformative solution to this challenge (Friedman et al., 2012). ROVs can rapidly survey large areas, access depths beyond safe diving limits, and provide high-resolution, georeferenced video data, enabling quantitative and repeatable assessments of benthic communities (Obura & Grimsditch, 2009). Importantly, recent comparative work has shown that ROV-based photogrammetric surveys can reconstruct benthic community structure with a degree of accuracy comparable to traditional diver-based methods, lending further methodological credibility to ROV-derived cover estimates (Paterson et al., 2024). While the potential of this technology is recognized, its application for comparative ecological assessment in remote, high-biodiversity regions of Indonesia remains underexplored.

This study addresses this gap by conducting a comparative assessment of coral reef condition at two distinct sites within Nabire Bay: a general site near the main coastal area (Site 1: Nabire) and a site adjacent to a small island (Site 2: Pulau Nusi). By applying a standardized, ROV-based quantitative analysis at both locations, this research aims to:

1. Quantify and compare the benthic composition and overall health status of the two reef sites.
2. Infer the dominant environmental drivers of degradation at each site based on substrate composition.
3. Demonstrate the efficacy of ROV-based surveys for rapid, comparative ecological diagnostics to inform targeted management interventions.

This "tale of two sites" framing is consistent with broader evidence that neighbouring reef systems can diverge markedly in condition and trajectory, even under similar regional climate forcing, owing to differences in local stressors, disturbance history, and coral life-history strategies (Gilmour et al., 2021). By explicitly contrasting two nearby but ecologically distinct sites, this study aims to demonstrate that site-specific diagnosis, rather than a single regional health score, is essential for designing effective, targeted management responses.

2. Method

2.1. Study Sites and Data Acquisition

Surveys were conducted at two sites in Nabire Bay, Indonesia. **Site 1 (Nabire)** was surveyed on 24 January 2025, at coordinates -3.1628197, 135.5. **Site 2 (Pulau Nusi)** was surveyed on 16 January 2026, at coordinates -3.1628197, 135.6590502. At both sites, a Gladius Mini ROV was deployed at a target depth of 8-10 meters to record high-resolution video transects.

2.2. Benthic Community Analysis

Video data from both sites were analyzed using a point-count methodology. For Site 1, a **Video Transect Analysis** was performed on 11 representative frames. For Site 2, a more intensive **Coral Point Count with Excel extensions (CPCe)** analysis was conducted on 50 frames, generating 1,500 random data points for robust statistical power (Kohler & Gill, 2006).

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For both analyses, the substrate under each point was identified and classified into major functional groups: Live Coral (further broken down by growth form), Recently Dead Coral, Rubble, Sand, and Rock. The percentage cover of each category was calculated to determine the overall benthic composition. The health status of the reefs was classified using the standard Indonesian criteria: <25% live coral cover is categorized as 'Poor' or 'Rusak Berat' (Hadi et al., 2019).

2.3. Comparative Analysis

A direct comparison of the percentage cover of major benthic categories was conducted between the two sites. This allowed for the identification of similarities and differences in the ecological state and potential drivers of degradation. An independent samples t-test or a non-parametric equivalent would be the appropriate statistical method to test for significant differences, though for this paper, a descriptive comparison is presented

3. Results and Discussion

Both sites surveyed in Nabire Bay exhibited conditions of severe degradation, with live coral cover well below the 25% threshold for a 'healthy' reef. However, the composition of the non-living substrate revealed stark differences, pointing to distinct ecological stories.

Site 2 (Pulau Nusi) was found to be in a critical state. Live coral cover was exceptionally low at only 3.13%. The benthos was overwhelmingly dominated by abiotic substrates, specifically Sand (61.73%) and Rubble (21.20%). Together, these two categories accounted for over 82% of the seafloor.

Site 1 (Nabire), while also in poor condition, showed a different degradation signature. Live coral cover was slightly higher at 6.64%. While sand was also a major component, the most notable feature was the high percentage of Recently Dead Coral (17.27%), a figure significantly higher than at Pulau Nusi (1.00%).

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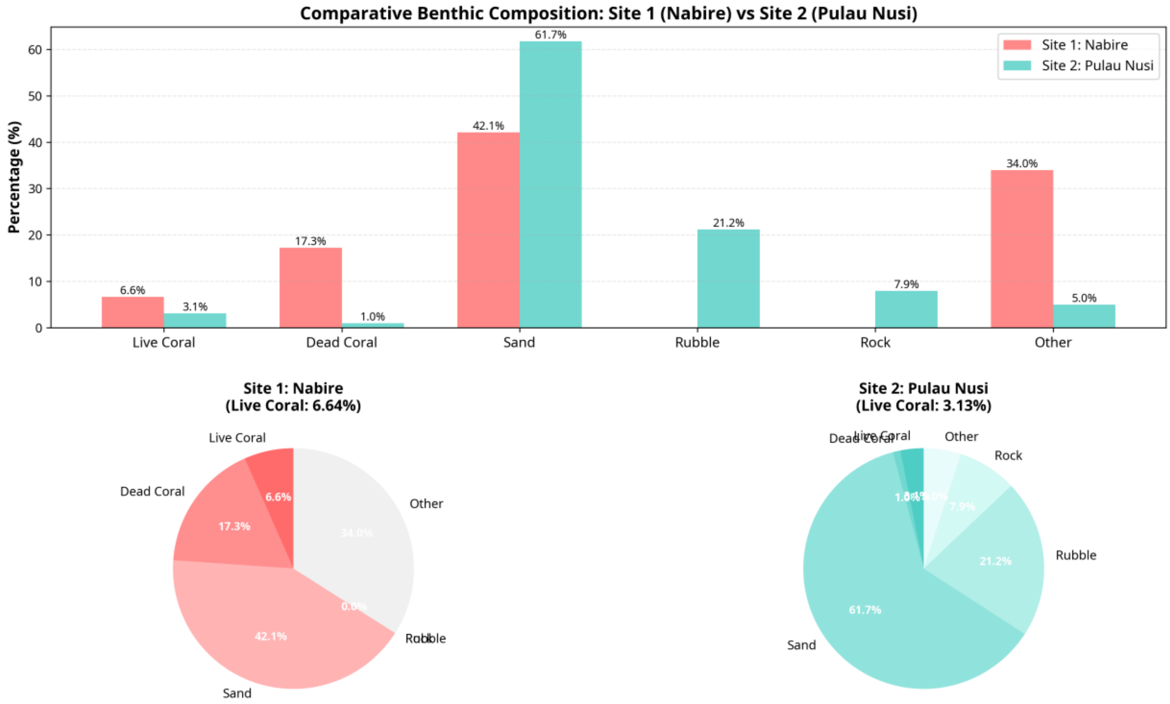

Figure 1: Comparative bar chart of major benthic categories at Site 1 (Nabire) and Site 2 (Pulau Nusi), highlighting the different degradation signatures.

Benthic Category	**Site 1: Nabire (%)**	**Site 2: Pulau Nusi (%)**
Live Coral	**6.64**	**3.13**
Recently Dead Coral	**17.27**	**1.00**
Sand	**42.09**	**61.73**
Rubble	*Not explicitly separated*	**21.20**
Rock	*Not explicitly separated*	**7.93**
Other (Sponge, Algae, etc.)	~34.00	~5.01

Table 1: Comparative benthic composition at the two study sites in Nabire Bay. Note: Categories for Site 1 were broader; 'Rubble' and 'Rock' were likely included in 'Other'.

Discussion

The results paint a concerning picture of the health of coral reefs in Nabire Bay, but the value of this study lies in the comparative diagnosis. The tale of these two sites is not one of uniform degradation, but of different ecological processes likely driving the decline.

The extreme dominance of sand and rubble at **Site 2 (Pulau Nusi)** is a classic symptom of chronic, high-level sedimentation (Rogers, 1990). The fine sediment (sand) smothers existing coral and prevents the settlement of new coral larvae, while the rubble indicates past structural destruction of the reef framework. This combination creates an unstable, shifting substrate that is inhospitable to reef recovery. The source of this sediment is likely terrestrial runoff, a common issue in coastal areas with significant land-use change (e.g., deforestation,

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agriculture, or development) in the adjacent watershed (Fabricius, 2005). The location's turbid water, as noted in the survey log, further supports this hypothesis. This interpretation aligns with recent evidence that semi-enclosed tropical bays are prone to pronounced short-term physicochemical variability, including turbidity and nutrient pulses linked to terrestrial input, which can compound chronic sedimentation stress on adjacent reef flats (De Jong et al., 2025).

In contrast, the high proportion of **Recently Dead Coral** at **Site 1 (Nabire)** suggests a more recent, acute mortality event. This could be the result of a coral bleaching event caused by thermal stress, a disease outbreak, or a sudden influx of pollution (Bruno et al., 2007). While sedimentation is still a factor (42.09% sand), the presence of a significant amount of recently dead, but still structurally intact, coral indicates that the primary driver of mortality here may be different from the chronic smothering observed at Pulau Nusi.

This comparative insight is critical for management. A 'one-size-fits-all' conservation strategy would be inefficient. At Pulau Nusi, management efforts must prioritize addressing the root causes of terrestrial runoff, a complex challenge involving land-use policy and watershed management. In contrast, at Site 1, while also addressing sedimentation, management might also need to focus on building reef resilience to bleaching and disease. The ROV-based assessment provided this crucial diagnostic capability rapidly and cost-effectively

4. Conclusions and Suggestions

This comparative study of two reef sites in Nabire Bay reveals a story of widespread degradation, but with distinct ecological drivers. Site 2 (Pulau Nusi) is critically degraded due to apparent chronic sedimentation, while Site 1 (Nabire) shows signs of a more recent mass mortality event. Both sites fall into the 'Poor' health category, with live coral cover far below sustainable levels.

This research demonstrates the profound utility of ROV technology as a tool for rapid ecological assessment and diagnosis. By enabling cost-effective, quantitative, and comparative surveys, ROVs can provide managers with the nuanced, site-specific data required to move beyond generic conservation measures and implement targeted, effective interventions. Addressing the specific drivers of degradation—be it sedimentation or other acute stressors—is paramount for any hope of preserving the invaluable marine biodiversity of the Coral Triangle.

Building on this foundation, future work could integrate machine learning-based image classification into ROV survey workflows, an approach recently shown to enhance the speed and consistency of coral reef restoration assessment at other Indonesian sites (Saputra, 2024). Coupling such automated classification with the standardized, temporally matched sampling protocol recommended above would further reduce the time and expertise required for large-scale, repeatable reef monitoring across Nabire Bay and comparable regions of the Coral Triangle.

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