Coral reef health assessment and ecological recovery potential in Seram Laut Island, Maluku, Indonesia

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Abstract. This study examined coral reef health and the potential for ecological recovery in the coastal waters of Seram Laut Island, Maluku, Indonesia. Field surveys were conducted at nine stations using the Underwater Photo Transect method along 100 m transects at approximately 3 m depth, combined with Snorkelling Visual Census. Live coral cover, benthic life-form composition, and habitat similarity among stations were analysed using CPCe and MINITAB 19. Live coral cover ranged from 22.81% to 60.15%, classifying two stations as good, five as moderate, and two as poor. Cluster analysis showed habitat similarity values exceeding 95%, grouping stations with comparable benthic structures and disturbance histories, which is relevant for spatial conservation planning. Signs of natural recovery were recorded at Stations 7 and 9, indicated by the regrowth of branching Acropora tubulata and massive corals on dead substrates. These results demonstrate that coral reefs under customary Sasi management can retain ecological resilience despite localized disturbances. This study provides empirical evidence linking benthic similarity patterns and natural regeneration processes within a local wisdom-based management context, supporting adaptive protection strategies and community-based monitoring for long-term coral reef conservation.

Keywords: Community-based conservation, coral reef health, ecological recovery, *Sasi* management

1 Introduction

Coral reef ecosystems are complex and highly diverse habitats that support a wide variety of biota and provide ecosystem services for community survival. Benefits from ecosystem services generally include fisheries resources, shoreline protection, and economic and

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cultural value. The study by [1] showed that services in tropical marine areas tend to be concentrated in coastal areas adjacent to human populations, emphasizing the importance of biodiversity in supporting the well-being of local communities in coral reef ecosystems. Ecosystem services offered in coastal waters are also found in buffer ecosystems adjacent to coral reefs, such as mangrove and seagrass ecosystems [2], helping strengthen protection from floods and large waves. However, population growth and coastal development have contributed significantly to coral reef degradation. The visible degradation of coral reefs leads to a loss of coastal protection, which slowly decreases the productivity of fish resources and undermines their economic resilience[3]. Research results [4] in coastal areas of Indonesia, especially in small islands, show that coral reef ecosystem services provide direct support to the livelihoods of coastal communities, especially in the provision of fish resources for traditional fishers. This is in line with the stability of coral reef health, as the survival of economic fish such as groupers makes healthy corals a key indicator of fisheries sustainability.

However, coral reefs in Indonesia face enormous pressure from human activity. Sediment flow from land, pollution from domestic waste and chemicals, the emergence of coral diseases, bleaching events due to global warming, and destructive fishing practices are among the primary causes of coral reef degradation and reduction in live coral cover [5, 6]. In coral reef environments, abandoned or lost fishing gear, such as gillnets and fishing lines, can become entangled within reef frameworks, causing physical damage, increased mortality, and structural degradation of branching corals, which are particularly vulnerable due to their fragile morphology [7]. The accumulation of these pressures has led to a decrease in the resilience of coral reef ecosystems and loss of biodiversity, which is important for ecological sustainability.

In this context, traditional marine management systems such as *Sasi Laut*, practiced by communities in Eastern Indonesia, offer a community-based conservation approach that has the potential to maintain and restore ecosystems. On Seram Laut Island, the Kilwaru waters are traditionally managed as a *Sasi* area, a form of Maluku local wisdom that regulates when and how marine resources are utilized to ensure the sustainability and recovery of natural stocks. This way of utilizing marine resources to ensure the sustainability and recovery of natural stocks reflects local communities' institutional resilience and concern for natural resource conservation [8], contributing to the ecological recovery of coral reefs and the viability of fisheries-based livelihoods. The dependence of the Seram Laut people on reef fish resources makes reef health a determining factor in economic well-being and food security.

One approach to support effective management is to evaluate coral reef health using a recognized scientific approach. By applying this framework to the Sasi customary conservation area in Seram Laut Island, this study aimed to evaluate the health status of coral reefs and identify the potential for ecological recovery that can be achieved. One widely used approach is the Reef Health Index (RHI), which integrates key benthic and fish metrics, including live hard coral cover and recovery potential (resilience), to summarise overall reef condition [5].

2 Method

2.1 Study sites

Surveys were conducted in June 2023 at nine stations designated as Sasi areas, which are custom-based marine conservation areas managed by local communities in the Seram Laut Islands of Maluku (**Fig. 1**). Station locations were determined using a clustered systematic random sampling design. First, the study area was divided into clusters based on different site conditions. Next, within each cluster, sampling sites were randomly selected. Finally, stations were established at approximately 100 m intervals [9]. **Fig. 1** shows the spatial distribution of nine monitoring stations (St.1 to St.9) that spread along the northern and eastern coastlines of Seram Laut Island.

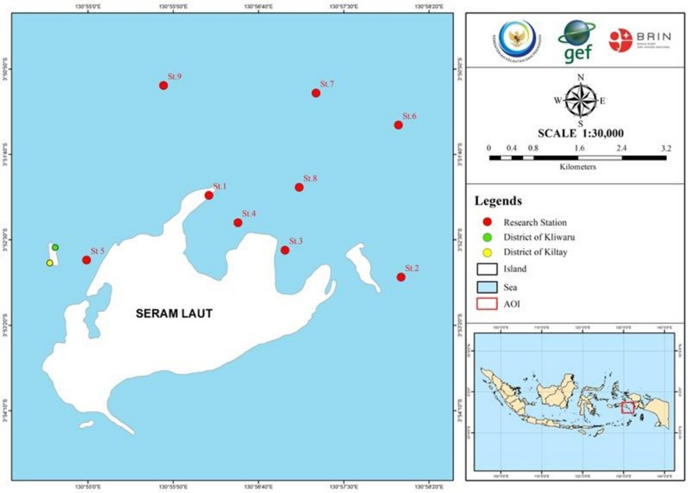

Fig. 1. Research stations in the Seram Laut Island, Maluku.

Station selection was based on a comprehensive assessment of coral reef locations across different habitat types in the management context. The distribution of stations in both exposed and sheltered locations was expected to capture the environmental heterogeneity that influences coral disease dynamics [10]. The integration of traditional marine conservation with *Sasi* (culturally based conservation) practices also provides a unique opportunity to evaluate the effectiveness of culturally based conservation approaches on ecological outcomes. Additionally, station distribution in the administrative areas of Kliwaru and Kiltay allows for spatial comparisons based on different intensities of enforcement and community participation, supporting analyses of social-ecological resilience in ecological and governance contexts [11, 12]. The Area of Interest markings and administrative boundaries on the map also reinforce the value of this mapping, both for scientific analysis and for communicating results to communities [12].

2.2 Data collection

Data were collected at nine stations located within the Sasi management area at an approximate depth of 3 m by employing the bottom transect method combined with the Snorkelling Visual Census (SVC) approach. At each site, a 100 m transect line was established where benthic data were obtained using the Underwater Photo Transect (UPT) method. High-resolution photographs were collected every 5 m (at the 0 m, 5 m, 10 m, 15 m, and 100 m transects) (**Fig. 2**) using a 58 × 44 cm quadrat. This method follows the protocol in [13], allowing non-invasive documentation of coral colonies and signs of disease through snorkel-based visual census surveys.

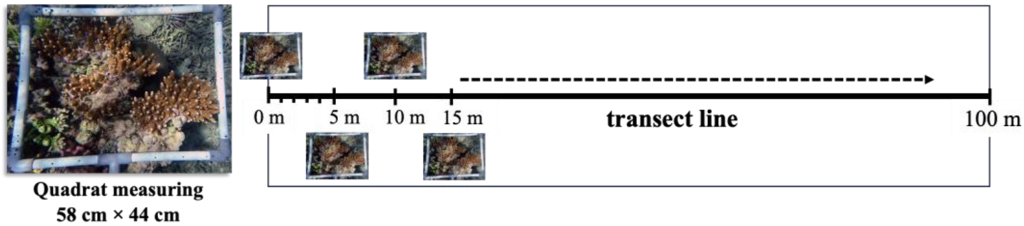

Fig. 2. Photo quadrat sampling design along a 100 m transect using the Underwater Photo Transect method. Benthic photographs were collected at fixed intervals with a 58 cm × 44 cm quadrat. This provided uniform spatial representation and ensured consistent documentation of coral life forms and substrate characteristics along the transect.

2.3 Data analysis

The obtained photographic data were analyzed to calculate the percentage cover of coral colonies and grouped into 17 categories according to the output of the CPCe software [14], which was modified by the *Research Centre for Oceanography - Indonesian Institute of Sciences (P2O-LIPI)*. The categories included Live Coral (LC), acropora (AC), non-acropora (NA), Dead Coral (DC), Dead Coral with Algae (DCA), Soft Coral (SC), gorgonians (G), zoanthids (Z), sponges (SP), Fleshy Seaweed (FS), other (OT), Other Live (OL), Coralline Algae (CA), rubble (R), sand (SD), silt (SI), and rock (RK) [4]. The assessment of coral reef health conditions was based on the Minister Decision of the Environment Minister of the Republic of Indonesia No. 4/2001 on the standard criteria for coral reef damage. A similarity index analysis was conducted using MINITAB 19 statistical software to evaluate the similarity of coral species communities among stations[6]. Patterns of similarity between stations were analyzed using the Complete Linkage clustering method, which enabled the identification of spatial cluster relationships based on similarities in coral community composition [15]. This approach minimizes intra-group variance while maximizing inter-group differences, thereby providing a more precise representation of the ecological relationships among sampling sites. The resulting dendrogram illustrates the degree of similarity between stations and highlights locations with comparable benthic community structure. These analyses support the interpretation of spatial variations in coral reef conditions, and serve as a scientific foundation for assessing ecological homogeneity and designing effective management zones for reef conservation.

3 Results and discussion

3.1 Percentage of coral reef

The analysis of coral cover (in percentage) at nine stations in the Seram Island waters showed variations in coral health status from poor to good. These variations can be further interpreted through a comparative approach with previous studies that used similar software and methods such as CPCe version 4.1 [14, 16]. The percentage of live coral cover found at Station 8 (60.15%) and Station 4 (50.89%) fell into the 'good' category (50-74.9%) according to Minister of Environment Regulation No. 4 of 2001, which reflects relatively stable habitat conditions and minimal anthropogenic disturbance. Similar conditions were also reported by [5], who found that reef sites with higher live coral cover were associated with better water clarity and more favourable physicochemical conditions, whereas locations exposed to higher sedimentation and human activities showed reduced coral cover and lower reef condition.

Table 1. Percentage of benthic cover across nine monitoring stations in the Seram Laut Island waters. Values represent the proportional composition of coral life forms and substrate categories obtained from Underwater Photo Transect analysis and are used to assess coral reef condition and spatial variation among stations.

No	Lifeform Category	St. 1	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8	St. 9
1	LC = *Live Coral* (AC+NA)	24.96	28.15	33.85	48.74	29.63	34.59	23.70	58.44	21.41
	▪ AC = *Acropora*	15.48	22.81	28.22	40.07	10.37	31.26	17.63	30.34	11.93
	▪ NA = *Non Acropora*	9.48	5.33	5.63	8.67	19.26	3.33	6.07	28.10	9.48
2	DCOR = *Dead Coral*	41.78	37.85	39.70	8.37	25.04	35.78	66.59	37.70	69.56
	▪ DCA = *Dead coral with algae*	40.15	36.44	36.37	7.56	19.04	33.19	65.85	36.88	68.89
	▪ DG = *Dead gorgonian*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	▪ ODC = *Old dead coral*	1.04	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	▪ RDC = *Recently dead coral*	0.59	1.33	3.33	0.81	6.00	2.59	0.74	0.81	0.67
4	SC = *Soft Coral* (G+Z)	0.15	0.22	0.01	2.15	0.00	5.70	0.00	0.00	0.96
	▪ G = *Gorgonians*	0.15	0.00	0.01	2.15	0.00	4.67	0.00	0.00	0.96
	▪ Z = *Zoanthids*	0.00	0.22	0.00	0.00	0.00	1.04	0.00	0.00	0.00
5	▪ S = *Sponges*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	MA = *Macro Algae*	0.00	0.00	7.22	0.34	4.67	0.07	0.00	0.07	0.00
7	O = *Other* (OT+CA)	2.67	0.37	0.00	0.00	0.74	0.00	0.00	1.71	0.44
	▪ OT = *Other Live*	2.67	0.37	0.00	0.00	0.74	0.00	0.00	1.71	0.44
	▪ CA = *Corraline Algae*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	DC = *Deseased Coral*	0.52	0.00	0.00	0.07	0.00	0.00	0.07	0.74	0.00
9	P = *Pavement*	0.74	0.37	0.67	0.00	0.00	0.00	0.00	0.07	0.22
10	R = *Rubble*	24.00	28.07	18.07	36.96	36.81	23.85	8.81	1.11	3.63
11	S = *Sand*	5.19	4.89	0.52	3.26	3.11	0.00	0.59	0.15	3.63
12	U = *Unknowns*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total coverage (%)		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Percentage of healthy coverage (%) = LC + SC + SP + OT		**27.78**	**28.74**	**33.86**	**50.89**	**30.37**	**40.30**	**23.70**	**60.15**	**22.81**

In contrast, the low coral coverage at Station 7 (23.60%) and Station 9 (22.81%), which are classified as 'poor' (0-24.9%), indicate high environmental pressure. The study [4] mentioned that similar poor conditions were also found in several locations on Tunda Island, especially on the southern and central sides of the island, which were adjacent to the port area, and snorkelling tourism activities and fishing using destructive fishing gear, such as arrows and anchors. This causes damage to the reef structure, particularly affecting the dominance of Dead Coral with Algae (DCA) and rubble categories, which are prominently visible in locations with high pressure.

These results are consistent with those of [4], who showed that reef sites characterised by higher sediment deposition and reduced water clarity exhibited lower live coral cover and resilience, indicating that fine sediments and unstable substrates can constrain coral growth and recovery. In contrast, the present study in the Seram Laut showed spatial variation in substrate composition, where stations with lower sand cover, such as stations 4 and 5, exhibited higher percentages of live coral cover. This pattern indicates that sediment accumulation and substrate stability are key factors that influence coral reef health in the study area. This condition contributes to a decrease in light intensity and inhibits the photosynthetic process of zooxanthellae, which are indispensable for hermatypic corals. As a result, coral growth is inhibited and natural regeneration does not run optimally. Observations also showed that stations in the 'medium' category (25-49.9%), such as Stations 1, 2, 3, 5 and 6, had varying live coral cover, illustrating the interaction of both biotic and abiotic factors. In the Seram Laut area, where all stations are located at similar shallow depths (approximately 3 m), differences in coral cover are not related to depth but rather to wave exposure, sedimentation rate, and human activities. As observed [4, 5] in other shallow-water reef systems, wave energy and sediment resuspension play crucial roles in shaping the coral community structure. Shallow-water corals in this region are frequently exposed to high hydrodynamic energy and physical disturbances, including wave action, snorkelling, and small-boat anchoring, which can damage fragile branching corals and limit their regeneration. However, areas with higher exposure to human activities such as snorkelling and boat mooring remain vulnerable to physical disturbances that can damage coral colonies. Low coral diversity in disturbed zones is often associated with tourism and sediment deposition. In the Seram Laut ecosystem, coral distribution is influenced by ocean currents and proximity to community-based fishing areas. Additionally, tidal fluctuations during the dry season periodically expose shallow reef flats to air and strong water movement, causing desiccation, sediment abrasion, and thermal stress to coral tissues. These tidal dynamics also facilitate direct human access to reef areas, thereby increasing the likelihood of physical damage. Interviews with local fishers confirmed that during extreme low-tide conditions, people can walk across the exposed reef flat, unintentionally breaking fragile corals and hindering their natural regeneration.

Monitoring coral reef cover on Seram Island provides an essential baseline for evaluating the current ecological conditions of coral reef ecosystems in eastern Indonesia. The observed variation in coral cover among the research stations reflects how local environmental settings and community activities shape reef health. This pattern highlights the importance of developing management strategies tailored to local site conditions, in which both habitat characteristics and human utilization are carefully considered. Community-based conservation and reef rehabilitation programs, including the installation of artificial reefs and coral transplantation, have been suggested as practical actions to restore degraded reef habitats [16, 17]. The reef ecosystems around Seram Island are generally moderately to severely degraded, with deterioration in some areas linked to anchoring practices and small-scale coastal tourism[18]. Strengthening local participation and integrating restoration planning with adaptive management can provide valuable guidance for long-term monitoring and sustainable conservation efforts in the region.

3.2 Similarity in coral reef habitat conditions

The percentage similarity analysis of reef habitat conditions among stations showed values exceeding 95.00%, forming three distinct groups with the highest levels of ecological similarity: (a) stations 7 and 9, (b) stations 1 and 2, and (c) stations 3 and 6. The results of the cluster analysis are shown in **Fig. 3**. Station 4 exhibited noticeably different baseline habitat conditions compared to the other sites. Specifically, Station 4 was characterized by a higher proportion of rubble and sand substrates, lower live coral cover, and greater sediment deposition, which likely reduced coral recruitment and regeneration potential. These features distinguish it from the predominantly coral-dominated substrates observed at other stations where the reef structure and complexity were higher. Differences may influence environmental variability in substrate composition, local hydrodynamic conditions, and the intensity of anthropogenic disturbances, including small-scale fishing and boat anchoring activities. Consequently, these factors may explain the lower habitat similarity at Station 4 compared to the other sampling sites.

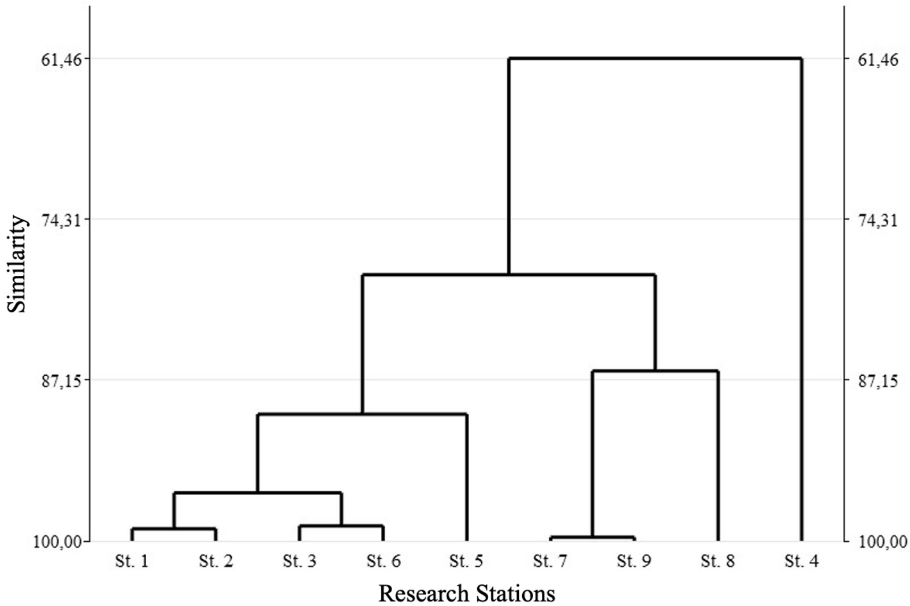

Fig. 3. Similarity of coral reef habitat at research stations in Seram Laut Island waters, based on benthic composition. The dendrogram shows clustering of stations with similar substrate and coral life-form composition.

3.3 Coral reef ecosystem condition based on benthic lifeform coverage

In this study, the condition of coral reefs was interpreted based on the composition and dominance of coral life forms, which represent indicators of reef structure, stability, and ecological resilience. The comparison between *Acropora* and *non-Acropora* groups helps to describe how coral assemblages respond to both natural and human-induced pressures. At Stations 7 and 9, the reefs were classified as moderately damaged, mainly because of the dominance of foliose and massive colonies and a noticeable decline in branching *Acropora*. This shift in composition suggests a moderate disturbance from sediment accumulation, wave exposure, and local human activities, such as anchoring and trampling. Similar findings have been reported by [19] and [20], who observed that branching *Acropora* species tended to decrease under turbid and high-energy conditions. In contrast, massive and encrusting growth forms are more tolerant, and thus remain dominant in such environments.

Previous studies have also shown that the prevalence of foliose and massive corals has dual ecological implications. These growth forms may indicate adaptation to high-energy or turbid environments. However, on the other hand, they can also serve as early warning indicators of reef degradation when environmental stress becomes chronic and prolonged [21, 22, 23], In the context of Seram Island, this mixed condition implies that coral communities are adjusting to persistent natural stressors while simultaneously facing reduced recovery potential. Supporting research [24, 25, 26]. have also associated similar changes in coral composition with anthropogenic impacts, including trampling, fishing gear contact, and sediment resuspension caused by tourism activities. Overall, the life form composition in Seram Laut waters reflects both environmental variability and cumulative human disturbances, providing a clear ecological justification for classifying reefs as moderately

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damaged [27]. The observed dominance of dead corals with algae and the high proportion of rubble further indicate localized reef damage, likely caused by trampling, anchor deployment, and the use of nets or traps in shallow reef areas (see **Fig. 4**).

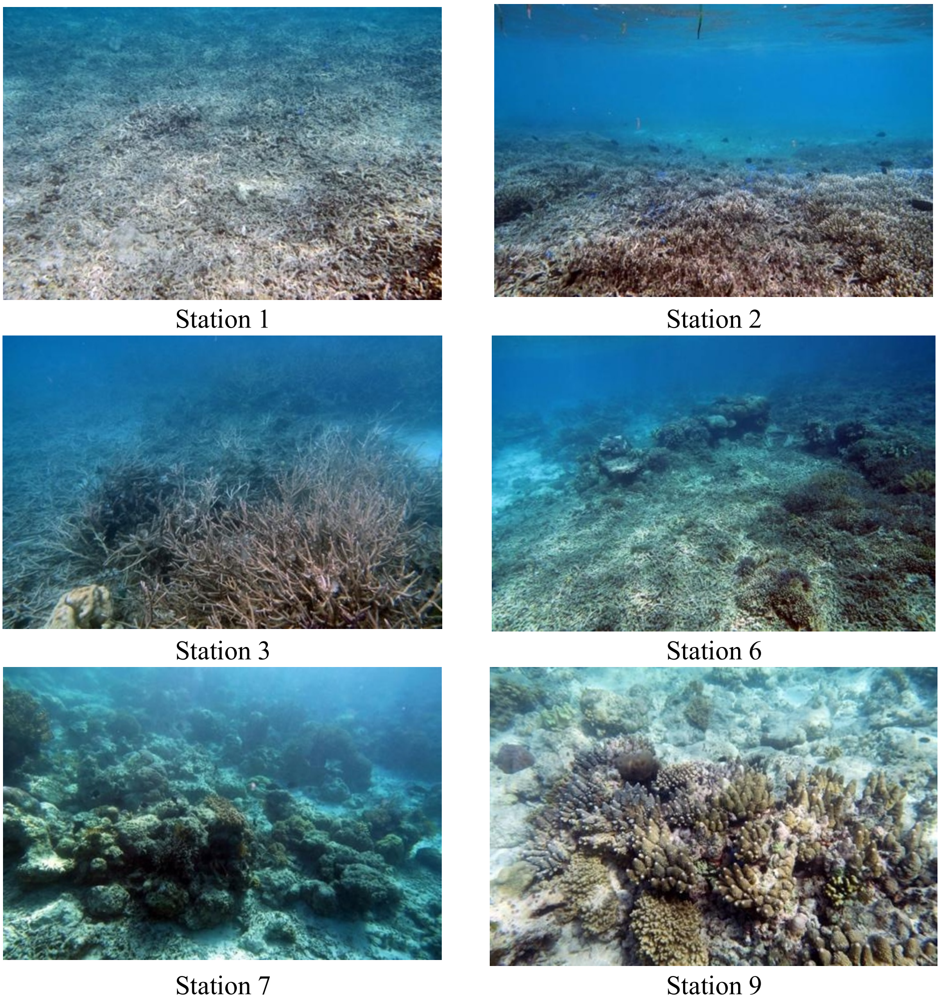
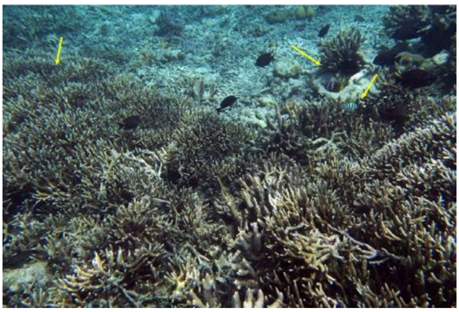
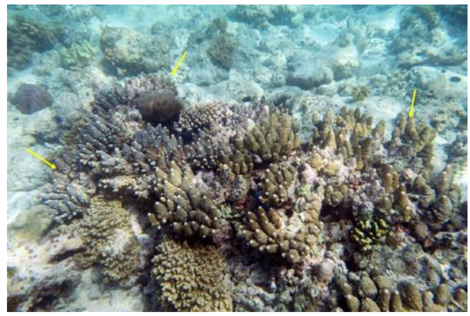


Fig. 4. Representative benthic conditions at research stations showing the highest similarity based on habitat similarity analysis. Visual records highlight comparable substrate characteristics and coral life-form assemblages that support the observed clustering patterns among stations.

The highest similarity from the cluster analysis results provided a general overview of the similarity of benthic habitat conditions. The resulting similarity is not based on the health level but on the overall similarity of the reef condition. This is consistent with the findings of [28], which stated that the classification of similarity in coral substrates reflects the physical form of the benthic habitat more than its ecological status. An overview of each benthic habitat in the three groups with similarity index values of > 95% is shown in **Fig. 4**. The highest similarity of reef coverage was between stations 7 and 9, where the benthic habitat was dominated by living corals of the genus *Acropora* and some dead corals of the life form Dead Coral with Algae and Debris. As noted by [29], the dominance of dead substrates, such as DCA and debris, is often an indicator of habitat structure rather than biological recovery. Meanwhile, at stations 1 and 2, similarities were found in the basic habitat conditions, including the presence of *Acropora* and non-*Acropora* life forms, rubble, and a relatively high percentage of dead coral. This similarity reflects a similar benthic structural heritage, rather than a healthy ecological condition [30]. Similarities between stations 3 and 6 were found because both stations were dominated by coral species of the genus *Acropora* and reef rubble along the transect. [31] A high similarity index often reflects parallel substrate structures, such as *Acropora* species and rubble.



Station 7



Station 9

Station 4

Station 8

Fig. 5. Natural growth of branching coral species at selected research stations in Seram Laut Island waters. Visual evidence shows new branching coral colonies forming on dead substrates and rubble. These findings indicate ongoing natural regeneration under varying local environmental conditions.

The similarity in bottom conditions between stations, with the most significant similarity based on the percentage of coral cover, indicated that the activities in each area were comparable. The presence of branching coral species that have begun to grow and form colonies on the surface of dead coral at stations 7 and 9 is shown in **Fig. 5**. Similarities in activity are clearly visible in the traces of coral breaks and damage caused. At several transect locations, coral breaks, which appeared to have been struck by a ship's anchor, and neat elongated rows of breaks, similar to those entangled in nets, were visible. Other similarities point to damage caused by trampling rather than by bombs or toxins, such as potassium. Anthropogenic activities, such as solid waste disposal, sedimentation from land clearing, and direct pressure from shipping activities, have a significant impact on coral reef damage in Ambon Bay, including evidence of damage similar to that caused by anchor dragging and gillnets. At several locations, the growth of new Acropora colonies on dead substrates suggested the potential for strong resilience to such pressure. A similar pattern has been reported in degraded reef settings [32], where benthic cover is dominated by dead coral substrates with algal growth and coral rubble, and where recovery actions that relieve local pressures and stabilise rubble can yield measurable benefits in coral cover within five years. The debris fracture patterns shown are fractures resulting from prolonged activity, indicating a visible coral growth pattern with long coral growth lengths (particularly branching corals and some massive corals on the surface of dead, massive coral).

Growth following disturbances in coral reef ecosystems is generally referred to as coral reef resilience. This refers to the ability of corals to recover and adapt to conditions to establish new colonies. [33] also pointed out that the strength of coral reefs depends significantly on the type of ground they grow on and whether new coral groups are starting up, especially in places where people cause limited to average levels of harm. These elements are important for corals to naturally bounce back by bringing in new corals and regrowing. Similarly, [34] showed that post-bleaching recovery is shaped not only by heat-stress legacy effects but also by early-stage recruit performance and the physical structure of the settlement substrate at the onset of recovery. Recent evidence shows that hydrodynamic energy and water flow regimes interact with coral morphology. Specifically, these physical factors and coral shape together determine how corals are exposed to disturbances and how they recover, ultimately shaping resilience patterns [35]. These forms can survive fluctuating flow conditions and provide complex habitat structures for associated organisms. Meanwhile, in moderate conditions, as an impact of anthropogenic pressure areas, the structural complexity of branching and massive coral colonies was crucial for providing spawning habitat and shelter for reef fish, thus contributing to long-term recovery.

Several factors, including environmental conditions and the management practices of local communities and local management, determine the resilience of coral reefs. This aligns with[36], who explains that highly resilient coral reefs are typically characterized by the active involvement of surrounding communities in the conservation area and the implementation of adaptive management strategies. Community-based conservation, based on an understanding of the ecological and economic benefits of coral reefs, particularly as habitats for economically valuable fish, plays a key role in maintaining and restoring coral ecosystem function. Given the resilience of the branching and the large numbers of coral species at stations 7 and 9, it is highly likely that the health of Seram Island's coral reefs will recover naturally over time if Seram Island's waters are managed through area protection in collaboration with the local community, combined with increased awareness of the benefits of coral reefs to fisheries.

4 Conclusion

A coral reef health assessment at nine stations in the Sasi area of Seram Laut Island Fisheries revealed variable conditions, with live coral cover ranging from 22.81 to 60.15%. Stations 7 and 9 demonstrated the potential for ecological recovery through the natural regeneration of branching corals (*Acropora* sp.) and massive corals on dead substrates. Analysis of similarity in the benthic habitat yielded three groups with a similarity index of >95%, indicating homogeneous benthic conditions and similar anthropogenic pressures, such as broken anchors and fishing gear. These findings emphasize the importance of mapping protected zones, considering the similarities in the substrate and natural resilience of corals. As a form of local wisdom, sasi practices have the potential to support ecosystem recovery when combined with bioecological approaches and data-driven adaptive management. Spatial analysis and life-form categories provide a snapshot of habitat conditions relevant to conservation policies. This study recommends strengthening local protection and further research into coral diseases, associated fish communities, and the long-term effectiveness of Sasi in maintaining the resilience of coral reef ecosystems on Seram Island.

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