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Research Article

Spatial distribution of coral reefs at Babi Island Waters, Aru Islands Regency

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ABSTRACT

This study analyzes the spatial distribution of coral reefs surrounding Babi Island, Aru Islands Regency, Indonesia. The research aims to understand the condition of the coral reefs, create coral reef maps, and monitor their health. Satellite imagery and transect surveys were used to determine coral reef area, species richness, and benthic cover. The results show that the coral reefs are more extensive in the western part of the island (129.91 hectares) compared to the southern part (56.5 hectares). A total of 96 species of stony coral were identified, representing 67.1% of the species found in the Aru Islands coastal waters. Fifty of these species are considered protected under IUCN classifications. The coral reefs in the western part of Babi Island are in good condition with a hard coral cover percentage exceeding 70%. The southern part of the island also has coral reefs in good condition, but with a slightly lower hard coral cover percentage.

Keywords: species richness, coral cover, hard coral, snorkeling zone, diving zone

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INTRODUCTION

Babi Island, located in the Aru Islands Regency, Maluku, Indonesia, is surrounded by well-preserved coral reefs. Coral reefs are important marine ecosystems due to their many functions, including serving as habitats for various marine biota, providing food for humans, and protecting coastlines from erosion. Babi Island has great potential for marine tourism. Tourism activities that have been conducted on the island and surrounding waters include camping, swimming, snorkeling, diving, and fishing. In the regional development policy of the Aru Islands Regency, this island is designated as one of the tourist destinations.

Coral reefs are vital marine ecosystems because of their diverse functions, serving as habitats for a wide range of marine life, including providing food and shelter for various species (Moriarty et al. 2023; Sobha et al. 2023). They are crucial for supporting global biodiversity, hosting a large portion of marine species, and playing a key role in stabilizing marine ecosystems (Dhanya & Jignesh, 2022). Additionally, coral reefs offer economic benefits by supporting fisheries that millions of people rely on for their livelihoods (Katili et al. 2020). However, these ecosystems face numerous threats, such as rising sea temperatures, pollution, sedimentation, and destructive fishing practices, leading to coral bleaching and degradation (Suyani et al. 2023).

These tourism activities and policies are strongly linked to the existence of coral reefs. Scuba diving ecotourism significantly contributes to coral reef conservation, supporting marine conservation through funding and sustainable practices (Nababan, 2023). Coral reefs are a part of marine ecotourism development (Tuwo et al. 2021). The marine ecotourism model includes well-maintained natural coral reefs, if developed within an ecotourism architecture that integrates coral reefs into marine tourism development (Haedar et al. 2021).

The economic dependence of communities on coral reefs is very significant, as is the case in the Aru Islands Regency. Globally, communities heavily rely on coral reefs for economic sustenance and livelihoods. Coral reefs support nearly a third of marine fish species, providing about 10% of the total fish consumed by humans worldwide, with more than 70% of artisanal fish production coming from coral reef ecosystems (Fairos, 2022). Nearly half a billion people, representing 8% of the world's population, live within 100 km of coral reefs, with around 100 developing countries highly dependent on coral reefs for their livelihoods (Maire et al. 2020).

The economic value of coral reefs is highly significant, with coastal fishing communities in Tanzania, for instance, entirely relying on coral reefs for their livelihoods, supplying 90% of the animal protein consumed and being the main source of income for the community (Mbije 2023). Additionally, coral reefs provide substantial economic benefits through activities such as tourism, fisheries, and coastal protection, making their conservation essential for sustaining the economic well-being of communities (Kittinger et al. 2015).

In addition to the ecological and economic benefits described above, coral reefs in Indonesia currently face various threats, such as environmental pollution, climate change, and overexploitation. These threats can cause damage and death to coral reefs, which ultimately can negatively impact marine biodiversity, natural resources, and the economy of coastal communities.

The above overview forms the basis for developing research on the spatial distribution of coral reefs in Babi Island, which has several important objectives: (1) to understand the condition of coral reefs in the area: this information can be used to develop effective coral reef management strategies; (2) to create coral reef maps: these maps can be used for various purposes, such as marine spatial planning, marine tourism development, and scientific research; (3) to monitor the health of coral reefs: this monitoring can help scientists understand how coral reefs respond to various factors, such as climate change and environmental pollution.

Through a strong understanding of the condition of the coral reefs on Babi Island, we can take appropriate steps to protect and preserve this important marine ecosystem. This study aims to analyze the spatial distribution of coral reefs on Babi Island. The research is considered very important for understanding the condition of coral reefs in the area and for developing effective coral reef management strategies. This study is expected to make a significant contribution to coral reef conservation efforts in Indonesia (Yulius et al. 2015).

METHODS

The research was conducted in November 2023 in the waters of Babi Island, Aru Islands. Data analysis of the coral reef area was performed using imagery used in the mapping process (Maulana et al. 2018; Amrilah et al. 2019).

Data on the species richness of hard corals, the length of colony intersections for each hard coral species (also including life forms), and the length of intersections of coral reef components (other biotic and abiotic components) at each reef station were collected using the Line Intercept Transect (LIT) method (English et al. 1997; Sahetapy 2015).

The types of coral life forms and benthic organisms were identified and determined following English et al. (1997) and Sahetapy (2015). The percentage cover of coral reef components (including hard corals) was analyzed and determined using the formula from English et al. (1997), Sahetapy (2015), Sahetapy et al. (2018), which is:

$$Pt = \frac{Pjc}{Pjt}\ x\ 100\%$$

where: *Pt* = percentage cover; *Pjc* = Category length; *Pjt* = Transect length.

The condition of coral reefs at each location/zone studied was determined using the percentage cover of hard corals and the Standard Criteria for Coral Reef Damage (Ministry of Environment Decree Nu. 4, 2001), English et al. (1997), and Sahetapy (2015), as shown in Table 1.

Table 1. Standard criteria for coral reef damage and condition

No.	Condition	Criteria	Cover Percentage (%)
1.	GOOD	Excellent	75 – 100
2.		Good	50 – 74,9
3.	BAD	Fair	25 – 49,9
4.		Bad	0 – 24,9

Source : Minister of Environment Decree Number 4 of 2001

RESULTS AND DISCUSSION

Satellite imagery analysis shows that the coral reefs in the waters of Babi Island cover an area of 186.41 hectares (Figure 1). Spatially, the distribution indicates that the coral reefs on the western part of Babi Island are more extensive (129.91 hectares) than those on the southern part (56.5 hectares). The distribution of coral reefs at the study location aligns with Suharsono's (2008) statement that coral reefs generally grow in more open waters facing the sea. This is likely due to the position of Babi Island, which is open towards the sea, having water conditions that support coral life, such as better and more stable water temperature and salinity due to continuous seawater movement and relatively low sedimentation levels.

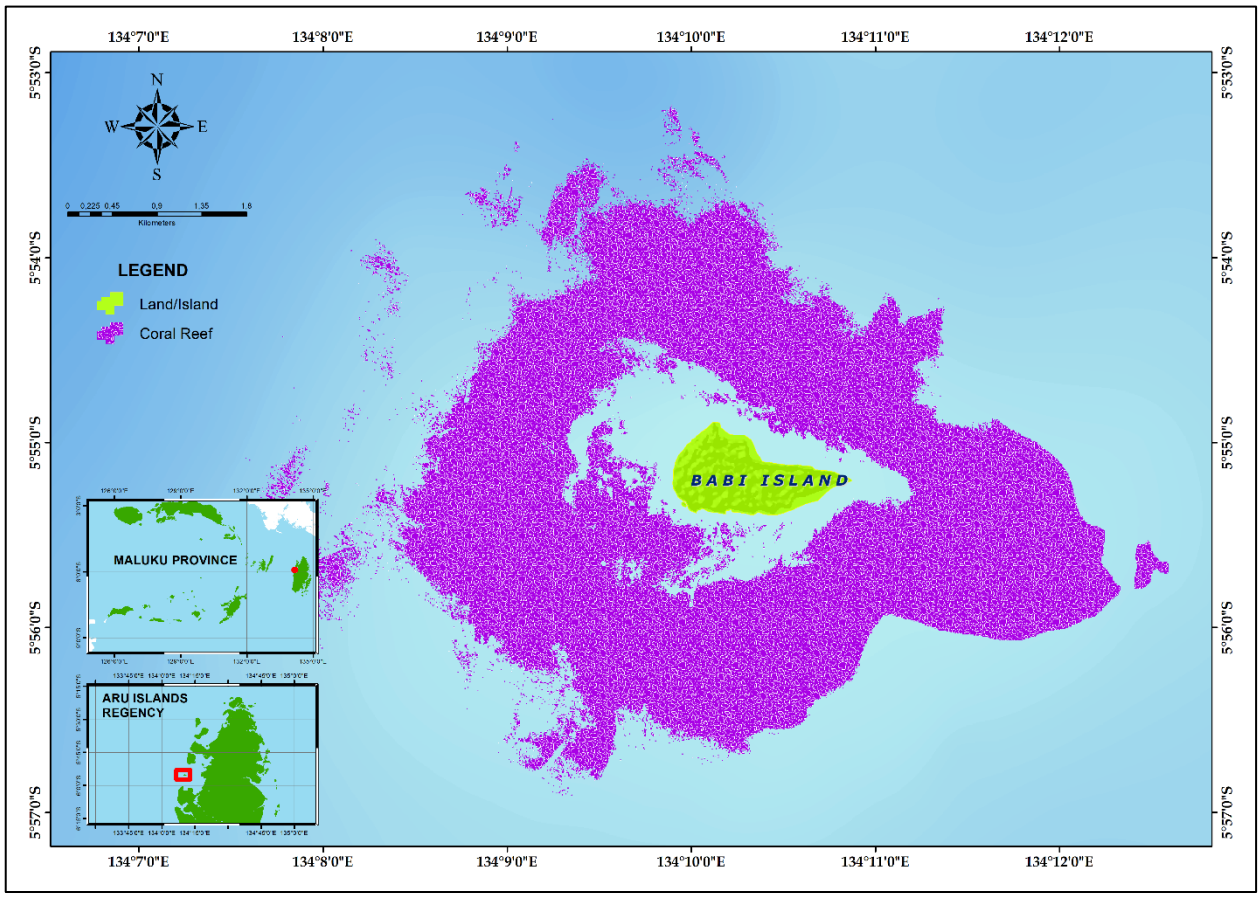

Figure 1. Research location map: coral reef waters of Babi Island

Coral Taxa Composition

The coral reefs in the coastal waters of Babi Island had 96 species of stony corals from 42 genera and 16 families (Tabel 2). This species richness represents 67.1% of the 143 species of stony corals in the coastal waters of the Aru Islands and 70.2% of the 126 species in the coastal waters of the Aru Islands District (Sahetapy, 2015). The coral species richness in the reefs of Babi Island accounts for 30.8% of the 312 species of stony corals in the coastal waters and small islands of Maluku Province and represents 82.8% of the 116 species in the coastal waters of Negeri Hukurila (Sahetapy et al. 2021). The coral families with the most species are Acroporidae (28 species), Faviidae (18 species), and Poritidae (21 species). Conversely, coral families with low species richness include Astroniidae, Oculinidae, and Helioporidae, each with only one species.

In two reef locations, 50 species of stony corals were found to be protected. Specifically, two species (*Acropora rudis* and *Palauastrea ramosa*) are classified as Endangered, three species (*Acropora aspera, Acropora elegans, Acropora loisetteae*) as Vulnerable, 35 species as Near Threatened, and 10 species as Least Concern. The protected coral species richness in Babi Island's reefs is lower than that of the coastal waters and small islands of Maluku Province, which had 97 protected species, including five Endangered, 11 Vulnerable, 70 Near Threatened, and 11 Least Concern species. This analysis highlights the necessity to protect the 50 protected coral species and their coral reef habitats.

Table 2. Distribution of coral species richness across stations and zones

	Western Part of Babi Island		Southern Part of Babi Island	
	SZ	DZ	SZ	DZ
Number of Species	73		84	
Number of Genera	33		41	
Number of Families	15		16	
Number of Species	53	42	46	57
Number of Genera	28	23	26	31
Number of Families	13	11	14	13

The species and genera richness of corals in the Snorkeling Zone of the western coral reefs of Babi Island is higher than that in the Snorkeling Zone of the southern coral reefs of Babi Island. Additionally, the species and genera richness of corals in the Diving Zone of the southern coral reefs of Babi Island is higher than that in the Diving Zone of the western coral reefs of Babi Island. Theoretically, the difference in the richness of protected coral species in these two reef locations is due to the variation in the biophysical environmental conditions of each zone at each reef location.

Additionally, 23 ornamental coral species were identified, which can be cultivated for the marine aquarium industry. This ornamental coral species richness represents 33.3% of the 69 ornamental coral species in the coastal waters and small islands of Maluku Province (Sahetapy et al. 2018). Despite the varying species richness of ornamental corals among reef stations, the 23 ornamental coral species in the western and southern reefs of Babi Island have significant economic potential. However, efforts to realize this economic potential should involve ornamental coral farming, followed by export. The successful ornamental coral farming in Seribu Islands (Jakarta Bay) serves as a model, though adjustments to the biophysical conditions of Babi Island's coral reefs and waters are necessary.

The identification results show that 10 coral species have a wide distribution. These species belong to several families, including Poritidae (3 species), Acroporidae (2 species), Faviidae (2 species), Fungiidae (2 species), and Pocilloporidae (1 species). Conversely, 19 coral species have a limited distribution, including *Acropora divaricata, Acropora nobilis, Acropora robusta, Acropora rudis* (Vulnerable), *Leptoseris explanata, Turbinaria bifrons, Favites chinensis, Goniastrea aspera, Goniastrea pectinata, Oulophyllia crispa, Cycloseris tenuis, Lobophyllia hemprichii, Symphyllia agaricia, Symphyllia radians, Alveopora spongiosa, Goniopora stuxchbury, Porites stephensoni, Coscinsraea exesa,* and *Psammocora contigua*. From a resource management perspective, these limited-distribution species, especially the Endangered Acropora rudis, require protection.

The richness of coral taxa (species, genera, and families) across locations and between snorkeling and diving zones at each reef site is presented in Table 1. The coral reefs in the southern coastal waters of Babi Island exhibit higher species, genera, and family richness compared to the reefs in the western part of Babi Island.

Condition of the coral reefs at the Western Part of Babi Island

The observation of the coral reef condition in the western part of Babi Island was conducted in the Mid-Reef Flat Zone (Snorkeling Zone) and the Reef Edge Zone or Diving Zone (Table 3), located at 04°33'38.9" S and 129°40'1.29" E. According to satellite image data interpretation, the coral reef area in the coastal waters of the western part of Babi Island is 129.91 hectares. The percentage of coral cover in the Mid-Reef Flat Zone or Snorkeling Zone (SZ) reached 70.52%, and in the Reef Edge Zone or Diving Zone (DZ) it was 72.66%. Referring to the assessment criteria proposed by English et al. (1997), Minister of Environment Decree Nu. 4 of 2001, and Sahetapy (2015), it can be said that both the Snorkeling Zone and the Diving Zone in the coastal waters of the western part of Babi Island are in the Good category.

In the shallow reef flat to mid-reef zones (Snorkeling Zone), the dominant coral life forms with high percent cover are Acropora Branching and Coral Massive. Additionally, in the deep reef slope zones (Diving Zone), the dominant coral life forms with high percent cover are Acropora Branching, Acropora Tabulate, and Coral Massive.

One of the main consequences is that coral colonies can grow into a variety of morphological forms as new individuals grow and develop. The development of these morphological forms is called a coral lifeform, and can be used as a first step in identifying corals, such as the genera and species of corals that grow into a particular lifeform (Sala et al. 2021).

The dominant coral species in the Snorkeling Zone of the western part of Babi Island's coral reefs are *Acropora pulchra, A. intermedia*, *Acropora aspera* (Acropora branching life form), as well as Porites lutea and *Porites lobata* (coral massive life form). These dominant species have relatively small ranges and average colony diameters but

high colony abundance. Coral species such as *Goniopora stutchbury*, *Montipora verrucosa, Acropora lositteae*, and the endangered *Acropora rudis* have low percent cover values despite having large ranges and average colony diameters due to their low colony abundance.

Table 3. Benthos life forms and coral cover percentage in the the western part of Babi Island waters

Benthos Life Forms	Reef Flat Zone - Middle (*Snorkeling*)			Reef Margin Zone - Slope (*Diving*)		
	Num. of Species	Num. of Colony	CP (%)	Num. of Species	Num. of Colony	PP (%)
Acropora Branching	10	41	40,10	5	25	23,74
Acropora Tabulate	1	1	0,20	2	15	15,20
Acropora Digitate	1	1	0,36	0	0	0,00
Acropora Submassive	1	6	2,58	1	21	9,88
Acropora Encrusting	0	0	0,00	0	0	0,00
Coral Branching	3	7	4,08	2	6	3,16
Coral Massive	5	19	18,32	6	23	16,58
Coral Encrusting	1	2	2,50	1	2	2,08
Coral Submassive	0	0	0,00	0	0	0,00
Coral Foliouse	3	3	2,38	2	4	2,02
Coral Mushroom	0	0	0,00	0	0	0,00
Coral Heliopora	0	0	0,00	0	0	0,00
Coral Millepora	0	0	0,00	0	0	0,00
Amount	**25**	**80**	**70,52**	**19**	**96**	**72,66**
Soft Coral (SC)			4,50			5,08
Coralin Algae (CA)			1,28			1,08
Macro Algae			0,92			0,00
Sponge			1,42			1,56
Other Benthic			1,96			1,74
DCA			10,38			4,28
Dead Coral (DC)			4,48			7,26
Sand (S)			2,02			3,08
Rubble (R)			2,52			3,26
Amount			**29,48**			**27,34**
T o t a l			**100**			**100**

In the Diving Zone of the western part of Babi Island's coral reefs, the dominant coral life forms are *Acropora hyacinthus* (Acropora tabulate life form), *Acropora palifera* (Acropora submassive life form), Acropora pulchra (Acropora branching life form), as well as Porites lobata and Porites lutea (coral massive life form). *Acropora pulchra* and *Acropora hyacinthus* dominate in terms of percent cover because of their relatively large range and average colony diameters combined with high colony abundance. Acropora palifera has a high percent cover with a relatively small range and average colony diameter due to its high colony abundance. The coral species *Acropora horrida* in the Diving Zone of the western part of Babi Island's coral reefs has a relatively small percent cover because of its low colony abundance, despite its large range and average colony diameter.

Johan et al. (2003) states that Acropora corals grow in clear waters and locations with wave action. Acropora branching species, in particular, are fast-growing corals (10-20 cm/year). This observation is consistent with field observations, where water clarity in the western part of Babi Island's coral reefs allows sunlight to penetrate to the depth of the Slope Zone.

Other abiotic and biotic components, especially soft coral, have high percent cover values in both the Snorkeling and Diving Zones of the western part of Babi Island's coral reefs. This indicates that dead coral components have a relatively prominent percent cover along with the presence of soft corals, which also have a relatively high percent cover. Consequently, the percent cover of hard corals does not reach the Excellent condition category for coral reefs in either the Snorkeling Zone (SZ) or the Diving Zone (DS).

Condition of coral reefs in the Southern Part of Babi Island

The coral reefs in the southern part of Babi Island are located at 04º32'55.8"S and 129º40'56.5"E. Satellite image data interpretation indicates that the coral reef area in the southern part of Babi Island is 56.5 hectares. According to data analysis based on the LIT method (Table 4), the percent cover of hard corals in the Shallow

Reef Flat to Mid-Reef Zones (Snorkeling Zone) is 52.92%, which is relatively lower than in the Deep Reef Slope Zones (Diving Zone), which is 60.32%. Referring to the percent cover values of hard corals in these two designated zones and the coral reef condition assessment criteria proposed by English et al. (1997), the Minister of Environment Decree Nu. 4 of 2001, and Sahetapy (2015), it can be said that both the Snorkeling Zone and the Diving Zone in the southern part of Babi Island's coral reefs are in Good condition. The results of this analysis indicate that the coral reefs in the southern part of Babi Island are still suitable for marine ecotourism activities, such as snorkeling and diving.

The Coral Massive and Acropora Tabulate life forms dominate the percent cover of hard corals in the Snorkeling Zone reefs. Additionally, the Coral Massive and Acropora Tabulate life forms dominate the percent cover of hard corals in the Diving Zone reefs in the southern part of Babi Island.

The dominant Acropora Tabulate live form in the Snorkeling Zone reefs of the southern part of Babi Island is *Acropora hyacinthus*, while the dominant coral massive with a high percent cover is *Porites lichen*. The high percent cover values of the hard coral species *Acropora hyacinthus* and *Porites lichen* in the Snorkeling Zone reefs are due to the relatively large or high range and average colony diameter, as well as the high colony abundance, compared to the other 25 hard coral species.

The dominant Acropora Tabulate coral species with the highest cover percentage in the Diving Zone of the southern coral reef of Babi Island is *Acropora hyacinthus*. The high cover percentage of this coral species is due to the large range and average colony diameter, as well as the high abundance of colonies compared to the other 38 hard coral species. The hard coral species *Turbinaria frondens* in the Diving Zone of the southern coral reef of Babi Island has a large range and average colony diameter but a low cover percentage due to its low colony abundance.

Regarding non-hard coral categories, the percentage cover of abiotic components is more dominant than other biotic components in both the Snorkeling Zone and Diving Zone of the southern coral reef of Babi Island. The abiotic components with dominant cover percentages in the Snorkeling Zone are sand, dead coral covered with algae (DCA), and coral rubble. Additionally, the dominant abiotic components in the Diving Zone are DCA, rubble, and sand.

Table 4. Benthic life forms and percent cover

Benthic life forms	Zona Reef Flat Flat - Middle (*Snorkeling*)			Zona Reef Margin - Slope (*Diving*)		
	Num. of Species	Num. of Colony	PP (%)	Num. of Species	Num. of Colony	PP (%)
Acropora Branching	4	5	2,08	3	7	4,40
Acropora Tabulate	4	12	19,24	5	14	39,06
Acropora Digitate	1	1	0,36	1	3	1,40
Acropora Submassive	0	0	0.00	0	0	0,00
Acropora Encrusting	0	0	0,00	0	0	0,00
Coral Branching	3	13	2,80	2	2	0,76
Coral Massive	13	27	27,22	15	22	13,66
Coral Encrusting	0	0	0.00	1	1	1,04
Coral Submassive	1	2	1,22	0	0	0,00
Coral Foliouse	0	0	0.00	1	1	1.04
Coral Mushroom	0	0	0,00	0	0	0,00
Coral Heliopora	0	0	0,00	0	0	0,00
Coral Millepora	0	0	0,00	0	0	0,00
Amount	**26**	**60**	**52,92**	**28**	**50**	**60,32**
Soft Coral (SC)			4,80			5,46
Coralin Algae (CA)			0,00			3,14
Macro Algae			7,20			6,22
Sponge			0,90			1,52
Other Benthic			2,08			1,74
DCA			9,24			8,78
Dead Coral (DC)			1,86			1,56
Sand (S)			12,08			5,42
Rubble (R)			8,92			5,84
Amount			**47,08**			**39,68**
T o t a l			**100**			**100**

CONCLUSION

The spatial distribution of coral reefs exhibits significant variations in area between the western and southern parts of the island. The western section had more extensive coral reefs, encompassing 129.91 hectares, compared to the southern part with only 56.5 hectares. Coral reef biodiversity on Babi Island is relatively high. A total of 96 hard coral species have been identified on the island, representing 67.1% of the total species found in the Aru Islands coastal waters. Notably, 50 of the hard coral species on Babi Island are categorized as protected under IUCN classifications. The overall health of coral reefs on Babi Island is considered good. In the western part of the island, the percentage of hard coral cover even exceeds 70%. The southern part of the island also possesses coral reefs in good condition, albeit with a slightly lower percentage of hard coral cover compared to the western part.

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