Coral reef health index on Tunda Island, Banten, Indonesia

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Abstract: Tunda Island in Serang Regency, Banten Province, has rich marine ecosystems, including mangroves, seagrass beds, and coral reefs. However, increasing environmental pressures threaten coral reef health, necessitating an assessment of their current condition. This study aimed to evaluate the status of coral reefs in Tunda Island using a coral reef health index based on benthic and fish components. Data were collected at six sites using the Underwater Photo Transect (UPT) method for coral assessment and the Underwater Visual Census (UVC) method for reef fish. Coral cover, fleshy seaweed, and coral rubble were analyzed using the CPCe software, while fish biomass and abundance were calculated with standard fishery assessment methods. Results showed significant variations in coral cover, ranging from 2.74% to 50.12%. Fleshy seaweed cover was between 6.89% and 43.94%, whereas the coral rubble ranged from 1.44% to 37.22%. Reef fish biomass varied from 2.50 kg/ha to 85.31 kg/ha, with fish abundance between 80 and 840 individuals per hectare. The coral reef health index ranged from 1 to 4, indicating a low recovery potential due to highly fleshy seaweed and coral rubble. These findings highlight the urgent need for conservation measures to enhance coral reef resilience and recovery in Tunda Island.

1 Introduction

Tunda Island is a small island located within the administrative area of Serang Regency. Serang Regency is an administrative region in Banten Province that has the potential for non-biological resources and can be developed as a marine tourism destination to support regional and community development [1]. The intertidal zone of Tunda Island consists of three typical tropical marine ecosystems: mangrove, seagrass, and coral reef ecosystems, which are generally still in very good condition. A well-preserved aquatic ecosystem has the potential to influence the diversity of its associated biota [2].

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Coral reefs are fascinating and important marine ecosystems formed by colonies of marine microorganisms, primarily corals [3]. They create beautiful underwater labyrinths with a variety of vibrant colors and shapes. This ecosystem serves as a habitat for diverse marine species, including reef fish, mollusks, and other marine biota. Coral reefs play a crucial role in maintaining the sustainability of marine environments. In addition to providing a habitat for marine life, they act as natural wave breakers that protect coastlines from erosion. The existence of coral reefs is also important for the fishing industry because they support fisheries and provide resources for fishermen and coastal communities [4,5].

However, coral reefs worldwide face serious threats such as bleaching due to climate change, marine pollution, and destructive human activities [6]. The Directorate General of Marine Spatial Management of the Ministry of Marine Affairs and Fisheries noted that the area covered by coral reefs in Indonesian waters currently reaches 2.5 million hectares, with a total of 569 species. Unfortunately, approximately 33.82 percent of them are damaged or in poor condition [7].

Previous research on the coral reefs in the shallow waters of Tunda Island classified their health status based solely on coral cover. The study found that corals on the East Side and the North toward the East Side were in moderate to good condition, while those on the Central North Side and the North toward the West Side were categorized as poor to moderate. In contrast, the coral reefs at the reef slope were classified as damaged to poor, with the moderate category located on the North toward the East Side and the damaged to poor category on the Central South and South toward the West Side [8]. However, relying only on coral cover may not provide a comprehensive understanding of reef health.

The primary parameter traditionally used to assess coral conditions is the percentage of live coral cover, where a higher percentage indicates a healthier coral reef [9]. However, field observations have revealed cases where locations with low coral cover still had high reef fish abundance and vice versa. Therefore, to gain a more holistic understanding, a coral reef health index has been developed, incorporating both benthic and fish components. The benthic component is determined by live coral cover and the level of resilience or recovery potential, while the fish component is based on the total biomass of the target reef fish [10].

This study was conducted to assess the condition of coral reefs and to determine the coral reef health index on Tunda Island. By analyzing both benthic and fish components, this study aimed to provide a more comprehensive evaluation of reef health. These findings are expected to contribute to coral reef conservation efforts and inform management strategies for protecting the marine biodiversity in the region.

2 Research Methods

2.1 Research Sites

The research location is on the coast of Tunda Island, Serang Regency, Banten Province at coordinates LS 5°48'36.99"S - 5°48'46.44"S and BT 106°15'14.10"E - 106°17'50.56"E. Field data collection was conducted from March 5 to 7, 2024. Data processing and analysis were performed at the Indonesian Coral Reef Foundation (TERANGI) Office in Depok, West Java. Six observational points were established in this study (Fig. 1).

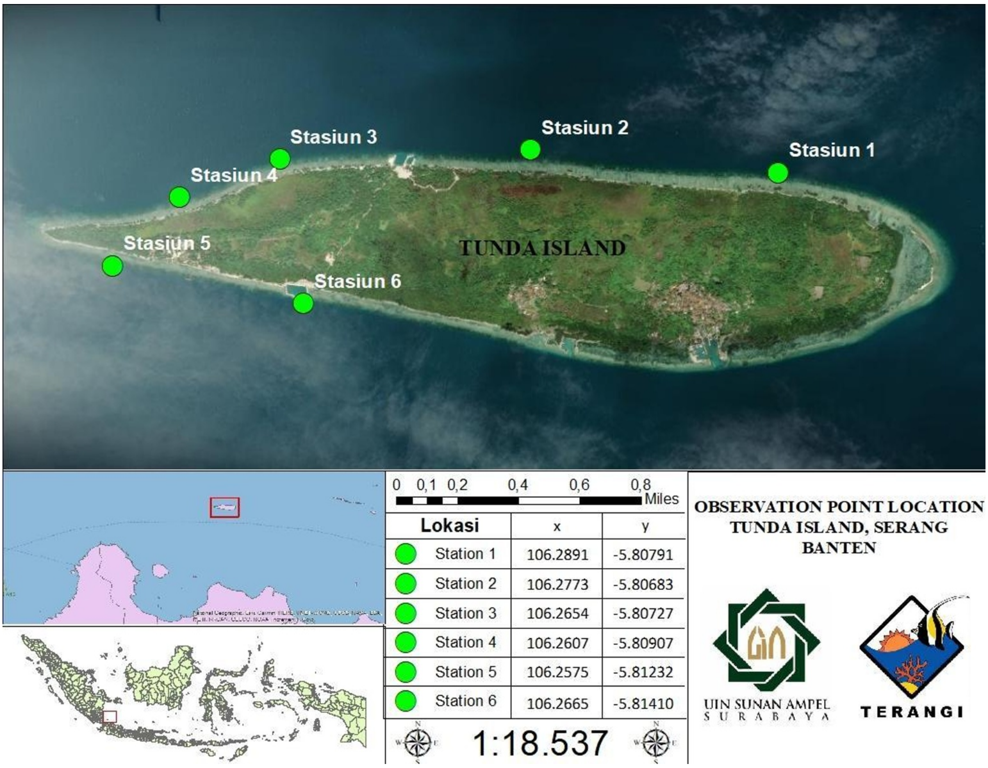

Fig. 1. *Research Location on Tunda Island, Banten*

2.2 Data Collection

2.2.1 Coral Reef Data Collection

Data collection was conducted using the Underwater Photo Transect (UPT) method (Fig. 2). This method involves SCUBA diving, capturing pictures with a high-resolution camera housed in a casing suitable for underwater operations, and using a rectangular metal frame painted in a highly visible color [11].

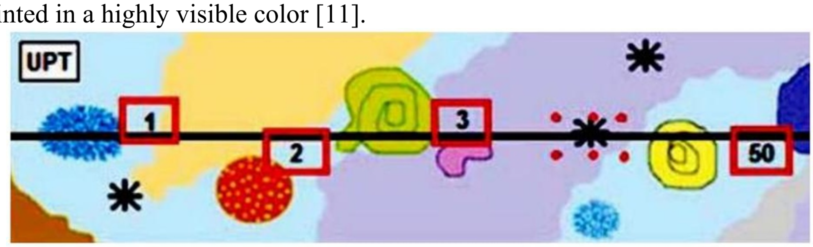

Fig. 2. *Illustration of data collection using the UPT method*

The UPT method used in this study included a slight modification: the transect length was set to 60 m, with photographs taken at 1-meter intervals using a 50 × 50 cm square transect as the photo frame. The identification method used was based on the percentage of cover assessed through snorkeling.

Coral reef data collection activities classify the data into three categories: hard coral, fleshy seaweed, and coral fragments (rubble), which serve as indicators of the coral reef health index [12]. Fleshy seaweed refers to macroalgal communities that can be seen without magnification, including species such as Sargassum, Gracilaria, and Padina. Data were collected from six stations across observation sites. The collected samples were then processed using MS Excel.

2.2.2 Reef Fish Data Collection

Fish data were collected using the Underwater Visual Census (UVC) method (Fig. 3). The UVC method was applied to count coral reef fish along a 20-meter transect, with three replications. The detection range was extended by 2.5 meters on both the right and left sides of the transect.

Data collected during the UVC survey were analyzed to estimate the population density [13]. In this study, only the target fish species were recorded, including seven families: Scaridae, Siganidae, Acanthuridae, Serranidae, Lutjanidae, Lethrinidae, and Haemulidae.

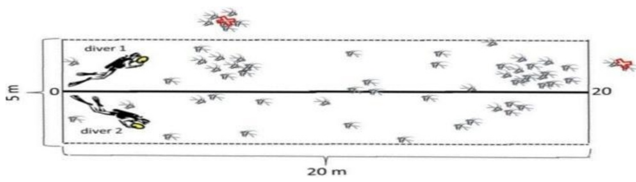

Fig. 3. *Illustration of reef fish data collection using the UVC method.*

2.3 Data Processing

2.3.1 CPCe Data Processing

The CPCe data-processing stage was used to determine the coverage of coral, fleshy seaweed, and rubble. Underwater photography data from each transect were analyzed using the CPCe software (Coral Point Count with Excel extension). The analysis of coral cover percentage followed the method described by English et al. (1997) [9] by calculating the percentage of coral coverage using the following formula. The categories of live coral covers are listed in Table 1.

$$\text{Coral coverage percentage} = \frac{Number\ of\ categories\ x}{Random\ number\ of\ points}$$

Table 1. Categories of live coral cover [14]

No	Category	Criteria
1	Poor	Live coral cover < 19%
2	Fair	19% ≤ Live coral cover ≤ 35%
3	Good	Live coral cover >35%

2.3.2 Reef Fish Data Processing

The processing stage for reef fish data using MS Excel was conducted to determine the total fish biomass and fish abundance as indicators of the coral reef health index. The methods used for calculating fish biomass and fish abundance were as follows:

1. Reef Fish Biomass

Reef fish biomass data were collected by recording and estimating the total length of each fish. The length-weight equation was used to estimate fish weight based on fish length by taking the average length (cm) of the fish and converting it to weight (g) using the length-weight index for each species, as derived from FISHBASE 2000 [15]. The equation used to calculate fish weight was as follows: The total biomass of the reef fish is shown in Table 2.

$$\mathbf{W} = \boldsymbol{a}\, L^b$$

Information :

W : Weight (g)

L : Total length per species (cm)

a dan b : Species specific index

Table 2. Total Biomass Category of Reef Fish [16]

No	Category	Criteria
1	Poor	Total biomass of reef fish < 970 kg/ha
2	Fair	970 kg/ha ≤ Total biomass of reef fish ≤ 1,940 kg/ha
3	Good	Total biomass of reef fish > 1,940 kg/ha

2. Abundance of Reef Fish

Fish abundance was calculated by comparing the number of individual fish to the total surveyed area. It is expressed as:

$$\text{Abundance of fish} = \frac{Number\ of\ Individuals}{Transect\ Area}$$

The transect area refers to the designated section of the reef surveyed during data collection. In this study, each transect was 20 m long, with a detection width of 2.5 meters on both sides, resulting in a total observation area per transect of 100 m^2.

2.3.3 Coral Reef Health Index Data Processing

The coral reef recovery potential was classified based on fleshy seaweed and coral rubble cover criteria, as shown in Table 3. The benthic component values were then determined using live coral cover and recovery potential categories [16] (Table 4). Finally, the overall coral reef health index was assessed by integrating benthic and reef fish components, following the criteria presented in Table 5. After calculating the index values, an index value map was generated using ArcMap software to visualize the results.

Table 3. Recovery Potential Criteria

No	Category	Criteria
1	Low	fleshy seaweed cover ≥3% or coral rubber cover >60% and live coral cover ≥5%
2	High	fleshy seaweed cover <3% or coral rubber cover ≤60% and live coral cover >5%

Table 4. Criteria for benthic component value

No	Live Coral Cover	Recovery Potential	Benthic Category	Benthic Component Value
1	Good	High	Healthy coral with high recovery potential in case of disturbance	6
2	Good	Low	The coral is healthy but if there is a disturbance it will be difficult to recover to its original condition	4
3	Fair	High	Corals are in fair condition and may be in the process of recovering from disturbance	5
4	Fair	Low	Corals are in fair condition but at risk of decline	2
5	Poor	High	Coral cover is low, but has potential to improve	3
6	Poor	Low	Coral cover is low, and it is difficult to improve its condition	1

Table 5. Criteria for coral reef health index values

No	Benthic Components		Fish Components	Coral Reef Health Index Value
	Live coral cover	Recovery Potential	Coral reef fish categories	
1	Good	High	Good	10
2	Fair	High	Good	9
3	Good	High	Fair	8
4	Good	Low	Good	8
5	Fair	High	Fair	7
6	Poor	High	Good	7
7	Good	High	Poor	6
8	Good	Low	Fair	6
9	Fair	Low	Good	6
10	Fair	High	Poor	5
11	Poor	High	Fair	5
12	Poor	Low	Good	5
13	Good	Low	Poor	4
14	Fair	Low	Fair	4
15	Poor	High	Poor	3
16	Poor	Low	Fair	3
17	Fair	Low	Poor	2
18	Good	Low	Poor	1

3 Result and Discussion

3.1 Live Coral Cover

The condition of coral reefs at six stations on Tunda Island varied in coverage, ranging from poor to fair and good. As shown in Fig.4, the lowest percentage of coral cover was at Station 6, with a value of 2.74%, which is categorized as low according to [13], as it falls below 19%. In contrast, the highest percentage of coral cover is at Station 4, with a value of 50.12%, which is categorized as high because it exceeds 35%.

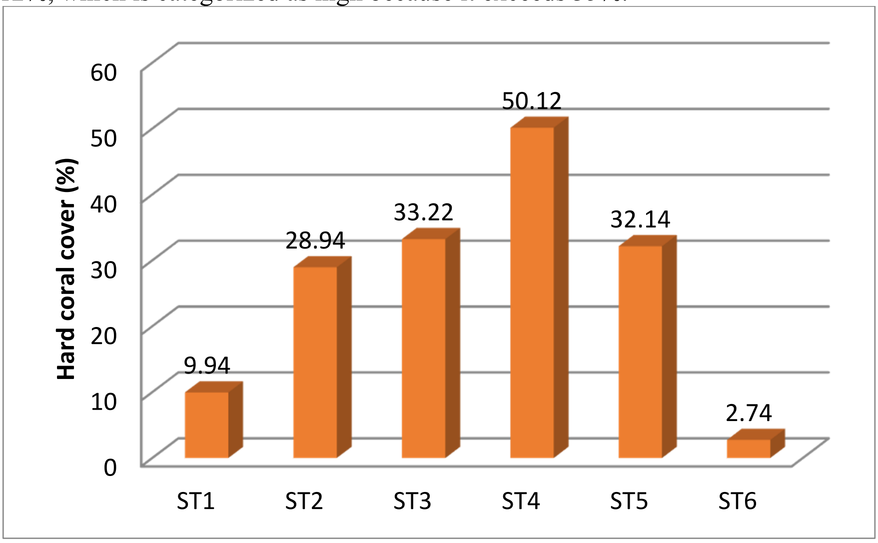

Fig. 4. *Percentage of hard coral cover in each station*

The variation in coral coverage at each station was influenced by multiple factors, such as high fleshy seaweed cover or extensive rubble accumulation. Other factors that affect coral coverage include the abundance of reef fish and human activities that harm the marine environment, such as waste pollution and sedimentation.

According to [17], fishing activities conducted by fishermen from outside Tunda Island, particularly at night in coral reef areas using non-environmentally friendly fishing gear, can disturb and damage coral reefs, making recovery difficult and leading to coral death. Another issue is the presence of marine debris, which is suspected to originate from the mainland and carried by the east and west monsoon winds [18].

3.2 Fleshy Seaweed

Fleshy seaweed cover is an important indicator of coral reef health, as excessive growth can outcompete corals and hinder reef recovery. As shown in Fig. 5, fleshy seaweed cover varied across stations, with the lowest percentage recorded at Station 1 (6.89%) and the highest at Station 6 (43.94%).

Fleshy seaweed competes with coral reefs, inhibiting their growth and preventing coral attachment owing to its secondary metabolites. The presence of algae in large areas causes physical disturbances to young corals, increases sediment deposition, reduces sunlight penetration, and lowers the success rate of coral larval settlement. Macroalgae can overgrow corals in nutrient-rich waters under abundant sunlight. An increase in macroalgal growth indicates a potential threat to coral development as macroalgae can grow on both living and dead corals [15].

According to [19], even a small percentage of macroalgal cover can affect coral reef resilience. A 0.5% increase in macroalgal cover can negatively affect coral reefs because algae grow faster than corals do. Therefore, even minimal algal growth could significantly hinder coral reef recovery.

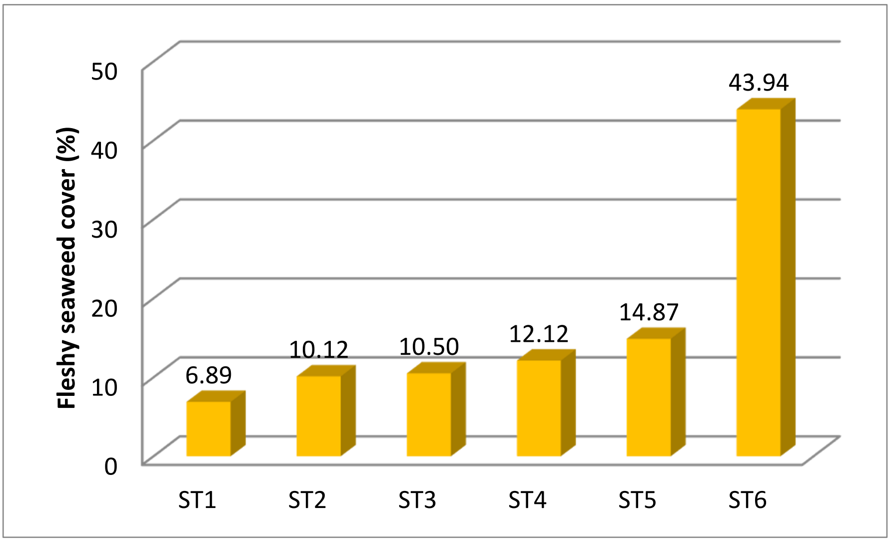

Fig. 5. *Percentage of fleshy seaweed cover in each station*

3.3 Rubble (Coral Fragments)

The lowest percentage of coral rubble cover was recorded at Station 3 (1.44%), whereas the highest was at Station 6 (37.22%) (Fig. 6). High coral rubble cover reduces the potential for coral reef ecosystem recovery, as coral rubble presents a challenging environment for coral larvae to grow.

Several studies have shown that coral rubble is not a suitable substrate for coral larval settlement and development because it remains dynamically unstable [9]. Similarly, [20] stated that substrates dominated by coral fragments are highly influenced by alternating currents and wave action, rendering them unsuitable for coral larval growth and development.

Additionally, coral fragments contribute to the physical damage to coral reef structures, which serve as critical habitats for various marine species. Habitat degradation can disrupt coral reef ecosystems, reducing the availability of shelter, food sources, and spawning sites for marine organisms.

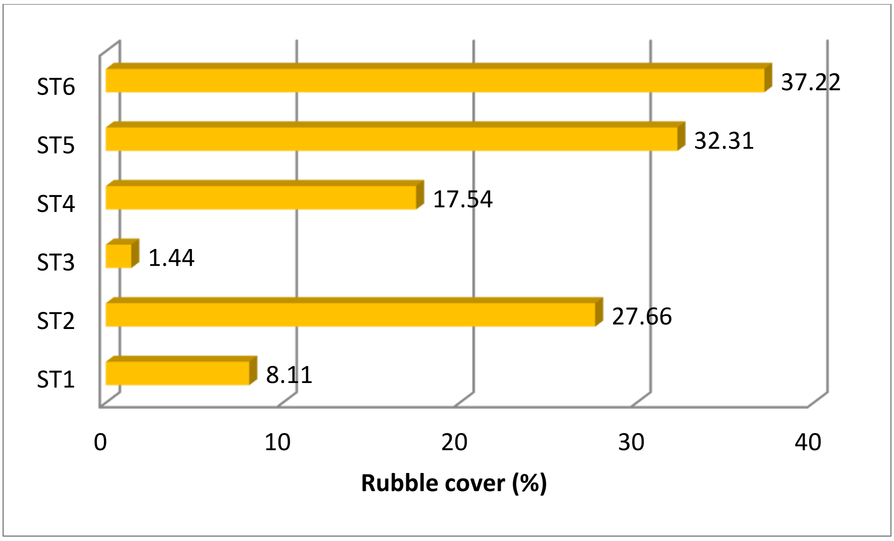

Fig. 6. *Percentage of rubble coverage in each station*

3.4 Reef Fish

Reef fish are economically important and serve as a key target species for fishermen. In this study, observations of the target reef fish identified only four families: Scaridae, Siganidae, Acanthuridae, and Serranidae. The recorded biomass values ranged from 2.50 to 85.31 kg/ha, whereas fish abundance varied between 80.00 and 840.00 individuals per hectare (Ind/ha). The relatively low fish biomass (below 970 kg/ha) indicates a limited fish population, which may affect both ecosystem balance and fishery sustainability.

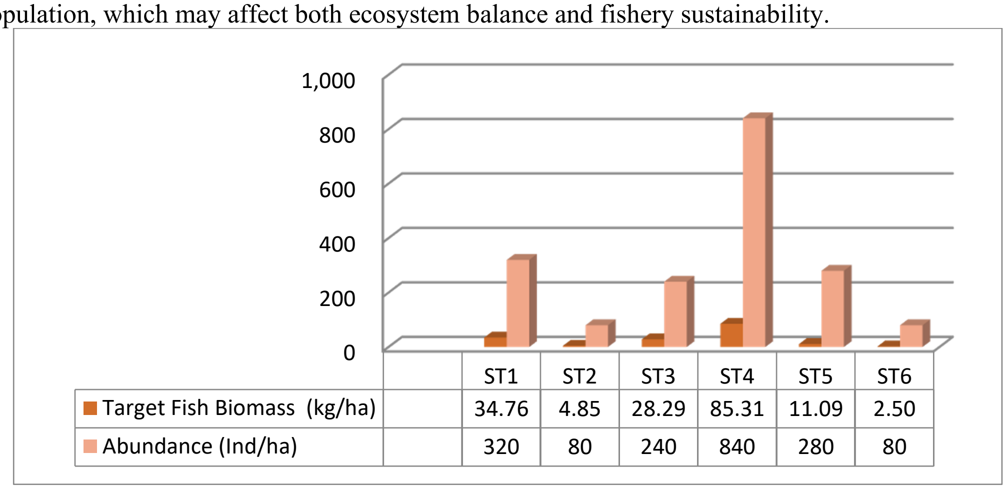

Fig. 7. *Biomass and abundance of reef fish in each station*

The lowest biomass value was recorded at Station 6 (2.50 kg/ha, whereas the highest biomass value was observed at station 4 (85.31 kg/ha). The lowest fish abundance was found at stations 2 and 6, with 80.00 individuals per hectare (Ind/ha), whereas the highest fish abundance was recorded at station 4 with 840.00 Ind/ha (Fig. 7).

The data indicated that biomass and abundance values varied across stations; some stations had high biomass but low abundance, and vice versa. At all six stations, the biomass values were lower than the abundance values. This discrepancy is likely due to the presence of small fish in greater numbers, resulting in a lower biomass value despite higher abundance.

According to [21], Tunda Island fishermen believe that this ecosystem crisis was a consequence of sand mining activities in Banten waters. Fishermen have observed these activities for several years but are uncertain when they first began. They believed that marine sand mining has led to declining fish catches and environmental degradation, contributing to the low population of reef fish. Additionally, fishermen from outside Tunda Island use destructive fishing practices, such as anesthetics and other harmful tools, which further affect reef fish populations.

Reef fish play a crucial role in coral reef ecosystems, particularly in controlling macroalgae that compete with corals. Herbivorous reef fish help protect corals by reducing excessive macroalgae growth, which could otherwise lead to coral mortality. Therefore, reef fish abundance is a key indicator of the coral reef health index. However, a high abundance of reef fish alone is not sufficient to maintain coral reefs if destructive human activities persist.

3.5 Coral Reef Health Index

The coral reef health assessment on Tunda Island revealed low recovery potential (Table 6), with index values ranging from 1 to 4 (Fig. 8). The combination of low live coral cover, high fleshy seaweed cover, and substantial rubble accumulation contributed to limited reef resilience. Additionally, the consistently low fish component values across all stations further constrained the reef's ability to recover.

Stations 1 and 6 recorded the lowest index value of 1, indicating severe degradation. Station 6 had the lowest coral cover (2.74%), extremely high fleshy seaweed cover (43.94%), and significant rubble accumulation (37.22%), creating unfavorable conditions for coral regeneration. Station 1, with slightly higher coral cover (9.94%), also showed limited recovery potential due to excessive fleshy seaweed growth (6.89%) and inadequate fish populations (value: 2).

Stations 2, 3, and 5 had an index value of 2, indicating moderate coral cover but low recovery potential. Station 2 had coral cover of 28.94%, but high fleshy seaweed cover (10.12%) and substantial rubble cover (27.66%) constrained recovery. Station 3 exhibited slightly higher coral cover (33.22%), but recovery remained limited due to the presence of fleshy seaweed (10.50%). Despite having a low rubble cover (1.44%), the insufficient herbivorous fish population (value: 2) allowed macroalgal to proliferate unchecked. Station 5 had coral cover of 32.14%, but high fleshy seaweed cover (14.87%) and rubble accumulation (32.31%) negatively impacted recovery potential.

Table 6. Benthic and Fish Component Values

No	Location	Benthic Components			Fish Components	
		Live Coral Cover	Recovery Potential	Value	Fish Category	Value
1	Station 1	Poor	Low	1	Poor	2
2	Station 2	Fair	Low	2	Poor	2
3	Station 3	Fair	Low	2	Poor	2
4	Station 4	Good	Low	4	Poor	2
5	Station 5	Fair	Low	2	Poor	2
6	Station 6	Poor	Low	1	Poor	2

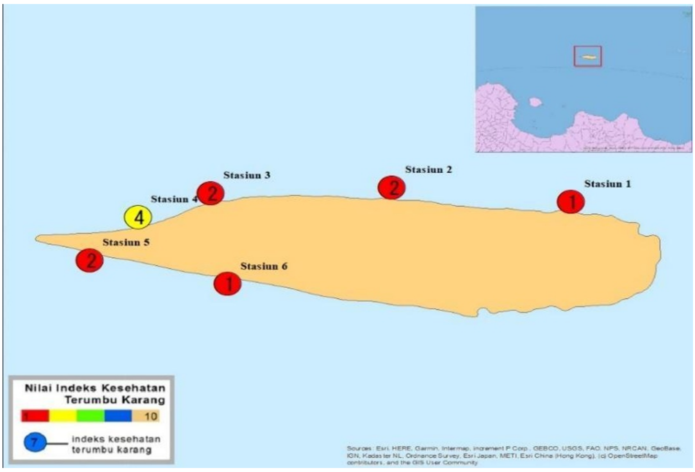

Fig. 8. *Coral Reef Health Index Map of Tunda Island*

Station 4 had the highest index value of 4, with the greatest coral cover (50.12%). However, recovery potential was still limited due to high fleshy seaweed cover (12.12%) and rubble accumulation (17.54%). Although the fish component value remained low (2), this station exhibited relatively better coral conditions compared to others.

Overall, the coral reef health index across all six stations remained low, with values not exceeding 4. The combination of high fleshy seaweed cover, substantial rubble accumulation, and low fish populations suggests that the coral reef ecosystem on Tunda Island faces significant challenges in recovery and resilience.

According to [22], reef fish play a crucial ecological role in supporting coral reef resilience by controlling macroalgal growth, which can be detrimental to coral communities. If macroalgal growth becomes too rapid and remains unchecked, it can dominate the reef ecosystem and compete with corals for space. This imbalance is worsened by low reef fish populations, which allow macroalgae to outcompete corals and disrupt the ecosystem.

4 Conclusion

This study found that live coral cover on Tunda Island ranged from 2.74% to 50.12%, fleshy seaweed cover varied between 6.89% and 43.94%, and coral rubble ranged from 1.44% to 37.22%. The total biomass of reef fish ranged between 2.50 and 85.31 kg/ha, while reef fish abundance varied from 80 to 840 individuals/ha. The coral reef health index across six observation stations ranged from 1 to 4, indicating that overall reef health remains relatively low.

Overall, Tunda Island’s coral reefs are in poor condition, with a low potential for natural recovery. This limited resilience may hinder the regeneration of coral reefs if further degradation occurs.

To improve future research, long-term monitoring is recommended to track coral recovery trends over time. Additionally, analyzing water quality parameters and human-induced impacts could provide a more comprehensive understanding of the factors affecting coral reef health. Expanding the number of observation sites and incorporating advanced remote sensing technologies may also enhance the accuracy and scope of coral reef assessments.

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