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Assessing Coral Reef Health in Northern Waters of Penata Besar Island West Kalimantan

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Abstract. *Penata Besar Island , designated as one of the Coastal and Small Island Conservation Areas (KKP3K) in West Kalimantan, is a critical site for conserving coral reefs and reef fish. Currently, global climate change and anthropogenic activities have exacerbated coral reef bleaching worldwide. In the context of escalating global climate change and human-induced threats, this study evaluates the health condition of coral reefs in the northern waters of Penata Besar Island, Bengkayang Regency. An exploratory approach was employed, utilizing the Line Intercept Transect (LIT) method across four stations at two distinct depths (2-3 m and 5-6 m). The results revealed that coral cover varied with depth. At a depth of 2-3 m, live coral coverage was between 51.2% and 62.4%, classified as good, while at 5-6 m, coverage ranged from 30.4% to 49.4%, categorized as fair. Coral Massive (CM) was the predominant growth form observed. The diversity index (H') ranged from low to medium, the evenness index (E) from medium to high, and the dominance index (C) was categorized as low. These findings highlight the varying health of coral reefs in different depths and provide a basis and essential insights for targeted conservation efforts.*

Keywords: *coral massive, life form, LIT method*

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INTRODUCTION

Penata Besar Island, situated within the Sungai Raya Islands Sub-district of Bengkayang Regency, West Kalimantan, covers an area of approximately 4,875 ha (BPS Kabupaten Bengkayang, 2023). This island, characterized by its significant natural resources and rich biodiversity, including extensive coral reef systems, plays a crucial role in the region's ecological health. In 2019, Penata Besar Island was officially incorporated as part of the Coastal and Small Island Conservation Areas (KKP3K) in Bengkayang Regency under the West Kalimantan Provincial Regional Regulation No. 1 of 2019, and the Minister of Marine Affairs and Fisheries Decree No. 90/Kepmen-KP/2020. This designation highlights the island's critical role in conservation efforts, emphasizing the need to protect its coral reefs and reef fish populations. The designation also reflects ongoing efforts to manage and preserve the island's unique marine environment, which is vital for maintaining local biodiversity and supporting ecological balance (BPSPL Pontianak, 2019).

Coral reefs are critical ecosystems found in coastal areas, renowned for their immense contributions to marine biodiversity and ecological functions. Coral reefs are known for their significant role in primary productivity. Through processes like photosynthesis carried out by symbiotic algae within their tissues, corals generate organic matter (Muller-Parker et al., 2015), forming the basis of the food web in marine environments. This productivity supports various marine organisms, from microscopic plankton to larger fish and marine mammals. Ecologically, coral reefs serve as essential areas for foraging, spawning, and rearing numerous aquatic organisms (Rosdianto et al., 2021). The complex structure of coral reefs also offers hiding places and hunting grounds for a wide range of marine organisms, contributing to the overall biodiversity of coastal ecosystems. Furthermore, coral reefs provide a habitat for many aquatic life (Tony et al., 2021), including rare and protected species. Iconic examples include giant clams like *Tridacna gigas* and *T. squamosa* (Niwasdita et al., 2020), both ecologically valuable. Additionally, endangered species such as the green (*Chelonia mydas*) and hawksbill sea turtle (*Eretmochelys imbricata*) (Bechhofer and Henderson, 2018) rely on coral reefs for feeding and nesting grounds. Even soft coral organisms like Gorgonian corals (Sanchez,et al., 2019) find it crucial to habitat in the intricate structures of coral reefs.

Numerous studies have been conducted on the state of coral reefs in West Kalimantan, including those around Penata Besar Island. According to Edrus et al. (2004), the coral reefs initially showed good condition with an average live coral cover of 65.9%. However, subsequent studies by Sudiono (2008) indicated a decline in coral cover to 55.18% in 2005 and 54.08% in 2008. These coastal communities rely heavily on coral reef ecosystems for capture fisheries and underwater tourism. Unsustainable fishing practices and destructive fishing gear pose significant threats to the physical integrity of coral reefs (Ayal et al., 2021). These activities can directly damage coral structures and reduce their ability to support marine biodiversity. Moreover, the impact of snorkeling tourism on coral reefs has been documented on nearby Lemukutan Island. Guntara et al. (2023) classified the damage caused by snorkeling as moderate, with affected coral reefs showing signs of physical injury ranging from 1.47% to 3.29% and corals observed in a wounded state ranging from 1.57% to 3.52%. These findings highlight the complex interaction between human activities and coral reef ecosystems. Efforts to manage and conserve these fragile habitats are crucial to sustaining their ecological and economic benefits to local communities and the marine environment.

The health and resilience of coral reef ecosystems are essential for sustaining the biodiversity and ecological stability of coastal waters. Coral reefs act as habitats and nurseries crucial for marine life, contributing to the overall productivity and balance of marine environments. As these ecosystems face increasing pressures from climate change and human activities, effective conservation strategies are imperative to safeguard their functions and biodiversity. This study aims to evaluate the condition of coral reefs in the northern waters of Penata Besar Island, providing critical insights for managing conservation areas in this region. By assessing coral reef health, this research will contribute to a better understanding of current conditions and trends, enabling more informed decision-making for protecting and managing these vital marine resources. The findings will serve as a foundational resource for developing and implementing targeted conservation measures to ensure the long-term sustainability and resilience of coral reef ecosystems in the area.

MATERIALS AND METHODS

Time and Sampling Area

The research was conducted in 8–10th March 2024, focusing on the northern waters of Penata Besar Island, Bengkayang Regency, West Kalimantan (Figure 1). During this period, comprehensive data on coral health and water quality parameters were meticulously collected in situ. The study involved detailed fieldwork, including underwater assessments and measurements, to capture the current status of coral reefs and their surrounding marine environment.

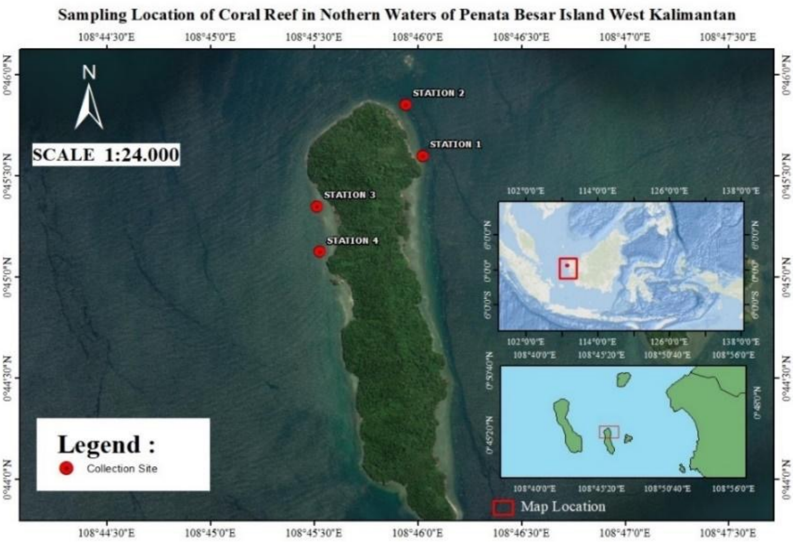

Figure 1. Sampling locations of coral reef in northern waters of Penata Besar Island,West Kalimantan

Data Collection

Data on coral cover percentage and growth forms were collected using the Line Intercept Transect (LIT) method, with transects of 50 m in length (Figure 2) (English et al., 1994) at four observation stations. Station I was located near residential areas and their "Bagan Tancap" (a local type of stilt fishing platform) (0° 45' 53.32" N 108° 45' 54.18" E), Station II was along a boat crossing route (0° 45' 38.05" N 108° 46' 1.2" E), Station III was in an area with minimal human settlement (0° 45' 23.33" N 108° 45' 27.97" E), and Station IV was more remote and situated far from human activity (0° 45' 11.88" N 108° 45' 30.89" E). The LIT method facilitates a quantitative evaluation of coral reef structures. Laying transects along coral colonies yields data on coral cover, growth, and distribution within the surveyed area. Data were collected at two distinct depths (2-3 m and 5-6 m) to compare coral reef conditions at different levels. Observations of coral reefs were categorized according to their growth forms, each assigned a specific code (English et al., 1997).

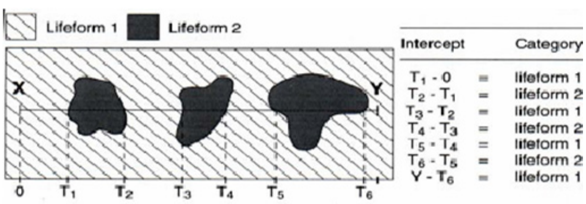

Figure 2. Line Intercept Transect methods (English et al., 1997)

Oceanographic Parameter Measurement

Physico-chemical parameters of the water were measured concurrently with coral reef data collection at the two different depths, with three repetitions. Samples were collected using a water sampler. A Water Quality Checker (WQC) AZ 8603 measured the temperature, salinity, and pH. Depth were measured during the dive using a gauge console in the regulator section, brightness was assessed with a secchi disk, and current speed was measured with a current meter.

Data Analysis

Coral Cover Percentage

The percentage of coral cover (lifeform) was calculated using Microsoft Office Excel 2016. To determine the coral reef cover percentage, the coverage of live corals was assessed according to the categorization by English et al. (1994), as detailed below:

$$L = \frac{L_i}{N} x\ 100\%$$

where : L is coral cover percentage, Li is length of coral cover of each life form, and N is transect length. English et al. (1994) devided coral cover category into four criteria, such as 0-24,9% (poor), 25-49.9% (fair), 50-74.9% (good), and 75-100% (excellent).

Diversity (H'), Evenness (E), and Dominance (C) Index

The diversity index (H') is employed to assess coral diversity. Coral abundance data at each station is analyzed using the Shannon-Wiener formula (1969). The diversity index values are classified into three levels of diversity: H' < 1 (low), 1 < H' < 3 (moderate), and H' > 3 (high) (Odum, 1993).

$$H' = -\sum_{k=0}^{n} p_i \ln \ln p_i$$

The evenness index (E) measures the uniformity of individual distribution among species within a community. A more even distribution of individuals among species reflects greater ecosystem balance. In the formula below, H' denotes the diversity index, while S refers to the number of coral life form identified. The evenness index values are classified into three levels of uniformity: $0 < E \leq 0.4$ (low), $0.4 < E \leq 0.6$ (moderate), and $0.6 < E \leq 1$ (high) (Odum, 1993).

$$E = \frac{H'}{Ln\, S}$$

The dominance index (C) assesses the extent of dominance of particular corals. Generally, low values of uniformity and diversity indices suggest that one species is dominating over others. Dominance index values are categorized into three levels of dominance: $0 < C \leq 0.5$ (low), $0.5 < C \leq 0.75$ (moderate), and $0.75 < C \leq 1$ (high) (Odum, 1993).

$$C = \sum \left(\frac{n_i}{N}\right)^2$$

RESULTS AND DISCUSSION

Aquatic Environmental Parameters Conditions

Environmental parameters play an important role in determining the health and condition of coral reefs (Table 1). Water temperature is a critical for marine life, influencing metabolic processes and reproduction (Neelmani et al., 2019) especially for coral species (Banc-Prandi et al., 2022; Merck et al., 2022). In this study, temperatures at both depths ranged from 28.8 to 30.6°C, within the optimal temperature for supporting coral health. Previous research has highlighted that corals are highly sensitive to heat stress (Abrego et al., 2021). Temperatures exceeding coral tolerance thresholds can lead to significant declines in their condition (Lough et al., 2018). The ideal temperature for corals is defined by genotypes of the coral host (Dilworth et al., 2021), the types of symbiotic algae (Jones et al., 2008), and the abundance of symbionts (Madin et al., 2016).

The salinity levels in the waters around Penata Besar Island range from 31.07 to 32.93‰, which is considered optimal for coral growth (Kordi, 2010). Salinity is a critical factor influencing the survival and development of aquatic organisms, including corals. Significant changes in salinity induce stress, impair photosynthetic efficiency, and disrupt osmotic regulation and coral physiology (Coles and Jokiel, 2018). Previous studies have shown that fluctuations in salinity can lead to bleaching, mortality, and disrupt egg fertilization (Humphrey et al., 2008). Seawater acidity (pH) is crucial for the health and survival of corals within reef ecosystems. At Penata Besar Island, the pH of the surrounding waters ranges from neutral to slightly alkaline, between 7.56 and 8.6. According to the quality standards of Ministerial Decree EF No. 51 of 2004, these levels are considered optimal for coral growth. Corals build their calcium carbonate ($CaCO_3$) skeletons through a calcification process highly sensitive to pH changes. A drop in pH reduces the availability of carbonate ions (CO_3^{2-}) necessary for skeleton formation, leading to weaker coral structures that are more prone to degradation, thus affecting the overall density of coral reefs (Barkley et al., 2017).

The brightness in the waters around Penata Besar Island reaches depths ranging from 2.5 to 4 meters, which do not meet the optimal conditions needed for coral growth (Zurba and Nabil, 2019). Light is crucial for the health and survival of corals within the ecosystem. As water depth increases, light availability decreases, requiring corals to adapt to lower light levels. Corals depend on their symbiotic relationship with zooxanthellae, which live within their tissues. These algae need light to perform photosynthesis,

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producing glucose ($C_6H_{12}O_6$) that serves as energy and nutrients for the corals (Izumi et al., 2023).

In parallel, current flow is also critical in shaping coral reef ecosystems.. The speed of ocean currents influences water quality, nutrient distribution, larval movement, and the physical stability of coral reefs (Zamani et al., 2012). In the waters around Penata Besar Island, current speeds range from 0.02 to 0.23m/s, higher than the optimal range for coral growth and health (Suharsono, 1991). While currents help remove debris from coral polyps and transport nutrients, plankton, and other organic matter that benefit zooxanthellae growth (Muqsit et al., 2016), excessively high current speeds can exert strong drag forces that may damage or break coral structures (Roger et al., 2013).

Table 1. Physico-chemical parameters in Penata Besar Island

Parameter	Station I		Station II		Station III		Station IV		Optimal condition
	A	B	A	B	A	B	A	B	
Temperature (°C)	29.2	28.8	30	29.8	30.6	30.2	29.4	29.6	25-30*
Salinity (‰)	32.67	32.93	32.4	32.53	31.07	32	31.87	31.8	27-35**
pH	7.9	7.56	8.18	8.16	8.44	8.08	8.58	8.6	7-8,5*
Brightness (m)	3	4.08	3	4.37	3	4	2.5	2.5	>5*
Current (m/s)	0.02		0.05		0.10		0.23		0.05-0.08***

Notes : (A) 2-3 m depth; (B) 5-6 m depth
Sources : Environmental and Forestry (EF) Ministerial Decree No. 51 of 2004*, Kordi, 2010**, Suharsono,1991***

Coral Cover Percentage at 2-3 m Depth

The health of coral reefs in a water body can be assessed by the percentage of live coral cover and their growth/life forms. In the northern waters of Penata Besar Island at depths of 2-3 meters, live corals dominate around 51.2% to 62.4% of the area (Figure 3). This level of coverage indicates that the coral reef is considered to be in good condition (English et al., 1994). Nevertheless, compared to earlier research by Edrus et al. (2004) and Sudiono (2008), the percentage of coral cover in the waters around Penata Besar Island has declined, although the overall condition of the coral reefs remains relatively good. Observations reveal that live coral polyps cover most of the substrate, and new coral colonies have been spotted at several monitoring sites. These observations suggest an ongoing process of reef formation. Halisah et al. (2020), the presence of new colonies and the attachment of coral larvae indicate that environmental conditions are favorable for supporting life within the coral reef ecosystem.

Activities such as environmentally harmful fishing practices or the use of destructive fishing gear can damage the physical structure of coral reefs (Ayal et al., 2021). Stations I and II exhibit lower percentages of live coral cover compared to Stations III and IV. Station I is situated near residential areas with presence of “Bagan Tancap” within the coral reef zone. Station II is located along a busy boat traffic route between Teluk Suak and Lemukutan Island. In previous studies, Fudjaja et al. (2020) noted that ship traffic, ship berthing and building, as well as fishing gear installation can harm coral reefs, as observed in the Spermonde Islands. In addition, poorly managed marine tourism negatively affects coral reef conditions. Guntara et al. (2023) also highlighted that snorkeling on

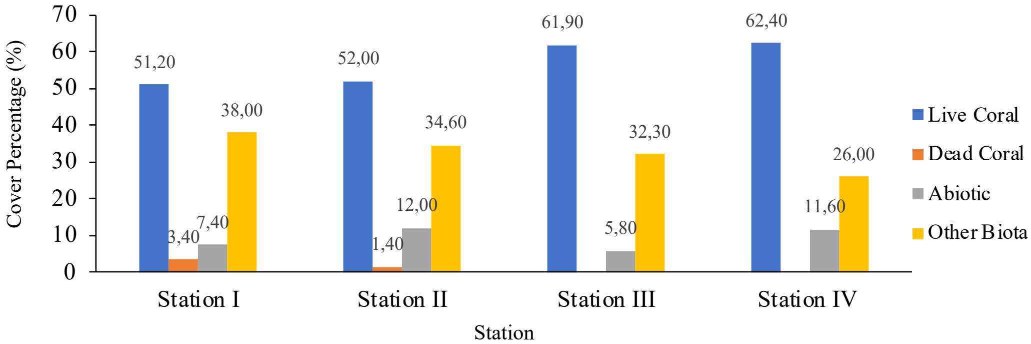

Figure 3: Percentage of coral cover at 2-3 m depth in the waters of Penata Besar Island

Lemukutan Island has resulted in moderate damage to coral reefs (1.47-3.29%) and caused corals to be in a wounded state (1.57-3.52%). Stations III and IV, which are situated farther from human activities, showed the highest percentage of live coral cover and no signs of dead coral. A coral reef community with high biodiversity and low human impact is generally more resilient to disturbances and can recover more rapidly (Ferrigno et al., 2016).

The coral presence covering at a depth of 2-3 m can also be affected by the physico-chemical properties of the water. Depth influences the amount of light penetrating the water column. In this study, sunlight was observed reaching this depth, supporting the photosynthesis of zooxanthellae within coral tissues. Corals that receive adequate light generally exhibit optimal growth and calcification (Zurba dan Nabil, 2019). High percentages of live coral cover are typically found in well-managed and protected marine areas or in locations less affected by human activities. According to Mellin et al. (2016), an establishment of Marine Protected Areas enhance conditions and biodiversity in coral reef ecosystems. This is corroborated by Munasik et al. (2021), who found that coral reefs within the Karimunjawa National Park had better conditions, with coverage reaching up to 65%, compared to areas outside the conservation area. Reefs with more than 50% live coral cover are crucial for supporting marine biodiversity. Conversely, a reduction in live coral cover often leads to decreased species diversity, with only certain coral species, such as massive corals, managing to survive (Kennedy et al., 2020).

The coral life form found in the waters around Penata Besar Island include dead coral, abiotic materials, and other biota, each varying in percentage coverage. The presence of dead corals of 1.4-3.4% at stations I and II indicates coral bleaching. Coral bleaching is closely linked to water temperature conditions. At a depth of 2–3 m in this study, the water temperature ranges from 29.2–31.8°C while corals are generally reported to thrive within a temperature range of 23–29.1°C (Zurba dan Nabil, 2019). Although some species can tolerate higher temperatures, zooxanthellae have low heat stress tolerance and increased temperatures can impair their photosynthetic capacity (Hasanah et al., 2018). Research by Caroselli et al. (2015) found that Balanophyllia europaea, a zooxanthellate species endemic to the Mediterranean, achieves maximum photosynthetic efficiency at temperatures between 20.0 and 21.6°C, with performance declining at temperatures above 21.6°C up to 32°C. A decline in the photosynthetic rate of symbiotic algae is an early indicator of impending coral bleaching (Smith et al., 2005).

Coral Cover Percentage at 5-6 m Depth

At a depth of 5-6 m, live coral covering the waters around Penata Besar Island varies between 30.4% and 49.4% (Figure 4). According to the criteria set by English et al. (1994), this condition is classified to be in fair condition (Table 1). Several environmental factors influence coral health, with depth being a critical limiting factor for coral growth and survival (Roberts et al., 2019). Further research by Reskiwati et al. (2022) supports this statement, showing notable changes in the size and distribution of coral colonies as water depth increases. Most hermatypic corals have a symbiotic relationship with zooxanthellae algae (Kordi, 2010) which relies on sunlight for photosynthesis. In this study, brightness ranged from 2.5 to 4 meters and did not reach depths of 5-6 meters, thus falling outside the optimal range for supporting coral growth. As depth increases, brightness decreases, requiring corals to adapt to reduced light conditions. Lower light levels adversely affect photosynthetic activity, leading to less optimal coral growth (Izumi et al., 2023).

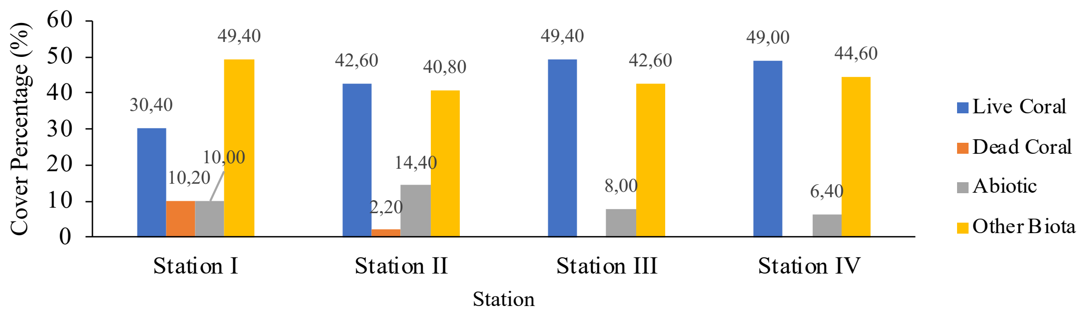

Figure 4. Percentage of coral cover at 5-6 m depth in the waters of Penata Besar Island

Coral Reef Life Forms

Evaluating coral life forms provides insights into the health and resilience of coral colonies. Coral species can exhibit significant morphological differences influenced by factors such as light intensity (brightness), water currents, waves, and genetic variations (Mardani et al., 2021). Live coral cover included both Acropora and non-Acropora species (Table 2) at both 2-3 m and 5-6 m depths in the waters around Penata Besar Island. According to Sudiono (2008), non-Acropora species in these waters cover a larger area compared to Acropora species. Non-Acropora corals are characterized by their robust and often massive structures, which develop calcium carbonate ($CaCO_3$) skeletons over time. This sturdy skeleton helps non-Acropora corals withstand environmental stresses effectively. In all sampling stations, the most prevalent coral growth form observed was Coral Massive (CM), which accounted for the highest percentage at 35.8%. The prevalence of CM is attributed to its structural stability, which allows it to better withstand physical stresses such as waves and storms compared to other coral types. Despite their slower growth rate, massive corals can live for hundreds of years, enabling them to accumulate biomass and significantly enhance the physical structure and complexity of coral reefs (Lough and Cantin, 2014).

Generally, massive coral species exhibit slower growth rates, gradually building their calcium carbonate ($CaCO_3$) skeletons to expand their colonies over many years (English et al., 1997). Massive corals are typically found in moderate to high wave areas and can also thrive in deeper reef habitats (Zamani et al., 2015). However, some species can thrive in shallow waters if conditions are favorable (Nurma, 2022). Massive corals play a crucial role in coral reef ecosystems by contributing to the reef's structure, biodiversity, and overall ecological function. In Stations I and II, Dead Coral Algae (DCA) was observed with a coverage ranging from 1.4% to 10.2% at 2-3 m depths and 5-6 m. DCA occurs when coral tissue dies following the loss of zooxanthellae, leading to coral bleaching. This process allows other types of algae and moss to overtake the coral (Giyanto, 2017). When corals lose their zooxanthellae, the exposed skeleton becomes susceptible to diseases, predation, and colonization by other organisms, such as algae and mosses. Dianastuty (2016) stated the presence of algae competes with remaining live corals for space, light, and nutrients. This competition can impede the recovery of coral reefs by obstructing the settlement and growth of new coral larvae.

Tabel 2. Coral Reef Life Forms in the Waters of Penata Besar Island

Coral Reef Life Forms	Coverage (%)							
	Station I		Station II		Station III		Station IV	
	A	B	A	B	A	B	A	B
Live Coral								
Acropora Coral Branching (ACB)	1.6	0.2	-	-	0.2	-	-	0.8
Acropora Coral Digitate (ACD)	0.2	2.8	0.8	2.8	1.2	-	-	-
Acropora Encrusting (ACE)	-	0.6	1.2	-	4.3	-	-	-
Acropora Submassive (ACS)	30.4	3	3.2	11.2	6.2	9.8	2.4	10.4
Acropora Tabulate (ACT)	-	-	12	-	7.4	1.6	34.6	12.6
Coral Branching (CB)	-	-	1.2	-	-	-	-	-
Coral Encrusting (CE)	-	-	-	-	-	-	-	-
Coral Foliose (CF)	-	2.2	6.2	3,1	1.6	2.2	3.8	-
Coral Heliopora (CHL)	-	-	-	-	-	-	-	1.2
Coral Massive (CM)	19	21.6	27.4	21	39	35.8	21.6	24
Coral Mushroom (CMR)	-	-	-	1.4	0.8	-	-	-
Coral Submassive (CS)	-	-	-	-	1.2	-	-	-
Dead Coral								
Dead Coral (DC)	-	-	-	-	-	-	-	-
Dead Coral Algae (DCA)	3.4	10.2	1.4	2.2	-	-	-	-
Abiotic								
Rock (RCK)	-	2.2	-	1.6	-	-	-	-
Rubble (R)	-	-	-	-	-	-	-	-
Water (WA)	-	1.4	-	4.4	-	11.4	-	10
Sand (S)	-	6.4	-	2.2	0.6	-	1	-
Silt (SI)	10	38.6	-	2.6	-	2.8	3.6	5.2
Other Biota								
Turf Algae (TA)	28	0.6	34.6	30	31.7	31.2	21.4	5.2
Soft Coral (SC)	4	3,2	11.8	13	5.2	5.2	11.6	1.2
Sponge (SP)	3.4	2.4	-	-	0.4	-	-	-
Other (OT)	-	3.2	12	1.4	0.2	-	-	-
Macroalga (MA)	-	1.4	-	-	-	-	-	-
Zooantid (ZO)	-	-	-	-	-	-	-	-

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Index of Diversity (H'), Evenness (E), and Dominance (C)

Biological indices are employed to evaluate the health and diversity of coral reef ecosystems. These indices, including diversity (H'), uniformity (E), and dominance (C), offer insights into the stability of coral reef communities. The H', C and E indices were calculated based on coral coverage. In the waters around Penata Besar Island, the values of these biological indices vary across different sampling stations (Figure 5). The diversity index (H') for corals in the waters around Penata Besar Island ranges from 0.80 to 1.34, reflecting a stability level categorized as low to medium (Odum, 1993). A lower diversity index suggests that the coral reefs are less resilient to extreme environmental changes. The condition of the aquatic environment is a major factor influencing coral diversity, as only certain highly adaptable coral species can thrive. Elements like water quality, temperature, salinity, nutrient concentration, and light levels directly impact coral health and the range of species within coral reefs. Favorable conditions promote diverse and thriving coral ecosystems, whereas adverse conditions such as pollution, rising temperatures, and acidification, can result in coral bleaching, disease, and a substantial reduction in coral diversity (Hoegh-Guldberg and Bruno, 2010). The highest diversity index was recorded at station II at a depth of 2-3 meters, while the lowest was observed at Station III at a depth of 5-6 meters. This variation is supported by the observed levels of brightness and current velocity, which are below the optimal range needed to support coral growth at the research site.

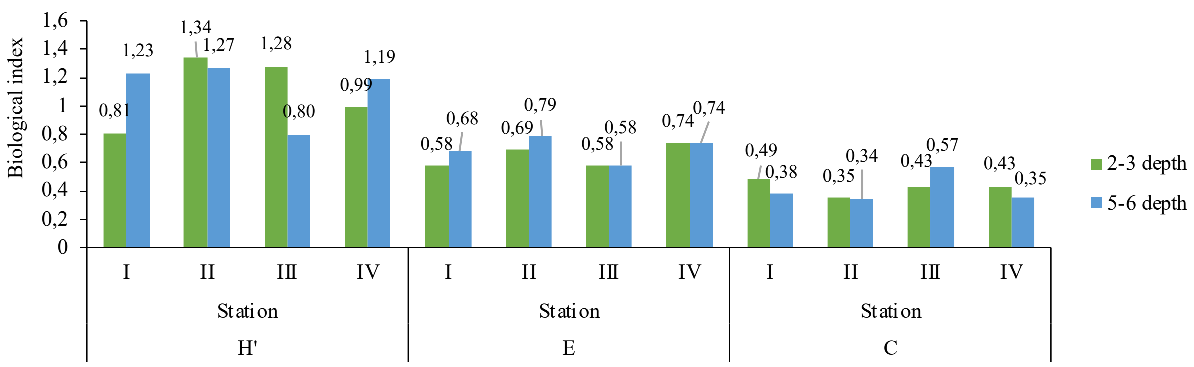

Figure 5. Index of Diversity (H'), Evenness (E), and Dominance (C)

The evenness index (E) in the waters of Penata Besar Island ranges from 0.58 to 0.79, placing the area in the medium to high category. These values reflect the degree of evenness in coral populations, suggesting a balanced distribution of different cover types. This finding indicates that no single coral type significantly dominates the community. High uniformity levels are indicative of a healthy and stable coral ecosystem, with environmental conditions that support species diversity. Such balanced distribution is crucial for the resilience of coral reefs against disturbances and environmental changes. The dominance index (C) ranged from 0.34 to 0.57, indicating a low level of species dominance. This low index value indicates a relatively even distribution among various coral growth forms, with no single type prevailing in the population. This low dominance index also reflects a well-balanced and healthy ecological state within the coral reef ecosystem.

CONCLUSION

Live coral cover varied by depth. At 2-3 meters depth, the live coral cover is high, indicating good reef condition. In contrast, coral cover is lower at 5-6 meters, falling within the fair category. The highest coral cover was observed in areas farther from human activity, while areas near residential zones and those with high boat traffic show signs of degradation, including coral bleaching. The prevalence of massive corals (CM) and the presence of Dead Coral Algae (DCA) indicate varying impacts of human activities and environmental stressors, particularly light availability and water temperature.

AUTHOR CONTRIBUTION

A.B. methodology, sampling, data analysis and curation, writing original draft. **I.S.** conceptualization, methodology, data analysis and curation, investigation, writing original draft. **Y.A.N.** conceptualization, methodology, data curation, writing original draft, funding acquisition. **M.S.J.S.**, writing original draft. **S.H**. funding acquisition. **I.F.** methodology, data analysis.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. The research was conducted and reported with full adherence to ethical standards and without any financial or personal conflicts that could have influenced the results or interpretation.

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