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Article

A Comparative Study of Coral Reef Cover Percentage Between Shallow and Deep Depths at Pramuka Island, Kepulauan Seribu

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Abstract: Indonesia possesses one of the largest coral reef resources in the world, representing approximately 14% of global reef coverage, and these reefs are highly vulnerable to environmental changes and human activities, particularly in densely populated areas like Pramuka Island, Kepulauan Seribu. This research was conducted to evaluate reef conditions around Pramuka Island through an analysis of coral cover at two depth ranges, namely shallow waters (3–5 m) and deeper reef zones (8–10 m). Data collection utilized Line Intercept Transect (LIT) method at six stations, with three transect replications at each depth. The results showed a significant difference in live coral cover between shallow and deep depths (p=0.018). The highest cover and best condition (very good category) were found at Panggang Cultivation Area, linked to ongoing coral cultivation and transplantation activities. Reef conditions among the observation sites ranged from poor to very good, reflecting considerable spatial variation in coral ecosystem quality, with the dominant lifeform being Coral Massive (CM), indicating high resistance to local pressures.

Keywords: coral reef percentage; depth variation; Pramuka Island

1. Introduction

Indonesia as an archipelagic country bounded by two continents and two oceans possesses extensive coastal and marine territories

(Kristianto *et al.*, 2023). Indonesia's vast maritime area encompasses approximately 14% of the world's total coral reef area (Utami *et al.*, 2021). Nugroho *et al.* (2024) indicated that Indonesia's coral reef area is estimated to reach around 50,000 km², characterized by high primary productivity. Despite having such extensive coral reefs, coral reefs in Indonesian waters exhibit vulnerability to environmental changes, with the Kepulauan Seribu region being particularly notable. Kepulauan Seribu Island cover approximately 897.71 hectares of terrestrial area and nearly 6,997.50 km² of marine waters, making them one of the prominent coastal regions in Jakarta. (Estradivari *et al.*, 2009; Khusna *et al.*, 2025).

Kepulauan Seribu is recognized as a tourist destination, particularly for marine tourism. The natural characteristics of Kepulauan Seribu include relatively clear waters and diverse coral reef ecosystems, which support the development of marine tourism in the area (Fauzan & Burhanuddin, 2023). Kepulauan Seribu also serves as a marine conservation area managed by Taman Nasional Laut Kepulauan Seribu (TNKpS) (Noviana *et al.*, 2019; Khusna *et al.*, 2025). The TNKpS zoning was established by the Ministry of Forestry, dividing the area into four zones: core zone, protection zone, utilization zone, and settlement zone. Panggang Island and Pramuka Island are designated as settlement zones, where research activities, education, utilization, and infrastructure development are permitted (Director General of PHKA, Department of Forestry, 2004). This zoning arrangement has resulted in significant pressure on Pramuka Island and Panggang Island due to dense human activities. This condition may contribute to the decline in coral reef extent and quality.

Reef-building corals are marine invertebrates that produce calcium carbonate skeletons, creating complex habitats that form the foundation of coral reef ecosystems (Spalding *et al.*, 2001). Meanwhile, reefs are limestone structures formed by corals, algae, or other photosynthetic marine organisms (Veron and Stafford-Smith, 2000). Reef-building corals, known as Scleractinia or hard corals, are animals that are almost entirely capable of producing calcium carbonate ($CaCO_3$) and live in close symbiotic association with zooxanthellae. Among coastal habitats, coral reefs are recognized as ecosystems that sustain exceptionally high levels of biological diversity. This ecosystem provides substantial benefits to the organisms inhabiting it (Triwibowo, 2023). Coral reef ecosystems also hold important ecological roles and provide benefits to coastal communities (Ipambonj *et al.*, 2025).

Coral reef ecosystems possess high attractiveness for tourists; however, they are susceptible to degradation (Koroy *et al.*, 2018). Continuous tourism activities can cause physical damage to coral reef ecosystems. For instance, snorkeling and diving activities conducted without proper care can destroy coral reef habitats (Taofiqurohman *et al.*, 2021). To protect coral reefs from various pressures, appropriate management is essential. An important aspect of management includes understanding depth variations, as coral reefs at different depths face different types and intensities of threats. Therefore, information regarding coral reef conditions across various depth zones is crucial. This research was conducted to evaluate reef conditions at different depth ranges and to examine variations in coral cover between shallow and deeper reef habitats.

2. Materials and Methods

2.1. Time and Location

This research was conducted from August 3rd to 9th, 2024, on Pramuka Island and its surrounding areas in Seribu Islands Regency, DKI Jakarta, at six research points. The observation sites consisted of the Panggang Cultivation Area (AKP), Marine Protected Area (DPL), West Air Island (BAI), West Pramuka Island (BPR), West Sekati Island (BSK), and South Panggang Island (SPG). The location map of the research sites is presented in Figure 1, while the coordinates of the observation stations are shown in Table 1.

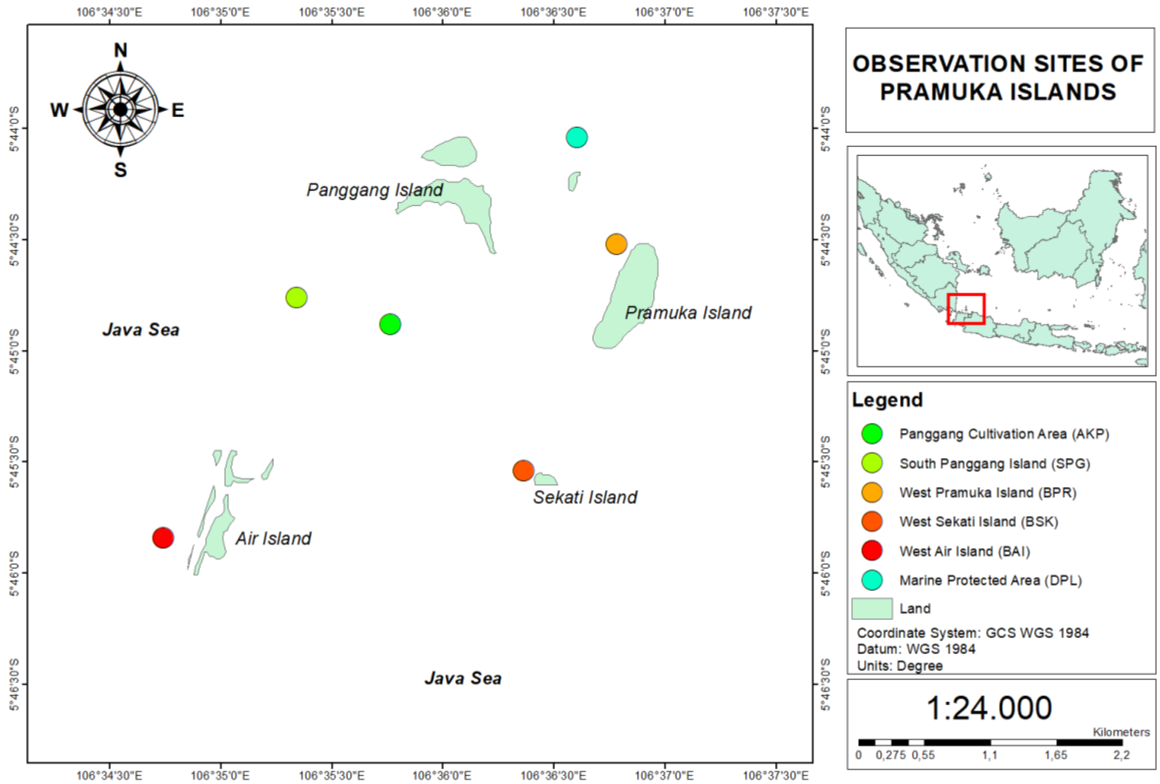

Figure 1. Research location map of the six coral reef observation sites around Pramuka Island, Kepulauan Seribu Islands, Indonesia, representing different reef conditions and management settings used to compare coral cover between shallow and deep depths

Table 1. Coordinate research location of the six coral reef observation sites around Pramuka Island, Kepulauan Seribu Islands, Indonesia, representing different reef conditions and management settings used to compare coral cover between shallow and deep depths

No	Research Location	Code	Coordinate	
			Lat	Lon
1	Panggang Cultivation Area	AKP	-5.748.300	106.596.833
2	Marine Protected Area	DPL	-5.734.790	106.610.950
3	West Air Island	BAI	-5.764.797	106.579.702
4	West Pramuka Island	BPR	-5.742.500	106.613.660
5	West Sekati Island	BSK	-5.759.066	106.606.317
6	South Panggang Island	SPG	-5.746.240	106.589.054

2.2. Tools and Material

Field activities employed standard diving gear, a transect tape (roll meter), recording equipment, and computer-based software for data management and analysis. Data were processed using Microsoft Office software and several coral identification references. Hard coral genera were identified following Veron and Stafford-Smith (2000), while soft coral genera were identified following Fabricius and Alderslade (2001).

2.3. Data Collection

Coral reef observations were performed through an adapted Line Intercept Transect approach to quantify substrate composition along predetermined transect lines (English *et al.*, 1997). A 20-meter transect line was installed parallel to the shoreline at two depth categories, namely shallow waters ranging from 3–5 m and deeper waters ranging from 8–10 m. Substrate types located directly beneath the transect line were identified and recorded throughout the observation period. Classification of benthic components followed the criteria described by Fahlevy *et al.* (2024), including hard corals, dead corals, algae-associated substrates, abiotic materials, and other benthic organisms. Several adjustments were made to accommodate local environmental characteristics. Living coral categories consisted of both hard and soft coral groups, whereas non-coral biotic components included algae and other biological materials that were not classified as corals. Abiotic categories comprised non-living substrates, while each coral colony encountered along the transect was documented according to its growth form to support morphological assessment.

2.4. Data Analysis

2.4.1. Persentage of Benthic Substrate Cover

The proportion of each benthic substrate category was determined by calculating the percentage contribution of every recorded lifeform along the transect line based on the approach described by English *et al.* (1997):

$$\textit{Percent Cover} = \frac{\sum li}{L} \times 100 \quad (1)$$

Explanation:

$\sum$li = Total length of the category

L = Total transect length

According to the Decree of the Minister of Environment No. 4 of 2001, coral reef ecosystems are characterized as marine habitats formed predominantly by reef-building organisms that produce calcium carbonate structures. These ecosystems consist of coral communities and associated organisms inhabiting the surrounding environment. Following the calculation of substrate cover percentages, reef condition was evaluated using the national classification system for coral reef status. Assessment was based on the percentage of living coral cover recorded at each observation station, with condition categories ranging from poor to very good, with the following standard:

Table 2. Standard criteria for coral reef condition and damage assessment based on live coral cover percentage according to the Decree of the Minister of State for the Environment No. 4 of 2001

Category		Percentage of Living Coral (%)
Damage	Poor	0 – 24,9
	Moderate	25 – 49,9
Good	Good	50 – 74,9
	Very Good	75 - 100

2.4.2. Paired T-test

Differences in benthic substrate cover between shallow and deep reef zones were evaluated using a paired t-test (Magdalena & Krisanti, 2019; Sinatrya *et al.,* 2024).. This statistical approach was selected because observations from both depth categories were obtained from the same monitoring stations, resulting in paired and dependent datasets. For each station, substrate cover values from individual transects were averaged prior to analysis. The mean value calculated for every station was subsequently treated as a single observation unit (n = 6). Statistical testing was performed using a 95% confidence level. A probability value below 0.05 indicated a significant difference between depth categories, whereas values greater than 0.05 suggested that no statistically significant difference was present.

3. Results

3.1. Percentage of Benthic Substrate Cover

The benthic assessment illustrates the relative composition of substrate categories observed at each monitoring location. Results presented in Table 3 indicate that substrate composition varied among stations and depth ranges. Analysis of these observations revealed that certain substrate groups occurred more frequently than others, reflecting differences in reef conditions across the study area. Variations in live coral, non-coral biota, and abiotic components contributed to the overall benthic structure recorded during field observations. Based on the data presented in Table 3, the most dominant substrate category across all stations is other substrates (50.7%), followed by live coral (40.4%), while the lowest proportion is recorded in the non-coral biotic category (8.8%). The percentage of hard coral cover also varies among stations and between depth categories. At deeper depths, the highest hard coral cover is observed at AKP (42.5%), whereas the lowest is found at BAI (19.7%). At shallow depths, AKP again exhibits the highest cover (82.8%), while the lowest value is recorded at BPR (21.5%). These patterns indicate that the substrate composition is dominated by non-coral components, with live coral remaining an important element that varies according to depth and station.

Table 3. Composition of benthic substrate categories (%) recorded at six reef monitoring stations surrounding Pramuka Island, Thousand Islands, Indonesia. AKP = Panggang Cultivation Area; APL = Marine Protected Area; BAI = West Air Island; BPR = West Pramuka Island; BSK = West Sekati Island; SPG = South Panggang Island

Research Sites	Live Coral				Non-Coral Biotic				Other Substrate			
	Hard Coral		Soft Coral		Algae		Other Biota		Abiotic		Dead Coral with Algae	
	8-10 m	3-5 m	8-10 m	3-5 m	8-10 m	3-5 m	8-10 m	3-5 m	8-10 m	3-5 m	8-10 m	3-5 m
AKP	42.5	82.8	2.63	10.9	0.0	0.0	2.0	0.1	47.7	1.6	5.1	4.6
APL	32.2	57.9	2.18	0	12.7	3.6	5.9	7.5	33.5	16.8	13.3	14.1
BAI	19.7	32.4	0.20	0.53	2.4	0	3.4	2.5	64.3	25.7	9.9	38.9
BPR	24.1	21.5	0.02	0.0	16.0	19.1	1.2	2.3	54.7	42.1	3.9	14.9
BSK	19.7	40.0	0.42	0.17	24.8	0.0	0.7	0.0	45.6	59.9	8.7	0.0
SPG	27.1	49.9	14.2	4.87	0.0	0.0	0.0	1.6	35.9	21.3	22.8	22.4

3.2. Percentage of Hard Coral Cover

Hard coral cover varied among the six monitoring stations and between the two depth categories evaluated in this study. In general, coral cover was greater in shallow waters (3–5 m) than in deeper waters (8–10 m). AKP recorded the highest coral cover at both depth categories, while the lowest values were observed at BPR for shallow depths and at BAI for deeper depths. An exception to the general pattern occurred at BPR, where hard coral cover at the deeper depth was slightly higher than at the shallow depth. These results indicate that shallow-water conditions tend to support higher hard coral cover relative to deeper areas.

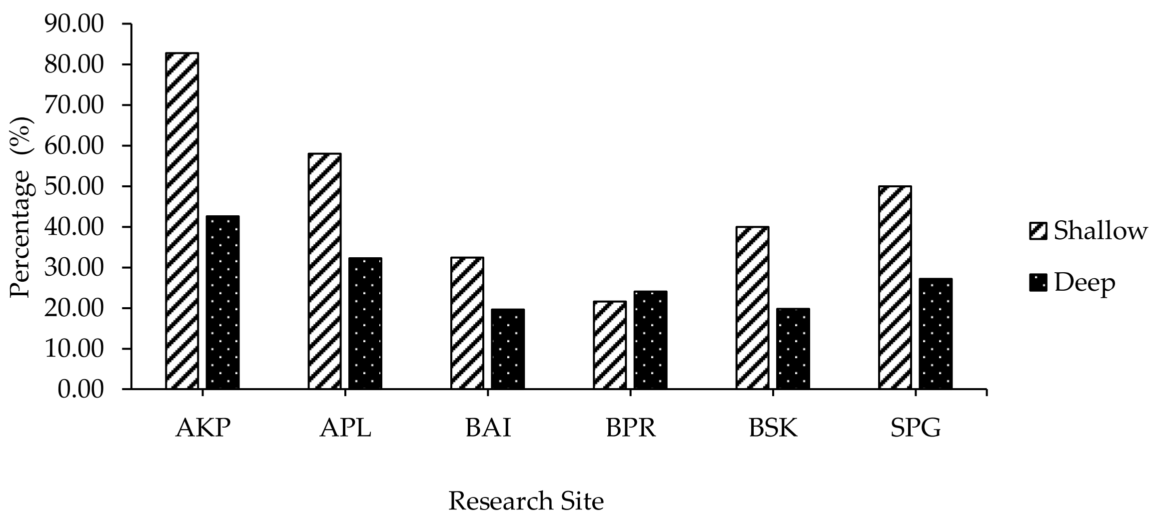

Figure 2. Distribution of hard coral cover (%) at shallow (3–5 m) and deeper (8–10 m) reef zones across six monitoring stations in the waters of Pramuka Island, Kepulauan Seribu, Indonesia. AKP = Panggang Cultivation Area; APL = Marine Protected Area; BAI = West Air Island; BPR = West Pramuka Island; BSK = West Sekati Island; SPG = South Panggang Island

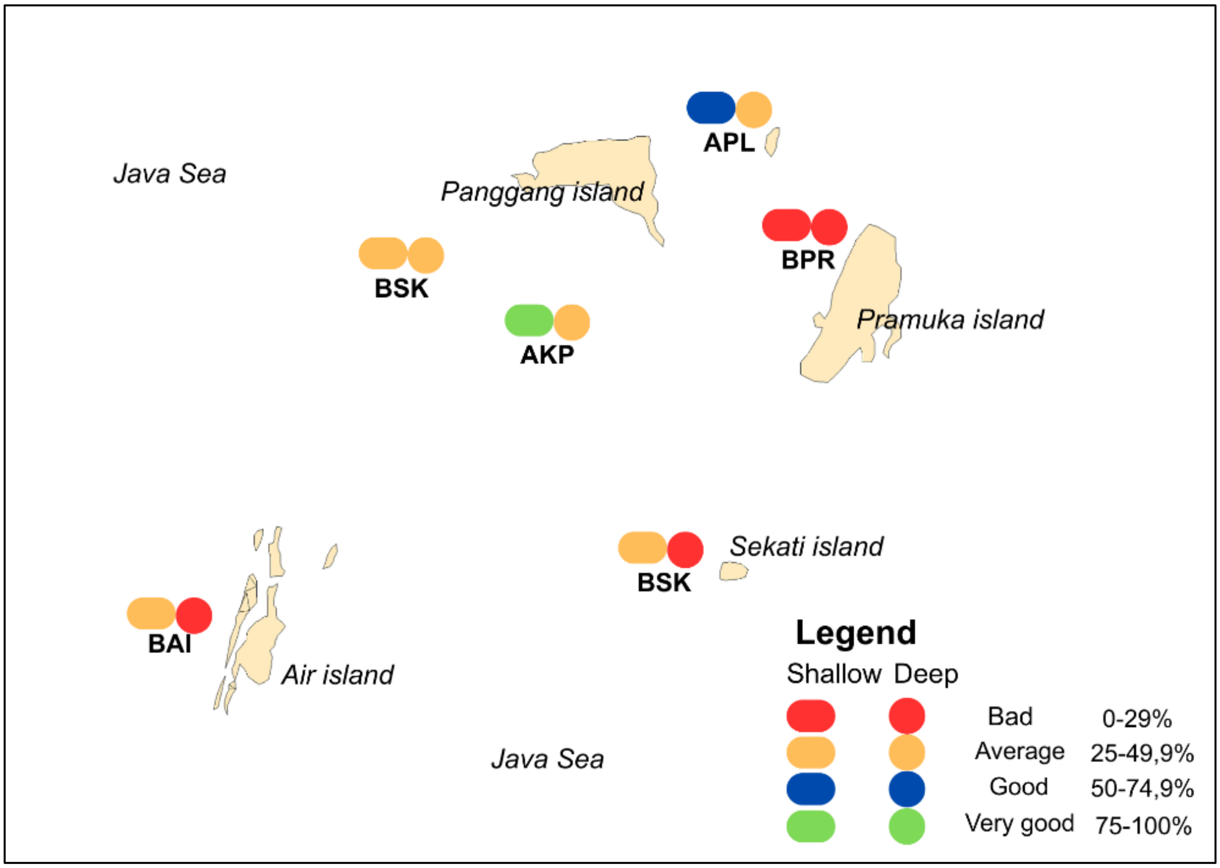

Figure 3. Spatial patterns of reef condition classifications at six monitoring stations surrounding Pramuka Island, Kepulauan Seribu, determined from the percentage of living coral cover and categorized using the national reef assessment criteria. AKP = Panggang Cultivation Area; APL = Marine Protected Area; BAI = West Air Island; BPR = West Pramuka Island; BSK = West Sekati Island; SPG = South Panggang Island

Based on the coral reef assessment standards applied in Indonesia, the percentage of living coral recorded at the six study locations indicates a range of reef conditions, extending from degraded to highly favorable categories. The very good category is found at AKP (82.8%; shallow), while the good category is observed at station APL (57.9%; shallow). The fair category includes SPG (27.1%; deep), APL (32.2%; deep), BAI (32.4%; shallow), BSK (38.5%; shallow), AKP (42.5%; deep), and SPG (49.9%; deep). The poor category is recorded at BAI (19.7%; deep), BSK (19.7%; deep), BPR (21.5%; shallow), and BPR (24.1%; deep).

3.3. Distribution of Coral Lifeform

The results of this study demonstrate variation in the dominant coral lifeform across the six research sites. A total of nine growth forms were identified at both depth categories, namely Acropora Branching (ACB), Acropora Digitate (ACD), Acropora Tabulate (ACT), Coral Branching (CB), Coral Encrusting (CE), Coral Foliose (CF), Coral Massive (CM), Coral Mushroom (CMR), and Coral Submassive (CS).

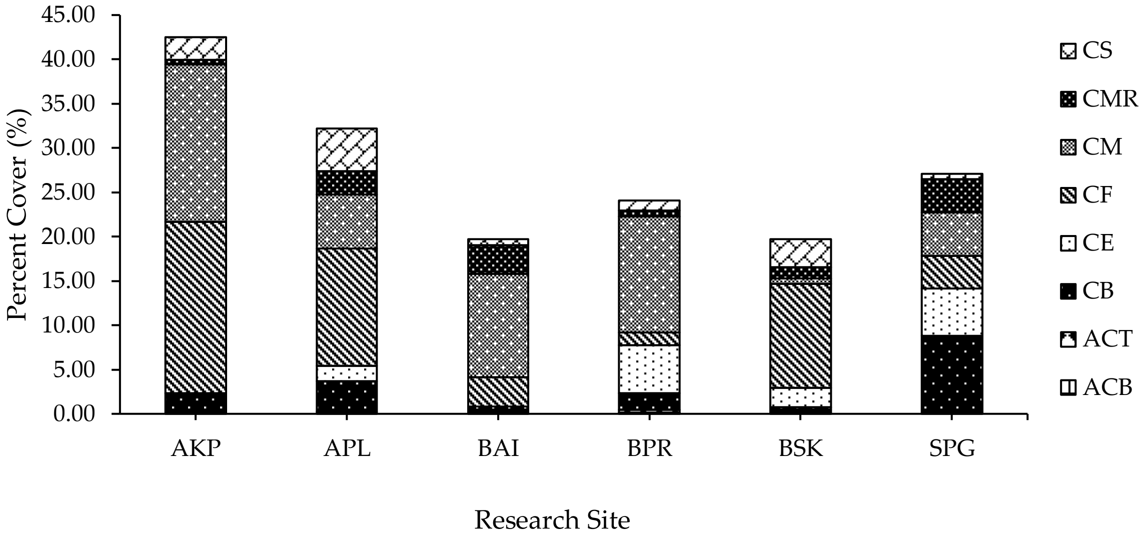

Figure 4. Percentage cover of coral growth forms at deep depth (8–10 m) across six coral reef observation sites around Pramuka Island, Kepulauan Seribu Islands, Indonesia. AKP = Panggang Cultivation Area; APL = Marine Protected Area; BAI = West Air Island; BPR = West Pramuka Island; BSK = West Sekati Island; SPG = South Panggang Island

Based on the composition of coral lifeforms across all stations, the highest to lowest proportions at deeper depths are CM (30.4%), CF (22.9%), CMR (16.7%), CE (10.7%), CB (9.3%), CS (9.1%), ACB (0.6%), and ACT (0.3%). The three dominant coral lifeforms at deeper depths by station are CM at station BPR (52.6%), CF at station AKP (38.5%), and CE at station BSK (29.6%).

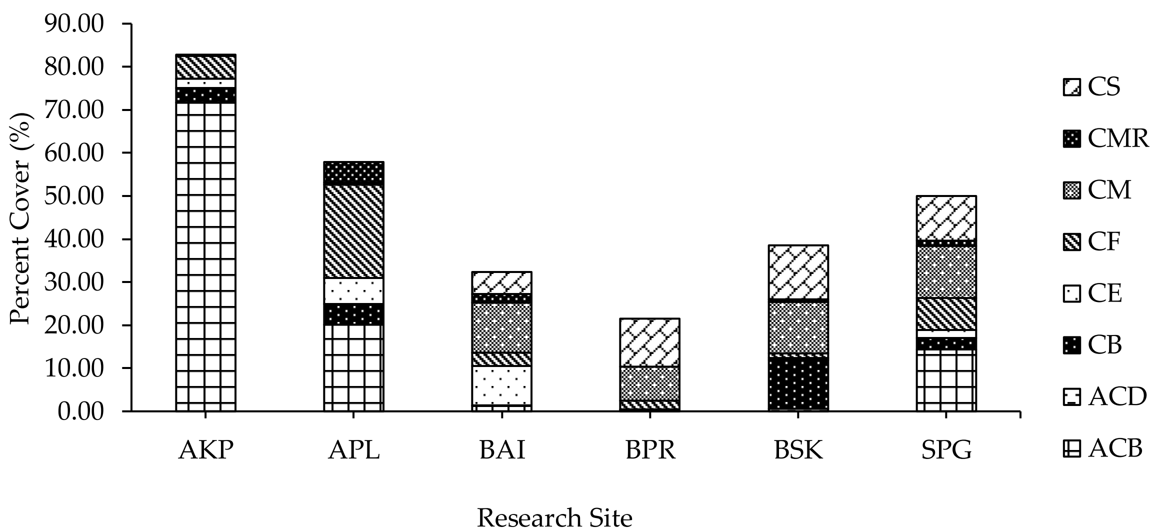

Figure 5. Percentage cover of coral growth forms at shallow depth (3–5 m) across six coral reef observation sites around Pramuka Island, Kepulauan Seribu Islands, Indonesia. AKP = Panggang Cultivation Area; APL = Marine Protected Area; BAI = West Air Island; BPR = West Pramuka Island; BSK = West Sekati Island; SPG = South Panggang Island

Based on the composition of growth forms across all stations, the highest to lowest proportions at shallower depths are CM (23.3%), CS (17.7%), ACB (14.5%), CF (14.3%), CE (13.9%), CMR (9.4%), CB (6.3%), and ACD (0.7%). The three dominant growth forms at shallower depths by station are CM at station BSK (49.1%), CS at station BPR (43.6%), and ACB at station AKP (50.0%).

3.4. Paired t-Test Analysis

The paired t-test results (Table 4.) show a significant difference in live coral cover between shallow and deep depths ($p = 0.018$; $p < 0.05$). This indicates that the two depth categories have statistically different cover values, with higher live coral cover occurring at shallow depths. The percentage data for each depth further demonstrate that live coral cover is greater in shallow waters.

Table 4. Paired t-test analysis of differences in live coral cover (%) between shallow (3–5 m) and deep (8–10 m) coral reef habitats at six observation sites around Pramuka Island, Kepulauan Seribu Islands, Indonesia

Depth	**p-value***	
	Shallow	**Deep**
Shallow	****	*0.018*
Deep	*0.018*	****

**Sig<0,05 = significantly different*

4. Discussion

The high percentage of coral reef coverage at the AKP observation station was due to the presence of coral transplantation activities in that area. This statement is supported by the regular coral transplantation activities conducted by the Ministry of Environment and Forestry (KLHK) since 2016, which have increased the coral reef coverage area at Panggang Island to reach 10.07 hectares over the past six years. Transplantation results can enhance the growth potential of new coral colonies and increase coral reef diversity at a given location (Nuryadin & Rahayu, 2023). However, it should be noted that coral transplantation without proper supervision and management will not yield positive outcomes (Anggara *et al.*, 2022). Monitoring of transplanted corals can minimize the impact of pests and ensure the availability of nutrients and good water quality, thereby increasing the survival rate of transplanted corals (Ranandya *et al.*, 2024). Several important aspects of post-transplantation monitoring and management include monitoring coral reef conditions, water quality, restricting tourism activities, and establishing regulations regarding fishing activities (Ginting, 2023). Conservation activities conducted by local communities, such as monitoring destructive fishing practices and awareness in maintaining ocean cleanliness, also contribute to preserving coral reef ecosystem sustainability (Ningsih *et al.*, 2021).

Coral reef damage in Pramuka Island waters is believed to be influenced by human activities in the area. For example, anchors dropped by fishing vessels can potentially break coral reefs. The use of inappropriate fishing gear in coral reef areas can also cause damage when fishing gear becomes entangled or drags coral fragments (Roslimah *et al.*, 2024). Coral reef damage is also believed to originate from tourism activities. Tourism activities in coral reef areas can cause disturbances through direct contact such as touching or holding coral reefs by divers/tourists (Wijaya & Prasita, 2024). Zaini *et al.* (2024) stated that coastal areas are highly sensitive and vulnerable to human activities, climate change, and natural phenomena. Similar findings were reported by Permana *et al.* (2020), who suggested that one of the causes of the high rate of coral breakage at Pramuka Island is the lack of caution by divers in paying attention to fragile coral reef locations.

Environmental conditions such as depth and currents can determine the dominance of a particular coral growth form (lifeform) (Cahyani *et al.*, 2025). Field observations indicated that massive coral represented the most abundant growth form within the study area. This category accounted for 30.4% of coral cover in deeper waters and 17.3% in shallow reef zones. The dominance of this growth form is due to the characteristics of massive corals, which tend to be more tolerant compared to other coral growth forms (Loupatty *et al.*, 2023). Massive corals are characterized by dense colony structures and are among the slowest-growing coral types, but have high resistance to currents, waves, and sedimentation (Hiola *et al.*, 2024). Massive corals also have a robust skeletal structure that allows them to survive strong currents and adapt well to water temperature fluctuations (Hanafi *et al.*, 2024). Their more tolerant characteristics make massive corals more competitive compared to other growth forms.

Foliose coral is the second most dominant coral growth form at deep depths. This coral type is commonly found in Kepulauan Seribu, which is a tropical water area. According to Alamsyah *et al.* (2024), foliose coral can live at depths of around 5–10 m and has high tolerance to strong current conditions. This is supported by Isdianto *et al.* (2020) who stated that foliose coral has wide and flat morphological characteristics that maximize light absorption by Symbiodinium sp. algae, enabling photosynthesis to occur more optimally even under low light conditions. The foliose growth form also shows better resilience to heatwave conditions, even in turbid waters (Zweifler *et al.*, 2024).

Corals of the genus Acropora have wide distribution in Indonesia, with branching being the commonly found growth form (Zurba, 2019; Alamsyah *et al.*, 2024). According to Syafni *et al.* (2022), Acropora corals have 2 corallites, namely radial corallites and axial corallites that help optimize light absorption. High light availability during growth periods will improve zooxanthellae photosynthesis performance, thereby accelerating colony growth. Acropora Coral Branching also has high growth rate characteristics, allowing this growth form to remain dominant in coral reef ecosystems (Fahlevy *et al.*, 2024). Results showed that ACB was most abundant in the AKP area, particularly at shallow depths. This location is used for coral transplantation, where coral transplantation often uses acropora branching corals for planting.

Although the overall percentage of live coral coverage at the six stations showed differences between shallow and deep waters, a different pattern was found at BPR Station. At this station, the percentage of live coral coverage in shallow waters was actually lower compared to deeper waters. To evaluate whether the observed variation between depth categories was statistically meaningful, a one-way ANOVA was performed. The analysis produced a probability value greater than 0.05.

5. Conclusions

Analysis results demonstrated that live coral cover differed significantly between the shallow and deeper reef zones of Pramuka Island, as indicated by a p-value of 0.018. Correspondingly, live coral cover was statistically higher in shallow depths. Based on the criteria from the Decree of the Minister of State for the Environment (KepMenLH) No. 4 of 2001, the live coral cover across the six observation stations falls into the categories of poor, fair, good, and very good. Station AKP recorded the best ecosystem condition (very good) and the highest coral cover at both depths, which is associated with its function as a coral cultivation or transplantation area. The most dominant coral lifeform at both depths was Coral Massive (CM) , indicating this form's superior tolerance and resilience to environmental pressures such as currents, waves, and sedimentation.

Author Contributions: Ratna Clara Laksmitha contributed to data analysis, data processing, interpretation of results, and manuscript writing (original draft and revision). Muhammad Farhan Haidar Rahman contributed to methodology and manuscript discussion. Try Feby Innocentia contributed to introduction and discussion. Imam Fatoni contributed to introduction and discussion. Ridha Rahman contributed to discussion. Firsta Kusuma Yudha contributed as a supervisor in the manuscript validation. All contributors approved and agreed to the final version of the manuscript prior to publication.

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Conflict of Interest: The authors confirm that there are no competing interests associated with this study.

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