Coral Reef Condition in the Utilization Zone of Menjangan Kecil Island Karimunjawa Islands

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Abstract

Karimunjawa Islands is a national park that has abundant natural resource potential and high biodiversity, especially in coral reef ecosystems. However, the utilization of coral reef ecosystems for marine tourism development has a negative impact on the condition of coral reefs. This study aims to determine the physical and chemical conditions of waters, the growth forms of coral reefs, and the condition of coral reefs in the marine tourism utilization zone of Menjangan Kecil Island, Karimunjawa Islands. A survey method was used for this research. Data were collected at four stations using the Underwater Photo Transect (UPT) method and analyzed using CPCe software. The results showed that the physical and chemical conditions of the water, including temperature, brightness, and pH, were still suitable to support the survival and growth of corals. There were 13 types of coral growth forms found, including Acropora Branching (ACB), Acropora Digitate (ACD), Acropora Encrusting (ACE), Acropora Submassive (ACS), Acropora Tabulate (ACT), Coral Branching (CB), Coral Encrusting (CE), Coral Foliose (CF), Coral Heliopora (CHL), Coral Massive (CM), Coral Millepora (CME), Coral Mushroom (CMR), and Coral Submassive (CS). The highest percentage of hard coral cover was found at station 2, with a value of 84.17%, and the lowest was found at station 3, with a value of 62.01%. Overall, the condition of coral reefs in the marine tourism utilization zone of Menjangan Kecil Island was in the high category.

Keywords: Coral Reef, Hard Coral Cover, Coral Growth Forms, UPT, Karimunjawa Islands

INTRODUCTION

Coral reefs are one of the most important ecosystems for the sustainability of the coastal and marine environment (Kordi and Ghufran, 2010). Coral reef ecosystem functions are connected to the well-being of millions of people who directly or indirectly gain benefits from coral reefs (Woodhead *et al*., 2019). Its function to maintain the stability of marine ecological conditions centers on eight complementary ecological processes, such as calcium carbonate production and bioerosion, primary production and herbivory, secondary production and predation, and nutrient absorption and release (Brandl *et al*., 2019). Furthermore, the coral reef ecosystem has economic value from tourism, coastal protection, and coral reef fisheries (Laurans *et al*., 2013; Hoegh-Guldberg *et al*., 2019; Rumahorbo *et al*., 2020). However, the condition of coral reefs in Indonesia has suffered a high level of damage caused by anthropogenic and non-anthropogenic factors. Marine pollution due to waste, destructive fishing, overexploitation of natural resources, ship anchoring, exhaust gas emissions from ships, and tourism activities has a considerable contribution in increasing damage to coral reefs (Hartoni *et al*., 2012; Indrabudi and Alik, 2017).

Karimunjawa National Park is one of the Marine Conservation Areas in Indonesia which has the potential for abundant natural resources and high biodiversity, especially in coral reef ecosystems and other associated biotas (Sulisyati *et al*., 2014). Karimunjawa National Park is managed by zoning system based on the Decision Letter of the Directorate General of Natural Resources and Ecosystem Conservation Number : SK. 28/IV-SET/2012, including: core zone, jungle zone, marine protection zone, land use zone, marine tourism utilization zone, marine cultivation zone, religious, cultural and historical zone,

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rehabilitation zone, and traditional fisheries zone (Destyananda *et al*., 2022). Marine tourism utilization zones are developed for the benefit of marine tourism, recreation, environmental services, education, research, support activities for cultivation, and development that support utilization (Karimunjawa National Park, 2022). The main attraction of this zone lies in the coral reef ecosystem as a marine tourism object. Coral reefs in Karimunjawa are important from a socio-economic standpoint, as well as a biological perspective, forming the main source of livelihood for most of the populations of 9000 inhabitants (Kennedy *et al*., 2020). However, marine tourism activities such as snorkeling and diving have caused ecological pressure on coral reefs through physical injury or sediment deposition (Lamb *et al*., 2014; Insafitri *et al*., 2021). Recreational diving and snorkeling in coral reef ecosystems are one of the most rapidly growing tourism sectors globally. In over 100 countries and territories, coral reefs attract foreign and domestic tourists and generate income, including foreign exchange earnings (Ransom and Mangi, 2010; Spalding *et al*., 2017). However, the economic function of coral reef ecosystems increases awareness about the need to manage and minimize the potential damage that results from marine tourism (Mazaya *et al*., 2019).

Several previous related studies have been published. Based on the technical reports of coral reef ecosystem monitoring from the Wildlife Conservation Society (WCS) in 2012 – 2016, there was a decrease in the percentage of hard coral cover in the marine tourism utilization zone of Karimunjawa National Park. A significant decrease occurred in 2016, with a percentage of 49.89%. The contributing factor is the pressure from marine tourism activities that are not environmentally friendly, where there was evidence of damage such as broken branching corals and massive corals that died as a result of being stepped on by snorkelers (Pardede *et al*., 2016). There is evidence documenting the impacts of recreational snorkelers and scuba divers on coral reefs. Various studies have shown that physical impacts from snorkelers' behaviors, such as fin kicking, sitting, standing, or kneeling on the reef, and touching the reef with hands, has the potential to break corals and reduce hard coral cover (Biondi *et al*., 2014; Akhmad *et al*., 2018; Prasetya *et al*., 2020; Pribadi *et al*., 2020). Locations with high marine tourism utilization tend to have a low percentage of coral cover and high rubble cover following the increasing number of tourists (Liu *et al*., 2012; Otto *et al*., 2015; Renfro and Chadwick, 2017) because coral reefs are highly vulnerable to environmental changes and pressures due to human activities that can result in a lower ability to regenerate or even the death of entire coral colonies (Hall, 2001). However, no recent research has been published on the condition of coral reefs in the marine tourism utilization zone of Karimunjawa National Park.

In the development and management of the Karimunjawa National Park area as the main destination for marine tourism that utilizes the beauty of the coral reef ecosystem, it is necessary to conduct research regarding the condition of coral reefs in the marine tourism utilization zone. Hence, this study aims to determine the condition of coral reefs based on the percentage of hard coral cover. In addition, the physical and chemical conditions of the waters and the form of coral growth found in the marine tourism utilization zone of Menjangan Kecil Island, Karimunjawa Islands were also determined. The data and information are expected to be taken into consideration to determine strategic steps in efforts to manage conservation areas in an integrated and sustainable manner, so that the ecological function of coral reefs can take place optimally and the utilization of environmental services can be obtained sustainably. Considering the high biodiversity in the coral reef ecosystem, it holds various potentials and also challenges managing it wisely.

MATERIALS AND METHODS

This research was conducted on Menjangan Kecil Island, Karimunjawa Islands, in August 2022. Field data collection was carried out at four stations, namely, (1) Shipwreck site at coordinates 5°53'24", 110°24'11"; (2) Maer site at coordinates 5°53'22", 110°24'18"; (3) Control site at coordinates 5°53'15", 110°24'22"; and (4) Tanjung Awani site at coordinates 5°53'6", 110°24'29". In addition, the four research stations have different regional characteristics and utilization rates (Figure 1).

Coral reef data collection was carried out using the Underwater Photo Transect (UPT) method. Data were collected at 6 – 12 m depth along a 50 m transect line parallel to the coastline by photographing the substrate as wide as the frame size (58 x 44 cm), resulting in 50 photos at each station. Frames with odd numbers were taken on the left side of the transect line, while frames with even numbers were taken on the right side of the transect line (Figure 2) (Giyanto *et al*., 2017). This zig-zag sampling pattern was applied to better capture spatial variability of benthic components across the transect and to reduce spatial autocorrelation. Previous studies have shown that zig-zag patterns may result in less adequate reconstruction of original distribution fields compared to strictly parallel transects; therefore, careful consideration of transect spacing and sampling distance units is required to ensure representative field reconstruction (Kalikhman, 2007).

Water Quality Measurement

Water quality measurements were conducted directly in the field (in-situ) and from the boat. Parameters measured include temperature (°C), brightness (m), and pH using two measuring instruments, namely Water Quality Checker (EC900, Amtast, USA) to measure temperature and pH then Secchi Disk to measure brightness.

Analysis Data

Data were processed using Coral Point Count with Excel extensions (CPCe) software to obtain quantitative data such as the percentage of hard coral cover and other benthic categories. Data analysis was conducted on each frame by selecting 30 random point samples. Data recorded included biota and substrate located right at the position of the point that has been determined randomly by the CPCe software. The percentage of hard coral cover

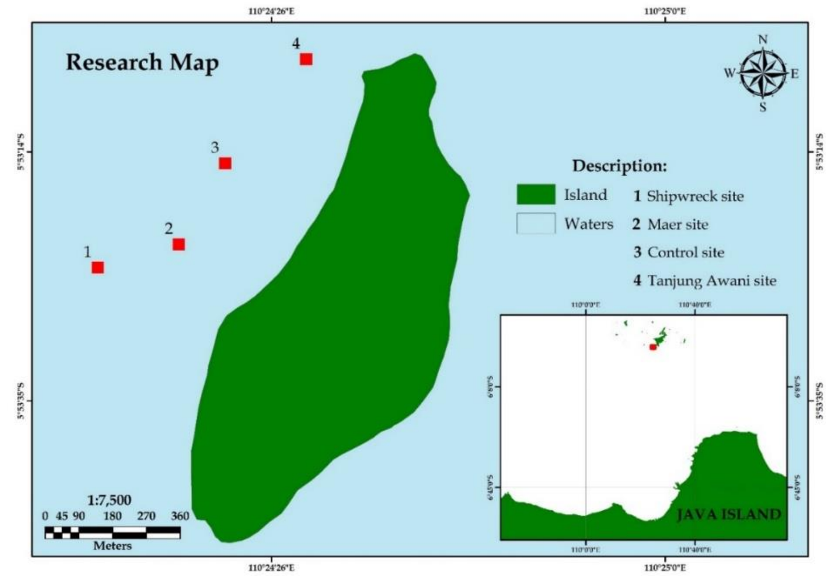

Figure 1. Research location map of Menjangan Kecil Island, Karimunjawa Islands

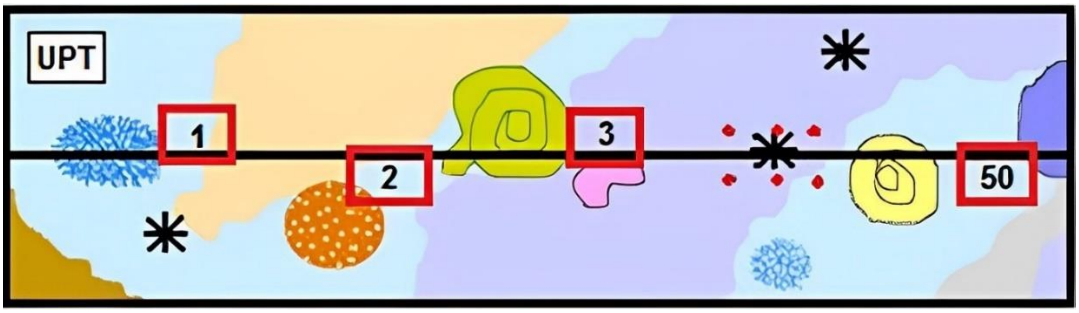

Figure 2. Illustration of data sampling using the UPT method. The black line is a 50 m long line transect. Red boxes to the left of the transect line indicate odd-numbered frames (1, 3, …) and to the right of the transect line indicate even-numbered frames (2, 50, …). Primary colors show illustrations of coral reefs (Giyanto *et al*., 2017)

and other benthic categories were calculated based on the following equation (Giyanto *et al*., 2017):

$$\text{Percentage cover of each category (\%)} = \frac{\text{(Number of points from that category)}}{\text{(Number of random points)}} \times 100$$

The condition of coral reefs was determined using categories based on the Coral Reef Rehabilitation Management Program – Coral Triangle Initiative (COREMAP–CTI) in 2017, namely: live coral cover < 19% (low), 19% ≤ live coral cover ≤ 35% (moderate), and live coral cover > 35% (high) (Giyanto *et al*., 2017).

RESULT AND DISCUSSION

The results showed that there were 13 types of coral growth forms in the research site, consisting of 5 Acropora forms and 8 non-Acropora forms, namely Acropora Branching (ACB), Acropora Digitate (ACD), Acropora Encrusting (ACE), Acropora Submassive (ACS), Acropora Tabulate (ACT), Coral Branching (CB), Coral Encrusting (CE), Coral Foliose (CF), Coral Heliopora (CHL), Coral Massive (CM), Coral Millepora (CME), Coral Mushroom (CMR), and Coral Submassive (CS). Coral Massive represented the highest percentage cover at stations 1 and 3, accounting for 20.72% and 11.44%, respectively. In contrast, Coral Branching dominated station 2 with a cover of 37.32%, while Coral Foliose was dominant at station 4 with a cover of 46.69%. The percentage cover based on coral growth forms at 4 stations is presented in Figure 3.

Based on Figure 3, coral growth forms at stations 1 and 3 were dominated by Coral Massive. This is probably because station 1 was located far from shore and exposed directly to the open sea (Figure 1), so these water conditions tend to be extreme because they are affected by strong currents and waves. Meanwhile, at station 3, there were high marine tourism activities, so this type of coral growth dominated due to its high adaptability to environmental pressures at the station. According to Sigarlaki *et al*. (2021), the high percentage of Coral Massive is because this type of coral has a dense and sturdy shape, so it can survive in extreme environmental conditions, such as strong currents and high levels of turbidity. This is also supported by Kanela *et al*. (2018), which stated that Coral Massive is resistant to environmental changes and has a high recruitment rate. This coral is also able to clean the surface of its body from sediment deposits with the help of current movements (Barus *et al*., 2018).

Coral growth forms at station 2 were dominated by Coral Branching. The high percentage of Coral Branching at this station was caused by the water conditions at the research site are still suitable for coral growth (Table 2), especially for branching corals, which has a high growth rate. In addition, this station was located in a sheltered reef slope area (Figure 1), where this area is generally dominated by Coral Branching. Suryanti *et al*. (2011) stated that corals living in reef slope areas usually have a branching growth form. According to Daniel and Santosa (2014), in sheltered areas, coral growth will form thin and elongated branching, while in areas that have strong currents and waves, coral growth will tend to be shorter, stronger, and encrusting. Wijaya *et al*. (2017) added that corals with branching growth forms have a faster growth and recovery rate compared to other growth forms, especially in optimal water conditions to support coral growth.

Coral growth forms at station 4 were dominated by Coral Foliose. This is due to data collection being carried out at a depth of 12 m and in the reef slope area, so it was dominated by Coral Foliose. In accordance with the statement of Hartoni *et al*. (2012), that the dominant forms of coral growth in the reef slope area were Coral Foliose and Coral Branching. Zurba (2019) added that corals found in deeper areas have a thinner and slimmer shape, this is caused by a calcification process that is less than optimal. Coral Foliose that live in shallow waters surrounded by strong currents and waves will be more easily broken and damaged, so this type of coral tends to be found in calm and deeper waters (Hughes, 1987). According to research conducted by Ompi *et al*. (2019), the growth form of Coral Foliose at a depth of 10 m tends to have a higher coral growth rate than at a depth of 5 m.

Coral Reef Condition and Benthic Composition

The results exhibited that the percentage of hard coral cover in the marine tourism utilization zone of Menjangan Kecil Island at 4 stations had values between 62.01 – 84.17%, which is categorized as high condition. The highest percentage of hard coral cover was found at station 2, with a value of 84.17%, and the lowest at station 3, with a value of 62.01%. The percentage cover of benthic categories in the form of biota and substrate is depicted in Table 1.

Based on Table 1, the highest percentage of hard coral cover was found at station 2, followed by station 4, station 1, and the lowest at station 3. Stations 2 and 3 were locations with a high level of marine tourism utilization. The high percentage of hard coral cover at station 2 may be due to the implementation of the close access system from 2018 to 2021. This close access system was implemented to restore the condition of the coral reef ecosystem by closing the area access from marine tourism activities. While at station 3, the percentage of hard coral cover was lower than at the other stations. This was caused by marine tourism activities that continued to increase due to the non-implementation of the close access system, so the condition of coral reefs at this station has continued to decrease. This is in accordance with the results of research conducted by Cahyani and Wijaya (2021), where the percentage of hard coral cover in the Maer close access area, Menjangan Kecil Island, was higher than the Control area, Menjangan Kecil Island, which does not implement the close access system. According to Juhasz *et al*. (2010), there was a correlation between the percentage of live coral cover and the utilization of a location, locations with high marine tourism utilization tend to have a low percentage of live coral cover.

Coral reef conditions at stations 1 and 4 (Figure 4) were categorized as high. Station 1 is primarily used as a diving site and is not commonly accessed for snorkeling activities due to its location facing the open sea, which limits accessibility for snorkeling tourists. In contrast, station 4 is a snorkeling site frequently visited by tourists. Indicators of coral reef degradation at snorkeling sites can be reflected by the proportion of rubble cover. In this study, the lowest rubble cover was observed at station 1, while the highest was recorded at station 4. Information obtained from local community members and the management authority of Karimunjawa National Park indicates that, despite ongoing conservation campaigns and environmental awareness programs, physical contact with corals by snorkeling tourists—such as accidental stepping or fin contact—still occurs, particularly in shallow reef areas. Such interactions are consistent with general forms of snorkeling-related disturbances reported in previous studies (Webler & Jakubowski, 2016).

Rubble observed at the study sites was predominantly derived from branching coral growth forms, which are structurally more fragile and prone to breakage when subjected to physical disturbances. Therefore, the higher rubble cover at station 4 may reflect the combined influence of reef accessibility, tourist pressure, and the vulnerability of branching corals, rather than direct measurements of tourist behavior. According to Insafitri *et al*. (2021), the presence of branching coral fragments in a coral reef ecosystem was caused by the high intensity of stepping on corals while snorkeling. Furthermore, rubble may also be caused by the anchoring of tourist boats on coral reefs, which can result in broken coral branches (Ginoga *et al*., 2016).

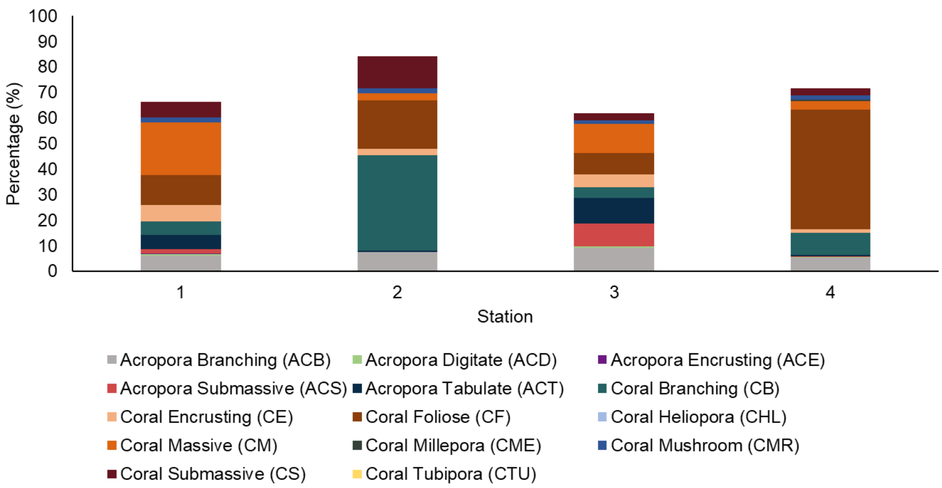

Figure 3. Percentage cover based on coral growth forms

Table 1. Percentage cover of hard corals, benthic biota and substrate categories at each station

Benthic Categories	Percentage Cover (%)			
	Station 1	Station 2	Station 3	Station 4
Hard Coral (HC)	66.38	84.17	62.01	71.64
Recent Dead Coral (DC)	5.66	3.39	4.90	0.67
Dead Coral with Algae (DCA)	7.24	3.52	8.24	8.83
Soft Coral (SC)	0.00	0.00	0.00	0.00
Sponge (SP)	1.15	0.07	1.16	0.07
Fleshy Seaweed (FS)	0.00	0.00	0.00	0.00
Other Biota (OT)	2.15	0.00	0.41	0.20
Rubble (R)	3.44	3.59	7.35	13.71
Sand (S)	0.07	0.07	0.61	0.13
Silt (SI)	0.00	0.00	0.00	0.00
Rock (RK)	13.91	5.18	15.32	4.75

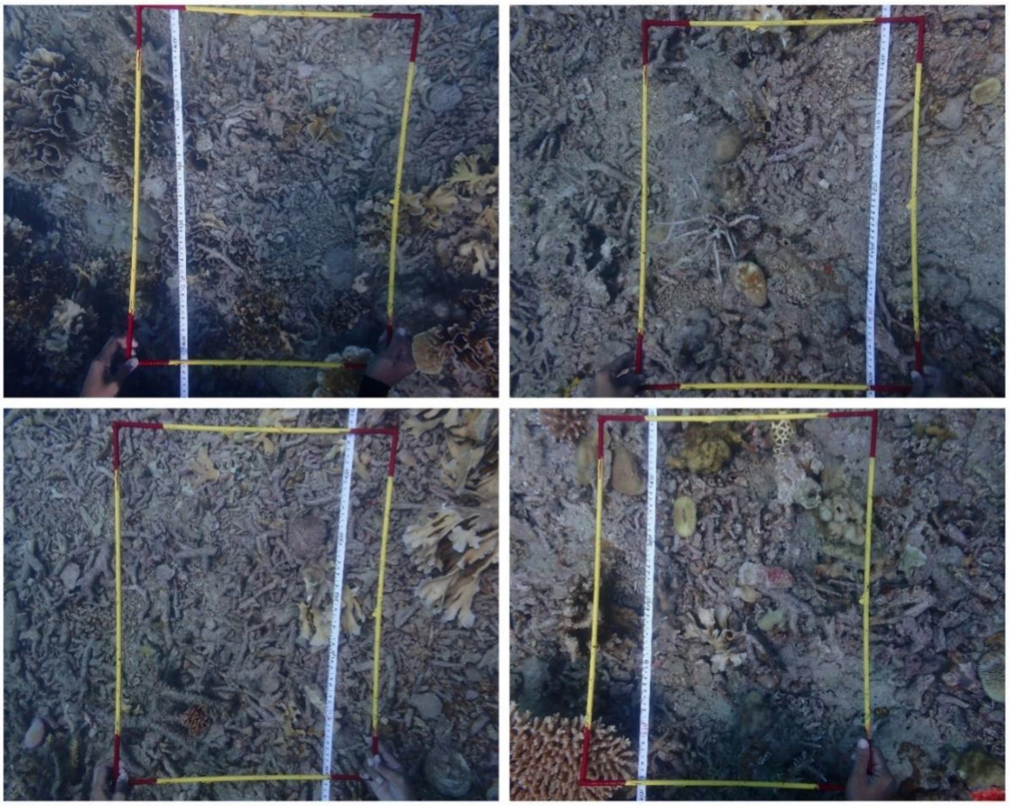

Figure 4. Condition of rubble cover at station 4 caused by destructive behavior of snorkeling tourists

The percentage of dead coral cover was found at all research stations. The highest percentage of dead coral cover for the recent dead coral category was found at station 1 with a value of 5.66% and the lowest at station 4 with a value of 0.67%. The presence of dead corals at station 1 indicates the degradation of coral reefs caused by anthropogenic factors such as marine tourism, intensive fishing, and the anchoring of tourist boats. In addition, the loss of competition for space between corals, sponges, and other biota found at this station also caused a high percentage of dead corals. This was shown by the percentage of other biota cover at station 1, which was higher than other stations. According to Idris *et al*. (2019), the percentage of dead coral cover provides opportunities for sponges and other marine biota, such as Ascidian, to attach, grow, and cover the surface of corals. Besides competing for space with corals, sponges and other biota are also able to invade living corals until they die.

Based on the percentage of dead coral with algae cover, the highest was found at station 4 with a value of 8.83% and the lowest at station 2 with a value of 3.52%. The high percentage of dead coral with algae is thought to be because there has been considerable destruction at station 4 and has been going on for a long time caused by human activities such as fishing activities that are not environmentally friendly and climate changes that contribute to coral bleaching, so it can stimulate algae growth on dead corals. The presence of dead coral with algae also represents the form of competition that occurs between corals and algae. The coral reef structure that has been abandoned by coral polyps becomes a space for competition between corals and algae to attach in the recruitment process (Faizal *et al*., 2020). Dianastuty *et al*. (2016) also added that the loss of coral competition with algae was caused by the decline of algae-eating herbivorous fish and increased nutrients in the waters (eutrophication), which could stimulate rapid algae growth on coral reefs. The high percentage of dead corals also indicates the impact of marine tourism activities on coral reefs. Akhmad *et al*. (2018) stated that coral reef degradation as an impact of marine tourism activities can be in the form of partial death of coral colonies, broken coral branches, and erosion of the surface of coral colonies.

Other biotic components found at the research site are sponges and other biota, including anemones, hydroids, ascidians, and clams. The highest percentage of sponge cover was found at station 3, with a value of 1.16%, while for other biota, the highest was found at station 1, with a value of 2.15%. However, the presence of sponges can be a strong competitor for corals in competing for space. According to Aerts (1998), high coral cover conditions will inhibit sponge growth due to limited space for sponges to live and overgrowth, while low coral cover conditions will increase sponge growth because there is enough space to support sponge growth. Only competitively dominant sponge species were able to maintain space in coral reef environments with high coral cover. This is in accordance with the results of this research, where at station 3 there was the highest percentage of sponge cover with the lowest percentage of hard coral cover compared to other stations.

Abiotic components of the water bottom substrate found at the research site include rubble, sand, and rock. The presence of this component was dominated by rock, with the highest percentage cover found at station 3 of 15.32%. The highest percentage of sand cover was also found at station 3 but had a low value of 0.61%. The highest percentage of rubble cover was found at station 4, with a value of 13.71%. The bottom substrate is needed by coral larvae to settle. The type of bottom substrate can affect coral recruitment, growth, and survival. Coral larvae need a hard and stable substrate during the settlement process until they grow into adult corals. Unstable substrates such as sand will cause difficulty in coral larvae recruitment (Rudi *et al*., 2005). In the research location, the presence of sand substrate was very low and dominated by rock substrate, where the condition of this substrate is quite solid, so it can be one of the factors supporting the success of coral living.

Water Quality Conditions

Water conditions, including temperature, brightness, and pH, in the waters of Menjangan Kecil Island were still in the optimum range to support coral growth and survival. Data from the measurement of physico-chemical parameters of waters is presented in Table 2.

The measured water temperature at the research location was 29.6°C. Although this value falls within the range specified by the Indonesian marine water quality standard (Ministry of Environment and Forestry, 2004), this regulation primarily serves as a management and compliance benchmark rather than an ecological threshold. From an ecological perspective, coral reef organisms generally exhibit optimal growth within a temperature range of approximately 23 – 30°C. Coral reefs are known to tolerate higher temperatures, up to 36 – 40°C, although prolonged exposure may induce physiological stress to (Prasetia, 2015). Water temperature also influences coral feeding behavior, with corals generally losing their ability to capture food at temperatures above 33.5°C and below 16°C (Supriharyono, 2000). Therefore, the observed temperature can be

Table 2. Measurement results of physico-chemical parameters of waters

Parameters	Units	Measurement Results
Water temperature	°C	29.6
Water brightness	m	10.8
Degree of acidity (pH)	-	8.00

Description: Quality Standard Based on Minister of Environment Decree Number 51 of 2004

considered suitable for coral growth under the present environmental conditions. Zurba (2019) added that sudden changes in temperature between 4 - 5°C above or below the ambient level can affect coral growth and even kill them.

The water brightness at the research location showed a value of 10.8 m. This value shows the level of water brightness was still in very good condition. The presence of sunlight is very influential on the survival and growth of corals. This is related to the continuity of the photosynthesis process by symbiotic zooxanthellae contained in coral tissue (Subhan *et al*., 2014). The lack of light intensity entering the water can inhibit the rate of photosynthesis of zooxanthellae, which in turn can affect the growth of coral colonies and the ability of corals to produce reefs (Fauzanabri *et al*., 2021).

The degree of acidity (pH) at the research location showed a value of 8.00. This value was still in accordance with the standard quality of seawater for marine biota, which is 7 - 8.5. According to Edward and Tarigan (2003), the optimal pH value for coral reefs ranges from 6 - 9. The pH value of seawater is influenced by the concentration of carbon dioxide (CO_2) dissolved in the water. A decrease in seawater pH caused by an increase in the concentration of dissolved CO_2 in the water, will cause ocean acidification. The absorption of CO_2 by the sea will react with water molecules and form carbonic acid. Carbonic acid in the water will release hydrogen ions and form bicarbonate. This causes a decrease in the pH of seawater and makes the ocean more acidic. This process will reduce the concentration of carbonate ions and inhibit the process of reef-building on corals (Haiqal *et al*., 2021).

CONCLUSION

Based on the research that has been conducted, it can be concluded that the growth forms of coral reefs found include Acropora Branching (ACB), Acropora Digitate (ACD), Acropora Encrusting (ACE), Acropora Submassive (ACS), Acropora Tabulate (ACT), Coral Branching (CB), Coral Encrusting (CE), Coral Foliose (CF), Coral Heliopora (CHL), Coral Massive (CM), Coral Millepora (CME), Coral Mushroom (CMR), and Coral Submassive (CS). The condition of coral reefs based on the percentage of hard coral cover was in the high category, this was supported by the physico-chemical conditions of the waters, including temperature, brightness, and pH, which were still in the optimum range to support the survival and growth of corals. However, it is necessary to conduct regular monitoring to assess the trend of changes in coral reef conditions, so if the condition of coral reefs tends to decline, then control and recovery actions can be performed to maintain a balance between utilization and sustainability.

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