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Assess the level of damage to the coral reef ecosystem based on substrate coverage on Bira Island, Kepulauan Seribu, Indonesia

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Abstract. *Komala R, Noer MI, Miarsyah M, Widyartini DS, Handayani. 2024. Assess the level of damage to the coral reef ecosystem based on substrate coverage on Bira Island, Kepulauan Seribu, Indonesia. Biodiversitas 25: 971-977.* Coral reefs are coastal ecosystems that have an important ecological and economic role. Environmental pressures cause damage to ecosystems and decrease coral biodiversity. This study aims to analyze the level of damage to coral reef ecosystems based on substrate cover and obtain the latest information on coral reef ecosystem resources. The study employs a descriptive method with a survey design, utilizing Underwater Photo Transect (UPT) sampling at various depths along the coastline. The data is analyzed using Coral Point Count with Excel extension (CPCe) for substrate cover percentage and the Shannon-Wienner index for coral diversity. The findings reveal nine categories of basic substrate cover, with living hard corals constituting 32.51%, indicating a fairly damaged state. Coral resources are identified across 53 genera and 15 families, exhibiting medium diversity across stations and depths. The study highlights the need to monitor environmental threats that could further damage coral reefs and decrease diversity. The coral reef ecosystem in Bira Island is in a relatively damaged condition, with a decline in coral biodiversity, indicating an imbalance in the ecosystem. Several recommended steps include implementing coral restoration programs, monitoring coral growth, establishing critical coral habitat protection zones, and conducting conservation efforts.

Keywords: Coral reefs, conservation, damage, ecosystem, substrate cover

INTRODUCTION

Coral reefs are part of the marine aquatic ecosystem formed by coral polyps living together. Coral polyps secrete calcium carbonate and form a massive accumulation of limestone skeletons that are their habitat (Reynaud et al. 2009; Nugraha et al. 2020; Souza et al. 2023). Various groups of marine life, including coral groups, are the main components of the coral reef ecosystem. There are two large groups of corals, namely hard corals (Scleractinia), with hard and dense calcium skeletons forming reefs, forming large colonies, and involving many polyp individuals (Costello et al. 2017). The other group is soft corals (Octocorallia), which do not have hard calcium skeletons and do not form reefs (Eddy et al. 2021). Environmental, biogeographical, and habitat areas affect coral distribution and biodiversity (López-Londoño et al. 2022).

Coral reefs attract the attention of various parties because of their ecological and economic roles (Eddy et al. 2021; Edmunds and Riegl 2020). This ecosystem acts as a refuge, foraging, reproducing, nesting, and spawning for various kinds of fish, shellfish, and other commercial marine life (Williams et al. 2021) and protection from storms (Arifin et al. 2020; Williams et al. 2021). It is also very beneficial for human welfare because it is a hotspot of high biodiversity, and its beauty supports various sectors such as the socio-economic, fisheries, and tourism (Mendoza et al. 2019; Kjerfve et al. 2021; Lin et al. 2021). One of the Islands that became a tourist destination is Bira Island, which is included in the conservation area and core zone of the Kepulauan Seribu. The pollution level in the Jakarta Bay area has an impact on the quality of several physical and chemical water parameters in the Kepulauan Seribu (Handayani et al. 2023)

Coral reef ecosystems worldwide, including those in Indonesia, face imminent threats leading to habitat degradation and destruction, primarily attributed to various direct and indirect human activities (James et al. 2023). Rapid population growth, business interests, and increased accessibility to coastal resources by technological advancements and climate change exacerbate those damages (Adam et al. 2021; Bax et al. 2022). The climatic change increases sea surface temperatures, thus accelerating the process of extensive coral bleaching; if this occurs continuously, it will affect the community structure and the basic substrate cover loss in the form of living hard corals, which are health indicators and the level of damage to coral reef ecosystems (Klepac and Barshis 2020; Adam et al. 2021).

Four main indicators can assess the health and damage to coral reef ecosystems: the percentage of substrate cover of living hard corals, macroalgae, herbivorous fish, and commercial fish that are mostly exploited (Kjerfve et al. 2021). Reefs are characterized by low base substrate cover and density as living creatures (Edmunds and Riegl 2020; Hughes et al. 2017). The dominance of other substrates can destroy this ecosystem cover, such as sea urchins, macroalgae, sponges, dead corals, and other types of substrate covers (Edmunds and Riegl 2020), boat runways, dredging, and the use of environmentally unfriendly fishing gear (Lin et al. 2021). Several studies on benthic community responses to coral reef ecosystem disturbances have been conducted (Stark et al. 2014); those conditions cannot be generalized, so it is necessary to understand the consequences of various environmental changes to manage and prevent their impact on certain areas. This research is focused solely on obtaining the level of damage to the coral reef ecosystem and the latest data on coral diversity in Bira Island.

The hard corals' health as a substrate cover reflects the sustainability of the coral reef ecosystem thoroughly; therefore, conservationists can identify threats, take protective measures, and design recovery strategies for coral reef ecosystems by monitoring and evaluating the condition of living hard corals. The essential parameters in evaluating the ecological status of coral reef ecosystems are based on information about their constituent biodiversity. Therefore, with limitation on information about the condition of coral reef ecosystems in the Kepulauan Seribu, the study aimed to analyze the level of damage to coral reef ecosystems based on criteria for the percentage of living hard coral substrate cover and investigated the latest conditions of coral resource diversity as a basis for management and conservation.

MATERIALS AND METHODS

This research used quantitative descriptive methods with a survey design. The observation site was selected purposefully, consisting of 4 stations representing the existence of coral reefs parallel to the coastline on Bira Island, Kepulauan Seribu, North Jakarta. Observations at each station were made at depths of 2, 4, and 6 meters; 30-meter-long transect lines were laid at each depth as auxiliary lines so that all transect lines were 12 transects.

Coral observations were done using the Underwater Photo Transect (UPT) method (Zamani and Madduppa 2011). The photographs were taken every 1-meter interval, starting from the 1st meter to the 30th meter of the transect line. The area of each photo frame was 58×44 cm or 2.552 cm^2. The samples observed included coral and substrate cover types at each station and depth, and the sampling locations are shown in Figure 1.

Substrate cover analysis was performed through photographs at 30 random points based on the computer-assisted Application of Coral Point Count with Excel extensions (CPCe). The identified substrate cover was coded according to the substrate cover category (Table 1). The substrate cover percentage value was calculated using the following formula (Kohler and Gill 2006).

$$Percentage\ of\ category\ coverage = \frac{Number\ of\ category\ point}{Number\ of\ point}\ x\ 100\%$$

Furthermore, the level of damage to coral reef ecosystems was determined based on the percentage of living hard coral substrate cover found compared to the coral reef quality standard criteria. The criteria for damage levels based on the percentage of living hard corals are divided into four categories (Kementrian Lingkungan Hidup 2001; Zamani and Januar 2020).

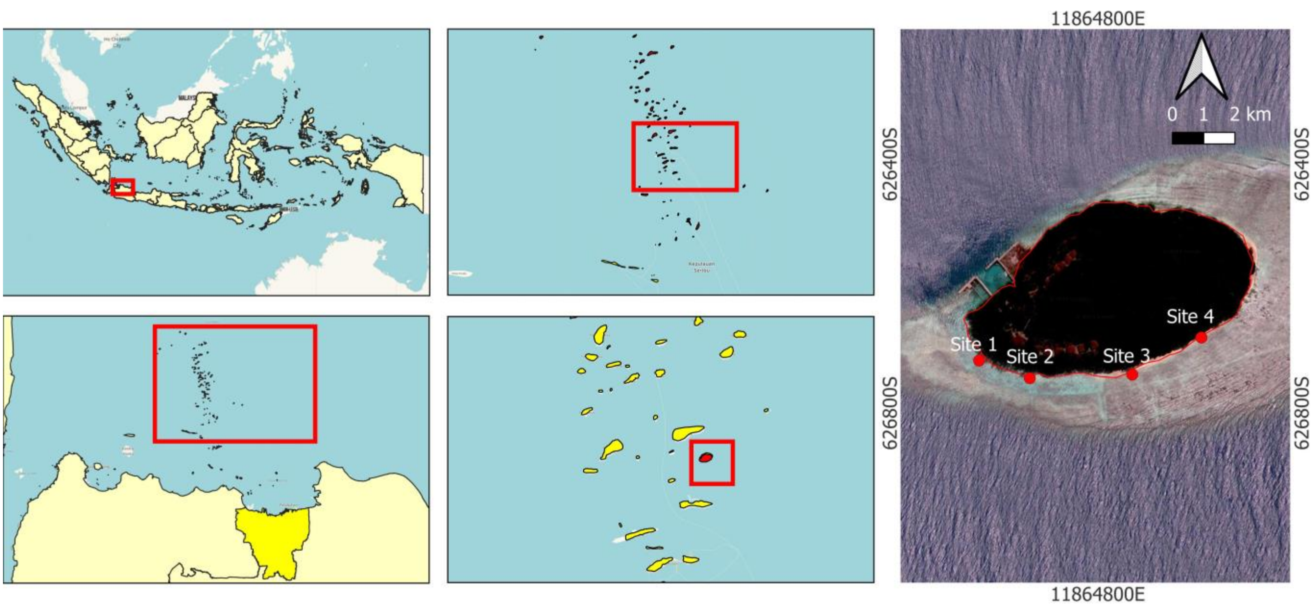

Figure 1. Sampling locations on Bira Island, Kepulauan Seribu Utara, Kepulauan Seribu, Jakarta, Indonesia

The percentage of living hard coral cover that can be tolerated is between 50 and 100%, while the range between 1 and 49 is categorized as damaged ecosystems. Coral diversity at each station and depth was calculated by the formula of the Shannon-Wiener diversity index (H') (Souza et al. 2023).

$$H" = -\sum_{i=1}^{s}(P_i \ln P_i)$$

Where:
H' : diversity index
Pi : ni/N
Ni : number of individuals of a species
N : total number of individuals

Coral diversity was determined based on 3 criteria: low diversity if H'≤2, medium diversity if 2<H'≤ 3, and high diversity if H'≥3.

RESULTS AND DISCUSSION

Substrate cover and extent of damage to coral reef ecosystems

There were 9 categories of substrate cover identified, namely: hard coral (HC), recent dead coral (RDC), dead coral with algae (DCA), rubble (R), sponge (SP), seaweed (SW), soft coral (SC), and not identified (N). Figure 2 shows the highest percentage of substrate cover represented by hard coral (32.51%), followed by rubber (28%) and recent dead coral (10.24%). In comparison, the lowest percentage was represented by soft coral (1.75%) and not identified (0.6%) (Figure 2)

There was a complex relationship between coastal environments and coral reefs related to benthic communities, such as substrate cover, abundance, fish richness, and other marine life (Li and Asner 2023). The low composition of living hard corals as substrate cover needs more attention as it will impact the overall stability of the ecosystem (Edmunds and Riegl 2020; Lin et al. 2021). Figure 2 shows the highest percentage indicated by the living coral cover of 32.52%; following the damage criteria, this damage level is included in the fairly category because the value is 25-49.9% range; this indicates that the coral reef ecosystem has been damaged (Kementrian Lingkungan Hidup 2001).

The coral reef damage can be caused by several factors, including increased surface temperature due to climate change that accelerates coral bleaching (Shlesinger and van Woesik 2023). Coral bleaching is the appearance of damage to the symbiotic relationship between the coral host and its symbionts, namely dinoflagellates, the pigment released from symbiont algae, causing the corals to have pale, white, disturbed growth and, subsequently, death (Maynard et al. 2015; LaJeunesse et al. 2018; Morikawa and Palumbi 2019; Denley et al. 2020). Important ecological factors in ecosystems of coral reefs include substrate cover (i.e., groups of macroalgae sponges) and other substrate cover such as sand, debris, hard bottom, and bedrock (Santavy et al. 2022). The coral reefs' health is important to implement ecological functions; losing structural complexity and diversity in coral reefs dramatically impacts fish communities (Vercammen et al. 2019). Substrate cover in the form of algae dead coral (DCA), Rubble (R), and other substrate cover affects the growth of living hard corals (HC). Changes in the composition of hard coral substrate cover in the long term will cause changes in fish biomass in the next period (Russ et al. 2021). Algae dead coral (DCA) has died and, on the surface, has been overgrown by fine algae, and the substrate cover is in the form of DCA with a percentage of 0.24%; this substrate allows coral larvae to attach and grow into adult corals (Idris et al. 2020).

Rubble substrate (R) reaches 28% and comprises branched corals damaged by strong currents or waves. According to the Kepulauan Seribu region survey, the average percentage of basic substrate cover is dominated by coral faults, 33.33% of the coral reef ecosystem on the island. Rubble and dead corals with algae (DCA) and other substrates have affected coral reef fish communities. Waves in the western, eastern, and transitional seasons affect the ecosystem and biota community on this island, causing the coral branches to break (Zamani and Januar 2020).

Table 1. Hard coral cover category to assess the extent of damage (Kementrian Lingkungan Hidup 2001; Zamani and Madduppa 2011)

Category	Hard coral cover (%)
Excellent	75-100
Good	50-74.9
Fairly	25-49.9
Bad	1-24.9

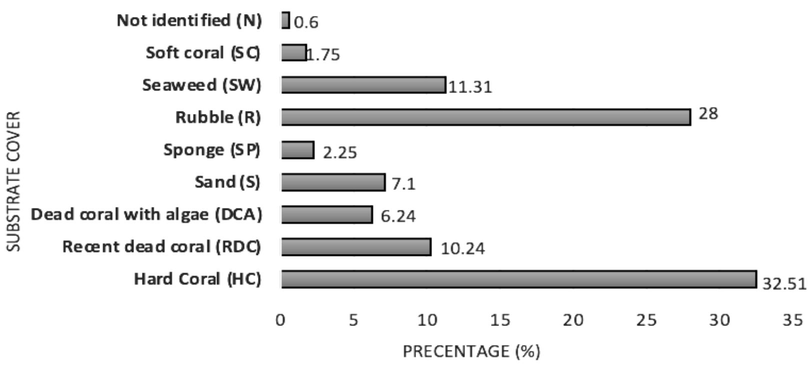

Figure 2. Percentage of substrate cover

Moreover, in locations with calm currents and waves, rubble allows coral larvae to attach, grow, and potentially increase the recoveries; on the contrary, the location is frequently exposed to strong currents or waves. Those strong currents or waves affect unstable rubble and are easily carried away by currents and waves, causing the death of larvae (Saad et al. 2023). The basic substrate of sand (S) found is relatively small, at 7.1%. Just like rubble, sand is an unstable substrate because it is easily moved by currents and waves, making coral larvae difficult to stick to; therefore, even though the percentage is small, it is still considered to affect coral populations (Zamani and Madduppa 2011; Santavy et al. 2022).

Damage measurement parameters based on substrate cover criteria will help evaluate coral reef ecosystems' management and conservation efforts. Sponge cover (SP) was 2.25%, while the rest not identified were below 1%. Sponge groups producing acid secretions can disrupt hard corals by dissolving the $CaCO_3$ skeleton. In some genera, sponges such as Cliona drill into the calcium matrix and cause the death of coral tissue (Santavy et al. 2022). Macroalgae commonly grow and spread on tropical coastlines and act as a feeding and shelter for coral reef fish. The growth of macroalgae is usually faster than that of corals, so it will inhibit the rate of coral growth (Dunne et al. 2023). The substrate cover of macroalgae and other environmental variables such as sedimentation, predation, and structural complexity affect the size and distribution of marine life populations; the macroalgae substrate cover was 0.22%. Although the percentage is small and is not considered the main cause, its existence will be a competitor for corals; therefore, the hard corals will be hard to survive (Westlake et al. 2021).

Environmental stressors such as substrate damage, overfishing, eutrophication, sedimentation, and other physical activities have reduced the resilience of most coral reef ecosystems (Hughes et al. 2017). In tropical countries and worldwide, pressure from rising sea surface temperatures worsens the condition of coastal ecosystems (Siegle and Costa 2017). Additionally, another substrate cover is algae-dead corals (DCA), rubble (R), sand (S), and sponge (SP). Hence, besides being a competitive habitat, this substrate covers are also unsuitable for larvae and adult corals to attach for their living. The characteristic role of basic substrates as habitats and food sources, an important ecological factor that determines the structure of coral animal communities, is still not widely studied (dos Reis et al. 2020). The decline in the condition of the Coral Reef ecosystem on Bira Island aligns with the decline that occurred globally for five decades (Romero-Torres et al. 2020). This causes the existence of ecosystem services to face great risks (Woodhead et al. 2019; Santavy et al. 2022). Dramatic damage to coral reefs in tropical marine regions is a crucial problem as an ecological function because changes in coral resource structure could impact fish communities and other biota (Loch et al. 2021).

Coral diversity

Corals identified in coral reef ecosystems belong to as many as 53 genera belonging to the 15 families. The highest percentage respectively represented families of Faviidae (15.9%), Fungiidae (13.21%), and Acroporidae (11.32%), while the percentage of families with the lowest percentage represented families of Dendrophylidae (1.90%) (Figure 3). The total number of coral genera identified from 15 families spread across several stations and depths (Table 2). The coral genus of each family are shown in Table 3. The value of the coral diversity index varies both based on the station and depth (Table 4)

Table 2. Percentage distribution of the number of coral genus by station and depth

Station	**Station**	**%**
	1	24.57
	2	25.71
	3	23.43
	4	26.29
Depth (m)	**Meter**	%
	2	24.59
	4	34.43
	6	40.98

Table 3. Genus of corals by family

Family	**Genus**
Faviidae	*Caulastrea, Cyphastrea, Diploastrea, Favia, Favites, Goniastrea, Monastrea dan Oulastre*
Fungiidae	*Fungia, Herpolitha, Ctenactis, Heliofungia, Zoopilus, Cycloseris dan Lithophyllon*
Acroporidae	*Acropora, Alveopora, Anacropora, Astreopora , Enigmopora, Montipora*
Agariciidae	*Agaricia , Dactylotrochus, Leptoseris, Pavona*
Pectiniidae	*Oxypora, Mycediu, Pectinia, Echinophyllia*
Poritidae	*Goniopora , Porites, Stylaraea, Bernardpora*
Merulinidae	*Hidnophora, Merulina, Favites*
Mussidae	*Blastomussa, Symphyllia, Acanthastrea*
Astrocoeniidae	*Astrocoenia, Palauastrea*
Carryophyllidae	*Bathycyathus, Euphyllia*
Oculinidae	*Galaxea, Oculina*
Pocilloporidae	*Pocillopora, Madracis*
Sederastreidae	*Psammocora, Anomastraea*
Dendrophyllidae	*Turbinaria*
Helioporidae	*Heliopora*

Table 4. Diversity index values by station and depth

Station	**Station**	**H'**
	1	2.413
	2	2.466
	3	2.361
	4	2.472
Depth (m)	**Meter**	**H'**
	2	1.896
	4	1.996
	6	2.340

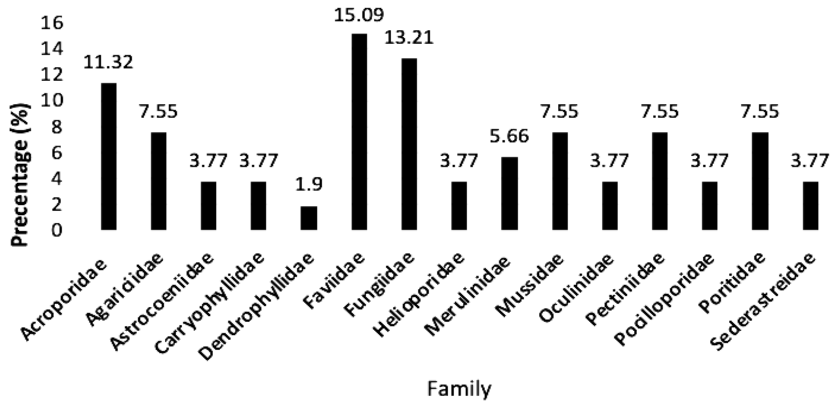

Figure 3. Percentage of corals by family

The essential parameter for evaluating coral reefs' ecological status is information about their constituent biodiversity (Lin et al. 2021). In studying macroecology, information about the distribution of biodiversity is essential for conservation by region (Kusumoto et al. 2020). Current information on changes in spatiotemporal marine biodiversity concerning interactions with human activities is critical for coral reef conservation management (Maynard et al. 2015; Denley et al. 2020). Paviidae, Fungiidae, and Acroporiidae are relatively more numerous than other families because they have a relatively wide distribution.

The diversity index by depth 2, 4 and 6 meters ranges from 1.896-2.340, while it ranges from 2.361-2.472 by observation station; the value falls into the medium diversity category referring to the diversity criterion. This indicates that the stability of coral communities in coral reef ecosystems is still quite good. The value of diversity is influenced by the number of coral families and genera found, consisting of 15 families from the order Scleractinia and 53 genera. In the prior study, Shlesinger and van Woesik (2023) have identified as much as 84 coral genera in Indo-Pacific. Therefore, the percentage of coral genera on Bira Island compared to all identified genera in Indo-Pacific area (32.51%) is still quite diverse.

The current diversity criteria are still the same as results from previous years and have not improved. According to the study by (Estradivari et al. 2009) in the Kepulauan Seribu, the percentage of living hard coral cover on Bira Island reached 38.1%, while on Kayu Angin Genteng Island, it reached 27.38%, falling under the category of fairly damaged conditions. The average diversity index values of 2.86 and 2.64, respectively, fall within the medium criteria.

A high diversity value is usually the same as a uniformity value but a low dominance value (Thomas et al. 2022). The decline in coral populations caused by bleaching and mortality will also negatively impact other marine life that depends on coral communities for shelter and foraging (Shlesinger and van Woesik 2023).

Changes in the composition of basic substrates to support coral reef ecosystems are causing cascading impacts on the disruption of ecosystem function, productivity, and biodiversity; the existence of corals is severely threatened by global warming, acidification of seawater, and local and even regional disturbances such as overfishing, habitat degradation, and land-based pollution (Quataert et al. 2015; Asner et al. 2022). Human activities directly or indirectly impact the symbiont, namely dinoflagellates (LaJeunesse et al. 2018). Pigmented symbiont algae, which causes corals to turn pale or white, has an impact on decreasing growth, health, production, and even eventually causing death) (Morikawa and Palumbi 2019; de Clippele et al. 2023). The decline in biodiversity due to human exploitation makes it difficult to implement effective conservation strategies (Romero-Torres et al. 2020).

Recently, some ecologists have concluded that the decline in coral colony populations is closely related to hard corals' low living substrate cover (Edmunds and Riegl 2020; Loch et al. 2021). Currently, Indonesia faces the challenge of habitat degradation and biodiversity decline in coral reef ecosystems caused by the dual pressures of climate change and anthropogenic disturbances; therefore, conservation efforts must be encouraged to protect biodiversity centers from the threat of climate change (Maier et al. 2019). The impact of ecosystem degradation accompanied by a decrease in coral reef resources is also observable in Indonesia's commercial and tourism sectors (Adam et al. 2021; Eddy et al. 2021)

Environmental parameters

The results of environmental parameter measurements vary based on observation stations, and this can be influenced by several factors, including changes in weather, time, and other natural conditions. The environmental parameter data for each observation station is shown in Table 5.

Table 5 shows the results of water quality on Bira Island that fluctuates between observation stations. The temperature at each station ranges from 28.34-29.290°C. A good temperature for coral growth is in the range of 25-29°C. Corals require warm water temperatures ranging from 25-32°C, so the temperature on Bira Island is not ideal conditions. However, recent research shows that corals have tolerance to varying temperatures and that there is a positive correlation between temperature tolerance and coral colony growth. Corals can still tolerate temperatures up to a minimum limit of 18°C and a maximum temperature of 36°C (Schoepf et al. 2015).

Table 5. Environmental parameters by stations

Station	Environmental parameter					
	Temperature (°C)	pH	Light penetration (m)	Current (m/s)	Salinity (ppt)	Dissolve oxygen (mg/L)
1	28.34	8.25	4.95	0.08	33.86	5.59
2	29.15	7.53	4.85	0.07	34.12	5.43
3	29.21	8,41	5.65	0.05	33.68	5.65
4	29.29	6.14	5.05	0.09	33.49	5.45

Corals can grow well at pH between 6-8.5. Aquatic environments with a highly acidic or alkaline pH can interfere with coral metabolism and respiration, so the pH range of 7.5-8.41 on Bira Island is within the normal range. Light penetration that supports coral life occurs above a depth of 5 meters, with an average measurement result of 5.12 meters, which is considered to support coral growth still. The speed of the current can help supply plankton with food for coral polyps. A current velocity of 0.07 m/s can help clean up dirt attached to coral polyps. Normal salinity for hermatipic coral growth is 27-40 ppt. Therefore, salinity between 33.49 and 34.12 is still within the supportive range (Kementrian Lingkungan Hidup 2001). Based on these parameter data, the environmental conditions of Bira Island, Kepulauan Seribu, in general, still support life in coral reef ecosystems.

In conclusion, based on the substrate cover of living hard corals, the condition of the coral reef ecosystem on Bira Island, Kepulauan Seribu, showed damage in a fairly category. Coral diversity based on the four observable stations on its depth also includes criteria indicating quite a variation in the number of corals in a coral reef ecosystem. This condition must be watched by paying attention to and maintaining this coral diversity from various threats that damage habitat parameters to decline the coral diversity further. Therefore, regular monitoring needs to be done so that resources remain sustainable due to the abundance of living hard corals generally associated with healthier and more diverse ecosystems. The study's results complement information about current coral resources and basic substrate types that inhibit coral animal growth as a basis for efforts to reduce threats to maintaining coral animal biodiversity. Finally, protecting corals and their habitats, reducing pollution, and sustaining fisheries resources management help restore coral animal populations and promote higher biodiversity.

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