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The health status of coral reef ecosystem in Taka Bonerate, Kepulauan Selayar Biosphere Reserve, Indonesia

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Abstract. *Wulandari P, Sainal, Cholifatullah F, Janwar Z, Nasruddin, Setia TM, Soedharma D, Praptiwi RA, Sugardjito J. 2022. The health status of coral reef ecosystem in Taka Bonerate, Kepulauan Selayar Biosphere Reserve, Indonesia. Biodiversitas 23: 721-732.* This study assessed the coral reef conditions in a tropical marine biodiversity hotspot, Tambolongan and Polassi islands, located within the transition zone of UNESCO's Taka Bonerate Kepulauan Selayar Biosphere Reserve in Indonesia. The islands' coral reefs receive a multitude of pressures from anthropogenic activities, risking the livelihood of local communities which rely on resources, such as fish stocks, from this ecosystem. This study measured the coral and reef fish characteristics and current biodiversity status in the coastal waters surrounding the two islands. The evaluation of the coral reefs condition used the Coral Health Index (CHI), which was determined from the two main components of benthic coverage (using underwater photo transect) and reef fish assemblages. The results showed that, overall, coral reef health status in both islands could be classified as very poor (with scores ranging from 1 to 3, out of 10 for CHI), with medium to nearly low diversity for coral (H' index of 1.5 to 2.24), and medium to high diversity for reef fish (H' index of 2.90 to 3.37). This study observed the ecological responses of both habitat and fish within each environment towards the existing damages, which indicated a degree of habitat resiliency. The results obtained contribute to further understanding the extent of pressures towards the quality of marine habitats in the area. They can also be used as baseline data to devise management measures, such as rehabilitation, restoration, or monitoring programs, to ensure that sustainable development can be pursued without neglecting the necessity for conservation.

Keywords: Coral reef, biodiversity, conservation, ecological monitoring, ecosystem health

INTRODUCTION

Coral reefs are complex ecosystems that provide important services in coastal areas, such as habitats for important marine organisms, coastal protection, and place for recreation and tourism (Kramer et al. 2014; Woodhead et al. 2019). The interaction between the environment and biota in coral reef ecosystems makes this ecosystem an important role in the earth's climate system dynamics (Bellwood et al. 2018). Corals hold vital roles to sustain the population of reef fish and other reef-associated fish, and that the reef's conditions are directly associated with the density and compositional characteristic of reef fish (Prabowo et al. 2019; Jaroensuutasinee et al. 2020). Loss or damage to coral reefs due to disturbance affects the presence of reef fish and its juveniles (Kerry and Bellwood 2012; Darling et al. 2017; Lampe et al. 2017). Vice versa, reef fish, can also influence the recruitment of coral and coral reef benthic communities' structures (Chong-Seng et al. 2012; McClanahan and Muthiga 2020), creating interdependencies within this complex ecosystem. Coral reefs in Indonesia are known for their high diversity and are affected by various pressures from humans and nature (Kunzmann and Samsuardi 2017). Therefore, it is important to study how coral reef ecosystems respond to these stresses in local areas.

Indonesia's coral reef ecosystems possess the world's richest Scleractinian coral and reef fish diversity (Allen and Adrim 2003; Veron et al. 2011). Scleractinian coral diversity in Indonesia, which spreads across 2.5 million hectares of Indonesian waters, represents around 69% species and 76% genera of the world's scleractinian coral (Giyanto et al. 2017a; Hadi et al. 2019). If appropriately maintained, the economic benefits of healthy coral reefs in Indonesia are estimated to have a value of 1 million USD per km of reefs (Laurans et al. 2013). As with other regions in Southeast Asia, coral reef habitat is especially important for the economy, health and well-being of coastal communities in Indonesia, particularly from fisheries and tourism activities (Hattam et al. 2021).

Despite its ecological and economic significance, coral reefs are threatened by many anthropogenic and natural stressors, such as overfishing, destructive fishing practices, pollution and climate change (Chen et al. 2015; Zaneveld et al. 2016; Camp et al. 2018). The results of twenty years of monitoring coral cover in the Indo-Pacific showed an estimated loss of about 1% per year and 2% between 1997 and 2003 (or 3168 km^2 per year) (Bruno and Selig 2007). In Indonesia, about 86% of coral reefs are threatened with moderate to high levels of damage due to overexploitation, blast and poisoning fishing, sedimentation, and pollution from land and sea (Burke et al. 2002; Adyasari et al. 2021). Coral damage will reduce the ability to provide goods and services, especially reef fish populations (Pratchett et al. 2014). According to a study (Caesar in Burke et al. 2002), the damage to coral reefs in Indonesia due to fish bombing equates to around USD 570 million in cost.

This study focuses on the coral reef conditions in Tambolongan and Polassi islands. Both islands are part of the Taka Bonerate Kepulauan Selayar Biosphere Reserve, an area where the economy and daily life of the local communities depend on natural and marine resources, such as fish inhabiting coral reef ecosystems. Despite this, the islands' coral reefs ecosystem is pressured by several anthropogenic activities, for example, destructive fishing practices and extraction of corals for building materials that are still recurrent due to their short-term economic benefits (Lampe 2017; Praptiwi et al. 2021). In addition, some traditional fishing practices and anchoring of boats have been commented to contribute to the degradation of corals in the region (Moore et al. 2017). It is therefore important to regularly monitor the condition of the marine environment in the area to ensure sustainable use and management of its resources. However, there are still limited documentations of the coral ecosystem condition in both Tambolongan and Polassi islands. This study aims to assess the conditions of the coral reef ecosystem in both islands through coral and reef fish diversity. The results of this study provide baseline data that can be used as an initial assessment towards a more thorough management strategy in the area.

MATERIALS AND METHODS

Study area

Field observation was conducted in October 2018, and took place in Tambolongan (6.6188ºS, 120.4098ºE) and Polassi islands (6.6741ºS, 120.4380ºE). The two islands are situated in the transition zone of UNESCO's Taka Bonerate Kepulauan Selayar (TBKS) Biosphere Reserve, South Sulawesi Indonesia. Biosphere Reserve is a model site to promote solutions reconciling both the needs for conservation of biodiversity and its sustainable use (UNESCO 2021). The majority of communities living in the two islands sourced their income and livelihoods from the fisheries sector. Tourism is not yet developed in the area, although a small number of tourists occasionally visit both islands for recreational diving activities. Therefore, it can be assumed that pressures to coral health conditions in the area may be more influenced by other significant sectors, such as fisheries. Monitoring data for biodiversity in the area are still lacking, and the previous study conducted to assess biodiversity focused only on the terrestrial environment (Praptiwi et al. 2019).

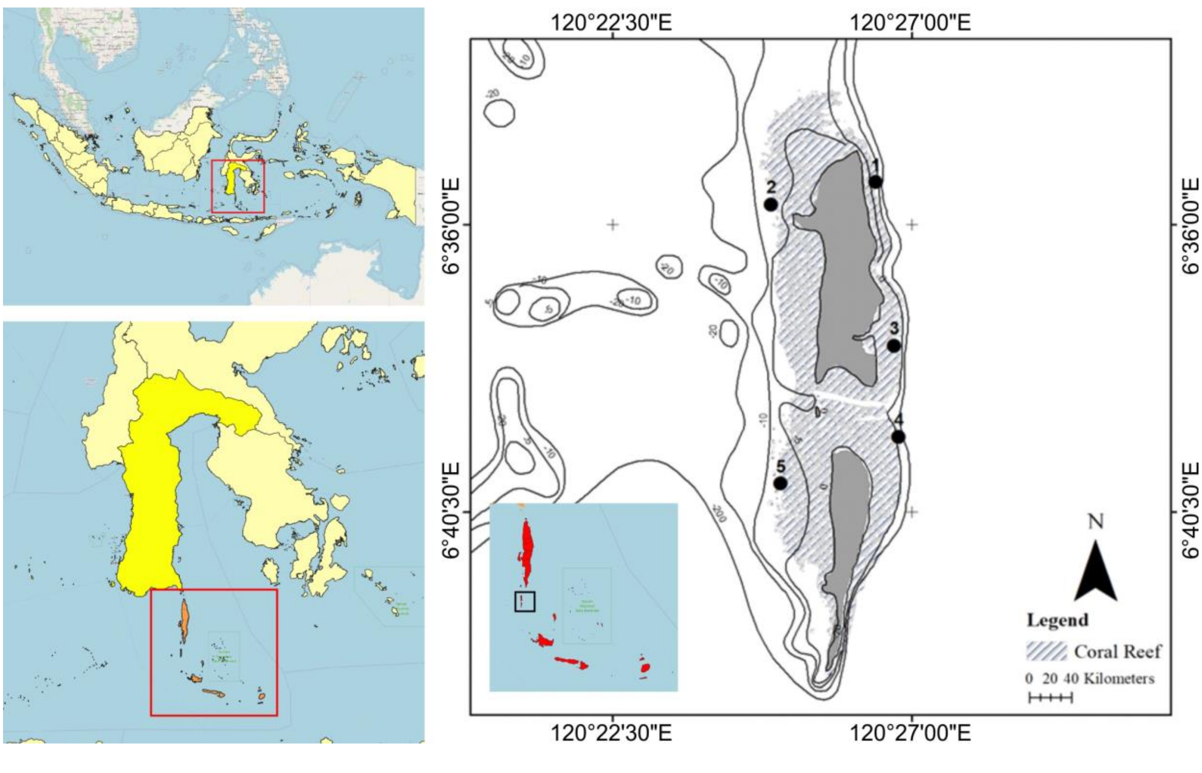

Figure 1. Map of Sampling Locations in Tambolongan and Polassi Islands, Indonesia

In this study, observation was conducted in five sampling locations around the two islands of Tambolongan and Polassi (Figure 1). These sampling locations were selected to represent the diversity of coral habitat used by local communities in both islands, as well as with consideration of safety for researchers who undertook the sampling activities. Tambolongan and Polassi islands have distinct reef topography characteristics. The reefs in the east side of both islands (locations 1, 3, and 4) are characterized by offshore reef edges with distance from the shoreline (Figure 1). Locations 1 and 4 samples were taken in the crest (5 meters) and slope (10 meters), where habitats in both locations consisted of shallow reef flat followed by wall reef with a deep steep slope (as seen in bathymetry lines in Figure 1). Whereas the habitat in location 3 consisted of the angled slope with no reef wall formed. Furthermore, observations located on the west side of the two islands (locations 2 and 5) were characterized as reef habitats with shallow and deep reef flats extending for more than 100 km from the shoreline.

Procedures

Water quality measurement

Several seawater quality parameters were measured: pH, temperature, salinity, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Nitrate (NO_3-N), and Ortho Phosphate (PO_4-P). The seawater samples were collected close to the reef structure at a depth of less than 1 m at each sampling location during the transitional season from east to west monsoon (around October to November each year). The samples were analyzed for the parameters as per Standard Methods APHA 22nd edition (Rice et al. 2012) methods. Salinity, pH, temperature and DO analysis were performed *in-situ* using a salinometer (RHS-10 ATC), pH indicator strips, and Temperature-and-DO meter (Oxygen Lutron DO-5510). The results of physical and chemical parameters analysis were compared to Sea Water Quality Standards for Marine Biota (Indonesian Ministry of Environment Decree No. 51/2004).

Benthic community and corals

Benthic cover and coral identification were performed using Underwater Photo Transect (UPT) method (Giyanto et al. 2017b).

Sixty-meter transects were placed parallel to the reef crest at depths of 5 meters and 10 meters at each observation location. Each transect consists of 3 replications 20-meters long, with 2 interval gaps of 10-meters long placed between replications. Photographs were taken each meter along the transect length, with a total of 60 photographs collected for each depth (120 photographs per observation location) using a frame sized at 58 x 44 cm. Photographs were taken perpendicularly at a distance of approximately 60 cm from the frame and media base. The frame was placed zigzagged on the left and right side of the transect line, with the odd-number sequence (i.e., photos number 1, 3, 5, etc.) taken on the left side of the transect line and even-number sequence (i.e., photos number 2, 4, 6, etc.) taken on the right side of the transect line (Giyanto 2012).

Photographs taken from each observation location were processed for further analysis of benthic cover and coral identification using Coral Point Count 4.1 analysis software with Excel extension (CPCe) developed by Kohler and Gill (2006) to obtain quantitative data (Giyanto et al. 2017b). The use of CPCe allows the identification of the types and coverage of benthic substrate and coral reef genus as identified and described in Veron (2000).

Reef fish assemblages

Reef fish visual census (English et al. 1997) was used to assess the coral fish community structure within belt transect of 350 m^2 area. In this observation, the belt transect uses the same transect line as the benthic transect. Fish observations are carried out 70 meters long with an estimated width of 2.5 meters on each side of the line. Observations were performed to identify the number and estimate the individual length of fish. Identification of fish species or genus was performed using a reference book (Kuiter and Tonozuka 2001). Observations were performed to identify the number and estimate the individual length of fish. Length-weight relationships are in great need for estimating the weight of fish for underwater visual censuses (UVC). We used the length-weight equations of the form W = a * TLb to estimate the fish biomass, where TL is individual fish total length, a and b are species-specific constant and W is the weight in grams (Kulbicki et al. 2005). Length-weight parameters for each species was collected from FishBase (Froese and Pauly 2016).

Coral health index

Coral health index (CHI) determined in this study followed a guideline of The Indonesian CHI developed by P_2O LIPI (Oceanography Research Center-Indonesian Institute of Sciences) (Giyanto et al. 2017c). The Indonesian CHI is considered an important standard for Indonesian coral management and determined by two main components: benthic and reef fish.

Data analysis

Several parameters were used to measure and evaluate their biological and ecological diversity, those are: Shannon-Wiener Diversity Index (H'), Evenness Index (E), species richness, and their relative abundance (Odum 1971; Ludwig and Reynolds 1988). Results are expressed as means of triplicate. Statistical analysis of the data was performed using R software version 3.6.1 using the 'dplyr' package to test the significant spatial variability. Benthic cover data did not meet the assumption of normality. Differences in overall benthic assemblages across locations were analyzed using non-parametric Kruskal-Wallis. Meanwhile, reef fish that met the assumption of normality was analyzed using the ANOVA test.

RESULTS AND DISCUSSION

Water quality for marine organisms

The environmental conditions, such as the quality of seawater, in a coral reef ecosystem, are known to influence the biota that lives in it (Chong-Seng et al. 2012). During observation, the eastern part of the Tambolongan and Polassi islands exposed by sizable waves and very low-energy occurred along the western coast. The average seawater current at each survey location measured 0.05-0.26 m/s. Data was taken at each sampling location on different days in a sequence. The measurement of the water current in the eastern part was conducted in a choppy condition.

In general, the water quality parameters were not significantly different among sampling locations. The average temperature was 28.16ºC, the average of salinity was 34 PSU, and the average pH was 7. According to the Decree of the Minister of Environment of the Republic of Indonesia No. 51 year 2004 about, seawater quality standards, temperature, salinity and pH value fulfill seawater quality standards for the life of marine biota. This indicates that there were no possible contaminations from external sources (for example, terrestrial or coastal activities) to the seawater quality in the area.

The other influential parameter for seawater quality for marine biota is inorganic nutrient concentration, such as Nitrate (NO_3) and Phosphate (PO_4). The results showed that both nitrate and phosphate did not vary significantly between sampling locations ($P>0.05$). The average concentration of nitrate was 0.12 mg/L, orthophosphate was 0.007 mg/L, and silicate was 1.044 mg/L. According to Decree of the Minister of Environment of the Republic of Indonesia No. 51 year 2004 and Chapman (1996), nitrate and phosphate contents in the waters indicated no nutrient enrichment and support marine life. This was also confirmed by the analysis of DO and BOD concentrations, which ranged from 7.43 to 8.53 mg/L for DO and from 0.80 to1.08 mg/L for BOD. The observed levels of several water quality parameters measured in this study further indicate that there was no apparent contamination from both anthropogenic activities (such as aquaculture or sewage discharge) and natural causes (e.g., algal blooms) to the seawater in the area.

Habitat characteristic and benthic community

Observations on the characteristics of coral reefs on Tambolongan and Polassi island were found to be relatively varied, with significant ($p<0.001$) variations displayed among coral cover and location, especially when comparing between observation locations in the east and west sides of the two islands. The average of live scleractinian (hard) coral cover within 183.7 m^2 of the sampled area around Tambolongan and Polassi coast was 8.4%±2.4% (mean±SE %). Benthic domination on average was varied between turf or filamentous algae (overall mean 26.5%±10.2%) or rubble (22.1%±10.2%) or sand (19.4%±7%) or dead coral with algae (12.5%±4.3%) (Figure 2). In addition to the water quality measurement as described above, which showed normal nutrient content, the macroalgae cover observed in this study was also generally low, 1.1% ± 0.5%.

In terms of the benthic substrate category, locations 2 and 4 were rather complex with less domination by a single benthic substrate category. Whereas location 3 appeared to be covered by sand by almost half of the sample area. Location 1 was 62% dominated by dead coral rubble, and location 5 dominated by turf algae for about 63% (Figure 3). Coral reefs at location 1 have a reasonably high level of damage, followed by a shallow coral cover. The very high algal turf cover at location 5 may indicate the occurrence of a post-damage succession process (Roth et al. 2020). The turf algae growing in this area is on old coral rubble and dead coral. Damage on coral reefs on Tambolongan and Polassi Island was uneven and had different levels in each location.

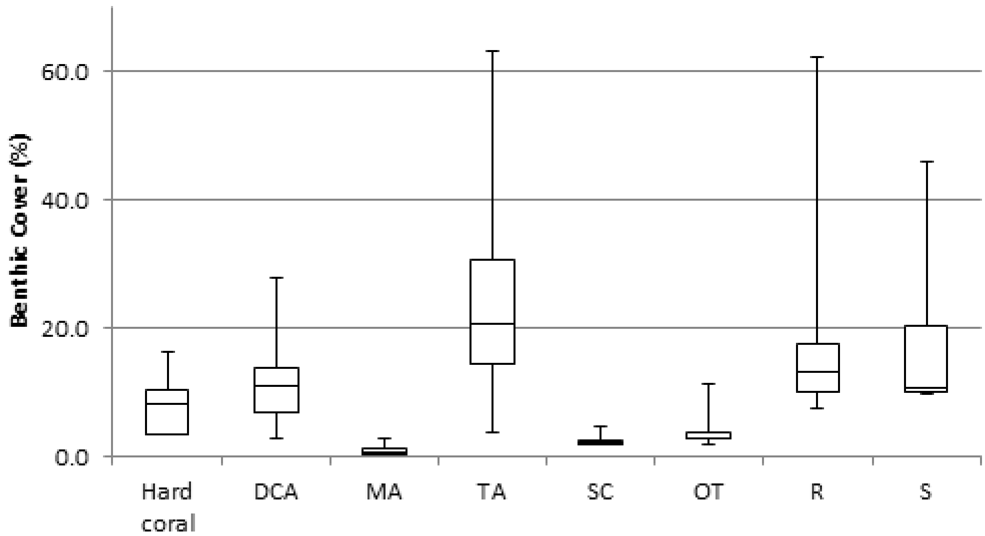

Figure 2. Comparison of benthic category in Tambolongan and Polassi islands, Indonesia (DCA: Dead Coral with Algae; MA: Macro Algae; TA: Turf Algae; SC: Soft Coral; OT: Other Biota; R: Rubble; S: Sand)

Table 1. Physical and chemical parameters of sea water quality in Tambolongan and Polassi Islands, Indonesia (East: Locations 1, 3 and 4; West: Locations 2 and 5)

Parameters	1	2	3	4	5	Standard
Physical parameters						
pH	7	7	7	7	7	7-8.5*
Secchi depth (m)	5.8	7.15	8.7	7.05	7.65	
Temperature (^oC)	28.17	27.23	28.7	28.2	28.17	28-30 C*
Chemical parameters						
Salinity (ppm)	33	34	33	33	34	33-34 ppm*
DO	7.87	8.53	7.47	7.73	7.93	> 5 mg/L*
BOD_5	1	1	1	0.95	0.8	<20 mg/L*
Nitrate (NO_3-N)	0.119	0.094	0.094	0.112	0.142	<5 mg/L**
Ortho phosphate (PO_4-P)	0.006	0.008	0.006	0.008	0.008	<0.015 mg/L*

Note: * Decree of the Minister of Environment of the Republic of Indonesia No. 51 year 2004. ** Chapman (1996)

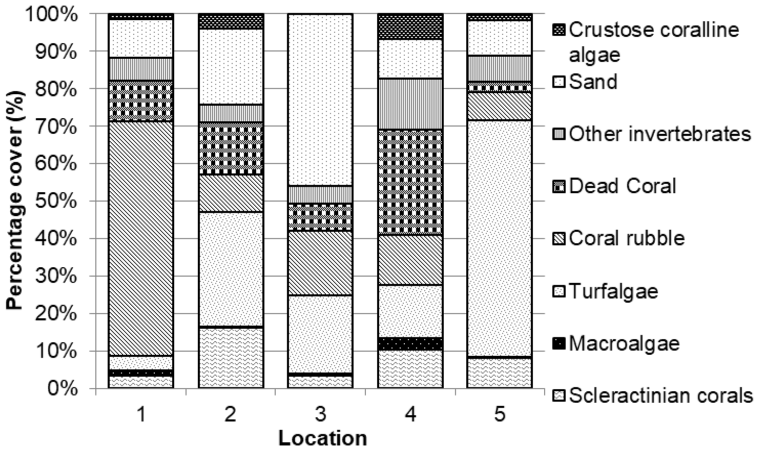

Figure 3. Benthic community structure distribution of each reef location in Tambolongan and Polassi Islands, Indonesia

Coral diversity

Coral diversity at all five sampling locations consisted of 33 genera from 12 families. The survey results show that there were 3 genera of corals that have a high average density in the study location, specifically Porites, followed by Acropora and Pocillopora. Other coral genera were less abundant and occasionally appeared on surveyed transects (Table 2). The identified genera can be found in all coral reefs in Indonesia (Suharsono 2017).

The value of scleractinian coral diversity between sample locations did not very much. Based on the diversity index, in general, Tambolongan and Polassi island have moderate scleractinian diversity. The value of the diversity index (H') ranged from 1.50 to 2.24 and the Evenness index (E) value ranged from 0.56 to 0.75 (Table 3). Coral communities were also in the medium level of stable communities. Diversity was highest in two non-complex with high damaged reefs, locations 1 and 5. The two low complexity reef flat and steep slope habitat characteristics shown very low live coral cover did not relate directly to diversity.

Reef fish assemblages

A total of 6451 fishes were observed across 3500 m^2 in 10 underwater visual surveys, representing 164 reef fish species from 31 families (Table 4). Significant spatial variability was recorded for fish biomass but was not statistically significant. The most representative fish families based on density and biomass were Balistidae, Acanthuridae, Pomacentridae and Labridae. All of the families identified in this observation can be found on other coral reefs throughout Indonesia (McKenna et al. 2002; Madduppa et al. 2013).

There was no significant gap between locations for H' diversity index values 2.90-3.37. The high diversity value shown from the Shannon-Weiner diversity index calculation is found in wall reef (locations 1 and 4) and reef flat (location 2). Then locations 3 and 5 were counted as having lower diversity values, categorized as moderate.

A clear pattern in the fish trophic group using fish biomass estimation. Offshore reef edges tend to be dominated by planktivores (43-69%), while on reef flat planktivore groups were rarely seen (0.1-9.3%) and dominated by omnivore fish (29-42%) (Figure 4). Planktivorous fish, *Odonus niger* (Balistidae), dominated the offshore reef edges habitat, especially at location 4, followed by *Pterocaesio pisang* (Caesionidae) at location 1. In the reef flat, large fish were absent (Figure 5), and small omnivore fish from Pomacentridae dominated.

Herbivore group fish consist of Acanthuridae, Pomacentridae and Scaridae. Herbivore fish in the reef flat area tended to be from Pomacentridae and were small in size (<10 cm). In contrast, herbivore fish from the Acanthuridae and Scaridae offshore reef edges were higher encounter and bigger (11-25 cm). Carnivorous fish such as the Lutjanidae, Nemipteridae and Serranidae in the offshore reef edges habitat were higher encounters and also larger in size compared to flat reef habitats. While the group of piscivora fish was recorded only found at location 4.

Table 2. Average percentage of coral genera in Tambolongan and Polassi Islands, Indonesia

Genus	Mean	±	SE
Porites	37.2	±	26.6
Acropora	22.3	±	34.3
Pocillopora	7.1	±	14.0
Montipora	4.3	±	6.5
Coeloseris	4.3	±	8.2
Favites	3.5	±	2.7
Goniastrea	3.3	±	4.8
Stylophora	2.1	±	5.8
Dipsastraea	1.7	±	2.4
Fungia	1.6	±	2.8
Cyphastrea	1.5	±	2.1
Galaxea	1.4	±	1.5
Hydnophora	1.2	±	1.9
Montastrea	1.0	±	0.8
Lobophyllia	1.0	±	0.7
Platygyra	0.8	±	1.3
Leptoseris	0.7	±	1.8
Astreopora	0.6	±	1.4
Echinopora	0.6	±	1.4
Leptastrea	0.5	±	1.0
Ctenactis	0.5	±	1.0
Leptoria	0.4	±	1.0
Goniopora	0.4	±	0.8
Gardineroseris	0.4	±	0.6
Psammocora	0.4	±	0.5
Merulina	0.3	±	0.5
Heliofungia	0.2	±	0.6
Pachyseris	0.1	±	0.4
Halomitra	0.1	±	0.4
Pavona	0.1	±	0.2
Euphyllia	0.1	±	0.2
Polyphyllia	0.1	±	0.2
Caulastrea	0.1	±	0.2

Table 3. Diversity index of coral community in Tambolongan and Polassi Islands, Indonesia

Location	No. of genus	No. of family	H'	J'
1	16	9	2.08	0.75
2	20	8	1.89	0.62
3	9	6	1.50	0.65
4	20	10	1.72	0.56
5	19	9	2.24	0.75

Table 4. List of taxa, density and biomass at each location

Taxa	Relative abundance (%)				
Family/species	1	2	3	4	5
Acanthuridae					
Acanthurus auranticavus	0.2	-	0.5	-	-
Acanthurus nigrofuscus	-	0.4	-	-	-
Acanthurus pyroferus	0.8	0.7	-	1.0	-
Ctenochaetus binotatus	-	2.8	-	0.5	3.2
Ctenochaetus striatus	2.9	3.6	1.6	2	3.3
Naso caerulaleacauda	-	-	-	0.4	-
Naso elegans	0.1	-	-	-	-
Naso lituratus	0.1	-	0.1	0.2	0.2
Naso sp.	-	-	0.2	1.3	-
Zebrasoma scopas	0.4	0.1	0.9	1.0	0.3
Apogonidae					
Apogon sp.	-	14.9	-	-	-
Balistidae					
Balistapus undulatus	0.1	-	0.1	0.1	0
Odonus niger	1.8	-	2.9	18.3	0
Sufflamen bursa	0.5	-	-	-	-
Sufflamen chrysopterus	0.3	0.1	-	0.1	0.8
Blennidae					
Meiacanthus ditrema	-	0.3	0.1	-	-
Meiacanthus grammistes	-	-	-	-	1.0
Caesionidae					
Caesio caerulaurea	-	-	-	1.9	-
Caesio teres	-	-	-	0.5	-
Pterocaesio pisang	3.0	-	-	-	-
Pterocaesio tile	2.1	-	0.3	0.1	-
Carangidae					
Caranx melampygus	-	-	-	-	-
Chaetodontidae					
Chaetodon auriga	-	0.3	-	-	-
Chaetodon baronessa	0.1	-	-	-	-
Chaetodon kleinii	0.1	3.6	0.7	0.9	3.2
Chaetodon lunulatus	-	0.7	-	-	-
Chaetodon melanotus	-	-	-	-	0.3
Chaetodon octofasciatus	-	-	-	0.1	-
Chaetodon sp.	-	0.3	-	-	-
Chaetodon speculum	-	-	-	0.1	-
Chaetodon trifascialis	-	-	0.1	-	-
Chaetodon vagabundus	-	0.6	-	-	0.3
Chaetodon xanthurus	-	0.1	-	-	-
Forcipiger flavissimus	0.2	-	-	-	-
Forcipiger longirostris	-	-	-	0.1	-
Hemitaurichthys polylepis	-	-	-	0.8	-
Heniochus chrysostomus	-	-	-	0.2	-
Cirrhitidae					
Cirrhitichthys falco	-	-	-	0.1	-
Paracirrhites forsteri	-	-	-	0.1	0.5
Dasyatidae					
Taeniura lymma	0.1	-	-	-	-
Gobiidae					
Nemateleotris decora	0.2	-	-	-	-
Nemateleotris magnifica	0.2	-	-	0.1	-
Haemulidae					
Plectorhinchus chaetodonoides	-	0.1	-	-	-
Plectorhinchus lineatus	0.1	-	-	-	-
Plectorhinchus vittatus	-	-	-	-	-
Holocentridae					
Myripristis hexagona	0.1	-	-	0.5	-
Myripristis sp.	-	0.1	0.3	0.5	-
Myripristis violacea	0.4	0.4	-	-	-
Sargocentron caudimaculatus	-	-	-	0.5	-
Sargocentrum sp.	0.1	-	-	-	-
Heterocongridae					
Gorgasia sp.	-	-	1.4	-	-

Labridae					
Anampses lineatus	-	-	-	0.1	-
Bodianus diana	0.1	-	-	-	-
Bodianus mesothorax	-	-	-	0.2	-
Cheilinus fasciatus	0.2	-	0.1	0.1	-
Choerodon anchorago	0.1	-	0	-	-
Cirrhilabrus ryukyuensis	3.0	-	0	1.6	2.9
Cirrhilabrus solorensis	0.3	-	2.7	4.4	8.1
Coris batuensis	0.2	6.4	-	0.1	0.5
Diproctacanthus xanthurus	-	0.1	-	-	-
Epibulus insidiator	-	-	-	0.4	-
Gomphosus varius	-	-	-	0.1	-
Halichoeres hortulanus	0.3	0.1	0.3	0.4	-
Halichoeres sp.	0.3	0.1	0.1	-	-
Hemigymnus melapterus	-	0.1	-	0.1	0.3
Labrichthys unilineatus	0.1	-	-	-	-
Labroides dimidiatus	0.7	0.9	0.6	0.5	0.2
Labroides sp.	0.1	-	-	-	-
Pseudocheilinus hexataenia	0.8	2.2	0.3	0.1	-
Pseudocheilinus sp.	-	0.1	-	-	-
Thalassoma amblycephalum	6.3	-	1.8	4.9	-
Thalassoma hardwicke	0.7	1.9	1.6	3.3	7.8
Thalassoma lunare	0.1	0.1	0.1	0.1	0.3
Wetmorella albofasciata	0.3	-	-	0.2	-
Lutjanidae					
Lutjanus biguttatus	-	-	-	0.1	-
Lutjanus bohar	-	-	-	0.3	-
Lutjanus decussatus	0.1	0.1	-	0.2	-
Lutjanus fulvus	-	-	-	0.1	-
Macolor macularis	0.2	-	-	-	-
Lethrinidae					
Monotaxis grandoculis	-	-	0.1	-	-
Mullidae					
Parupeneus barberinus	-	0.1	-	-	0.5
Parupeneus multifasciatus	0.1	0	0.5	-	-
Nemipteridae					
Scolopsis bilineatus	0.9	1.5	0.5	1.0	1.8
Scolopsis lineatus	0.1	-	-	-	-
Pentapodus trivittatus	0.2	-	-	-	0.2
Ostraciidae					
Ostracion meleagris	-	-	-	0.1	-
Parapercis hexophthalma	-	0.1	-	-	-
Parapercis sp.	0.1	-	-	0.1	-
Plotosidae					
Plotosus lineatus	-	-	-	-	15.9
Pomacanthidae					
Centropyge bicolor	0.3	0.1	0.2	-	2.4
Centropyge tibicen	0.1	0.7	0.1	-	0.2
Centropyge vrolikii	0.1	0.1	0.1	0.1	0.2
Pygoplites diacanthus	0.2	-	0.1	0.3	-
Pomacentridae					
Abudefduf sexfasciatus	0.0	-	-	1.9	-
Abudefduf vaigiensis	3.1	-	-	0.7	-
Amblyglyphidodon aureus	-	-	-	0.5	-
Amblyglyphidodon curacao	0.5	5.4	0.1	0.3	3.8
Amblyglyphidodon leucogaster	0.4	0.1	0.2	0.2	-
Amphiprion akallopisos	-	-	-	0.1	4.1
Amphiprion clarkii	0.2	0.6	0.4	0.5	11.1
Amphiprion ocellaris	-	-	-	-	0.8
Chromis analis	-	-	-	0.8	-
Chromis atripes	1.1	-	3.4	-	-
Chromis dimidiata	-	-	-	-	-
Chromis flavipectoralis	-	-	-	0.9	-
Chromis lineata	6.5	-	-	-	-
Chromis margaritifer	2.0	0.4	-	2.2	-
Chromis retrofasciata	0.4	-	31.2	-	-
Chromis sp.	-	0.3	-	2.4	0.6
Chromis ternatensis	6.2	-	10.9	0.6	-
Chromis viridis	-	3	1.4	6.5	0.3
Chromis xanthochira	0.8	-	4.2	5.4	-
Chromis xanthura	0.1	-	-	-	-
Chrysiptera caeruleolineata	-	-	-	0.2	-
Chrysiptera hemicyanea	5.1	-	0.7	-	-
Chrysiptera rollandi	0.5	2.2	1.2	-	-
Chrysiptera sp..	0.1	-	-	0.3	-
Chrysiptera talboti	0.8	0	1.7	0	0.2
Dascyllus aruanus	0.1	7.9	0.4	-	8.6
Dascyllus carneus	-	-	-	-	-
Dascyllus melanurus	-	3.6	1.1	-	-
Dascyllus reticulatus	4.1	4.3	1.9	2.1	0.5
Dascyllus trimaculatus	0.5	-	1.0	3.3	1.0
Dischistodus melanotus	-	0.6	-	-	-
Hemyglyphidodon plagiometopon	0.7	-	2.2	0.7	-
Neoglyphidodon nigroris	-	-	0.3	0.5	-
Neoglyphidodon sp.	1.0	-	-	-	-
Neopomacentrus violascens	0.1	-	-	-	-
Plectroglyphidodon lacrymatus	0.5	1.8	0.1	0.2	-
Pomacentrus alexanderae	-	0.6	-	-	-
Pomacentrus amboinensis	0.3	-	2.3	-	-
Pomacentrus auriventris	0.1	-	0.2	0.7	0.2
Pomacentrus brachialis	0.7	1.6	-	0.7	-
Pomacentrus chrysurus	-	3.0	-	-	8.6
Pomacentrus coelestis	14.7	-	8.0	1.4	-
Pomacentrus javanicus	-	2.8	-	-	-
Pomacentrus lepidogenys	0.6	-	0.3	-	-
Pomacentrus littoralis	-	4.6	-	-	-
Pomacentrus moluccensis	1.1	4.8	0.7	3.0	2.5
Pomacentrus nigromarginatus	-	0.7	-	-	-
Pomacentrus pavo	-	-	-	-	-
Pomacentrus philippinus	0.2	-	-	-	-
Pomacentrus reidi	-	0.1	-	-	0.2
Pomacentrus simsiang	-	1.9	-	-	-
Pomacentrus sp.	0.1	2.4	1.9	-	1.4
Pomacentrus vaiuli	-	0.3	-	-	-
Premnas biaculeatus	0.1	-	-	-	-
Pseudochromidae					
Pseudochromis moorei	-	0.1	-	-	-
Pteroninae					
Pterois volitans	-	-	0.1	-	-
Scombridae					
Gymnosarda unicolor	-	-	-	0.1	-
Scaridae					
Chlorurus capistratoides	-	0.1	-	0.2	-
Chlorurus sordidus	0.1	0.6	0.1	0.7	-
Scarus dimidiatus	0.3	-	-	-	1.4
Scarus niger	0.2	-	-	0.5	-
Scarus sp.	0.4	-	0.4	0.1	0.2
Serranidae					
Cephalopholis miniata	-	-	0.2	-	-
Cephalopholis urodeta	0.6	-	0.2	0.5	-
Epinephelus fasciatus	0.1	-	-	-	-
Epinephelus merra	-	-	-	-	0.2
Gracila albomarginata	0.1	-	-	-	-
Pseudanthias hutchii	16.4	-	4.0	11.5	-
Variola louti	0.1	-	0.1	-	-
Siganidae					
Siganus virgatus	0.1	-	-	-	-
Siganus vulpinus	-	0.3	-	-	-
Tetraodontidae					
Aspidontus taeniatus	-	-	-	0.2	-
Canthigaster papua	-	0.1	0.1	-	-
Canthigaster valentini	-	0.3	0.5	0.1	0.2
Zanclidae					
Zanclus cornutus	0.1	-	0.1	0.4	-
Number of individuals	1859	669	1457	1838	628
Density (ind.m^{-2})	3	1	2	3	1
Biomass (kg.ha^{-1})	58.23	27.66	15.92	81.65	19.66
Number of species	91	63	63	84	43
Shannon-Weiner (H’)	3.28	3.37	2.90	3.37	2.95
Evenness index (J’)	0.73	0.81	0.70	0.76	0.78

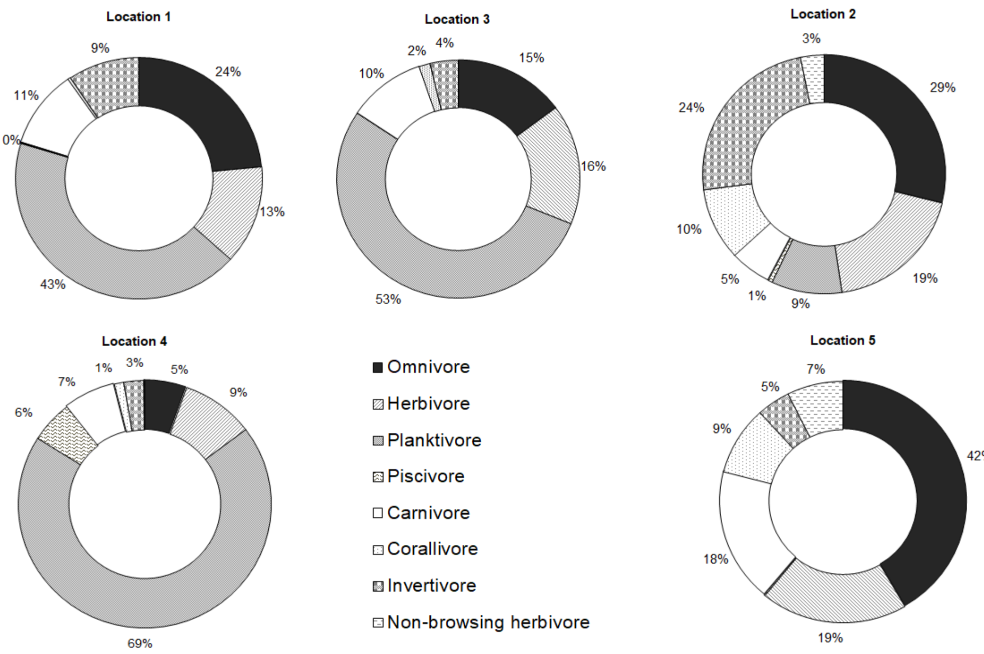

Figure 4. Percentage of reef fish trophic group biomass (gr.m^{-2}) in Tambolongan and Polassi islands, Indonesia (East part: location 1, 3 and 4; west part: Location 2 and 5)

Table 5. Coral Reef Health Index in Tambolongan and Polassi Islands, Indonesia

Location	Benthic component			Fish component		Total value	Coral reef health index
	Live hard coral cover class	Reef resilience	Value	Category of coral reef fish	Value		
1	Low	Low	1	Low	2	3	1
2	Low	High	3	Low	2	5	3
3	Low	High	3	Low	2	5	3
4	Low	High	3	Low	2	5	3
5	Low	High	3	Low	2	5	3

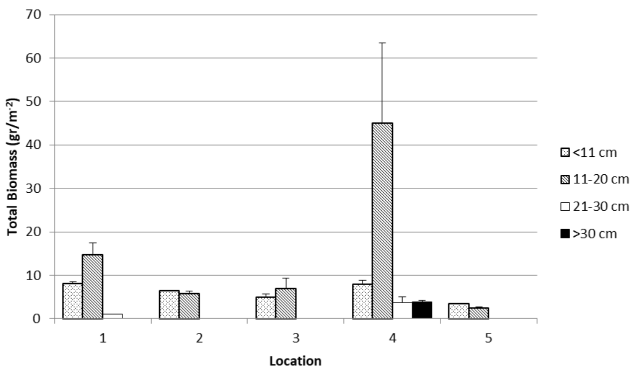

Figure 5. Comparisons of reef-fish biomass per size class for each sampling location

Reef health index

Increased macroalgae and dead coral fragmentation or rubble coverage are indicated as low reef resilience simultaneously live hard coral cover value contributes to benthic component value as the result range 1-6. Almost all of the survey location reef resilience classify as high value due to low macroalgae (<3%) and rubble (<60%) except for location 1. Location 1 evaluated has low resilience potential, about 62% benthic coverage in location 1 is covered by rubble. The CHI was calculated and categorized by the standardized levels of coral cover and reef resilience and coral reef fish. The results of benthic components gave a very low value to location 1 and a slightly better score of 3 for the rest of the location, as these locations have a high resilience potential (Table 5).

The fish component value calculation is total fish biomass on selective coral reef fish family, mostly from a targeted fish group such as Acanthuridae, Scaridae, Siganidae, Lutjanidae, Serranidae, Haemulidae and Lethrinidae (families that can be monitored regularly, not seasonally). The fish component value referred to a low category (<970 kg/ha) for all locations, with mean fish biomass ranging from 15.92 to 81.65 kg/ha (Table 4). Based on two main parameters of benthic and fish components, CHI values were scored with values from 1 to 10, with 10 indicating a very healthy coral reef and a value of 1 for the opposite. The total value of fish and benthic components is adjusted to the standard coral reef health index. Overall, the results showed that the coral reefs health condition in all sample locations indicated an unhealthy status with Location 1 indicated the poorest health status (CHI index: 1) (Table 5).

Discussion

The water condition of Tambolongan and Polassi Islands was found to be sufficient to support marine organisms' life and ecological process, with no evidence of pollution or organic enrichment that could threaten the coral ecosystem in the observed study location (Table 1). However, in this study, an analysis of Coral Reef Health Index showed that the coral ecosystems in the area were heavily degraded. Such findings indicate that as the results of water quality did not support possibilities for organic and toxic compounds contaminations, it may be suggested there may be another significant factor that influences the coral reefs conditions and health status in the study area, such as fishing activities.

The extent of damage to coral habitats was further characterized by low live coral and high dead coral rubble cover, which provides mediums for algae turf to grow successfully. Turf algae is a benthic pioneer community that usually dominates in dead or damaged coral reef conditions, occupying substrates previously occupied by coral tissue (Roth et al. 2020). Albeit turf algae could not replace ecosystem functions provided by corals, benthic pioneer communities maintain the nutrient cycle of coral reefs by accumulating biomass and importing macronutrients after coral loss (Roth et al. 2020). The corals and turf algae were competing for space but had no significant effect on the corals' growth (McCook 2001; Roth et al. 2020). During reef degradation, competition between benthic algae and corals is crucial in the reefs' community ecology (McCook 2001).

In terms of reef fish communities, the increase of density and diversity of Chaetodontidae fish in this study (Tabel 4) was observed in areas with higher coral cover (Figure 3). This confirms the dependency of Chaetodontidae fish to the availability of live corals. As has been suggested in previous studies (Madduppa 2012), Chaetodontidae fish are corallivorous and highly dependent on live coral polyps.

However, a previous study (Jankowski et al. 2015) also suggested that live corals are not the only determinant of reef fish community. Other factors, such as the physical characteristics of reef habitat (particularly depth and benthic complexity), can also influence the reef fish communities. The variations of habitat depth from shallow coastal plains to deep offshore (east part island) bottoms can affect the benthic reef community structures due to the difference in their physical and biological characteristics (Bonaldo and Bellwood 2011). In this study, the physical conditions of habitats in observation locations were varied (Figure 1), and resulted in the contrast of observed fish community, with highest diversity and density of reef fish were recorded in habitats with characteristics of a deep steep slope in offshore reef edges with lower live coral cover. Some large pelagic-reef-associate fish such as Carangidae and Scombridae were recorded in this habitat (Kuiter and Tonozuka 2001; Santini et al. 2013). Reef fish from genus *Naso*, family Scaridae, Serranidae and Lutjanidae were much more commonly found and observed to be bigger in size in habitats with high depth variations than gentle slope reefs. Such reef beds were observed to be having a higher flow of water velocity and direction change (Fulton and Bellwood 2005), and the water motions in these conditions can affect the reef fish community. Caudal user dominant swimmers fish species such as *Naso* (Acanthuridae), *Lutjanus* (Lutjanidae), *Cephalopholis*, *Epinephelus*, *Variola* (Serranidae) has greater capacity for high-speed power and acceleration (Fulton 2007). Greater flow velocity and direction are suitable for caudal swimming fish and increase the prevalence of pectoral swimming fish (Fulton and Bellwood 2005; Fulton et al. 2005). Exposed locations also give more benefits to planktivorous fish. Some species from the Caesionidae family and *Odonus niger* (Balistidae) dominate only in the offshore reef edges habitat. Planktivore fish dominate coral reef locations exposed to waves and currents (Krajewski and Floeter 2011). The main food of planktivores is macrozooplankton and microzooplankton (Krajewski and Floeter 2011). According to Ndour et al. (2018), the main driving factor of high zooplankton biomass is the circulation of ocean currents flowing in an area. *O. niger* was recorded as the highest density, especially in the wall habitat. *O. niger* has an Indo-Pacific distribution spanning the region known as the Coral Triangle and is the only known species in its genus. *O. niger* is typically found schooling in large groups along with coral reef channels or slopes feeding on the zooplankton brought in by strong currents (Fricke 1980).

In terms of benthic complexity, varied or more complex benthic can determine the composition and abundance of reef fish (Chong-Seng et al. 2012). In addition, Rogers et al. (2017) observed that non-complex habitats could not support large herbivores. Scaridae fish diversity, biomass, and density were higher at locations 1 and 4. Scaridae was low in habitats with low structural complexity despite abundant food availability (location 5 turf algae 63.1%). Among offshore reef edges with high fish diversity, Scaridae was recorded only low at location 3 with the lowest coral cover, gentle slope, and dominated by sand (low habitat complexity). Although location 2 has a more complex benthic structure (16.2% scleractinian live coral) than location 1, this may be due to the vertical movement behavior of Scaridae (Gomi et al. 2021), which corresponds with the reef habitat at location 1 (high depth variation).

Diaz et al. (2016) study suggested combining the classic coral and community health index could increase the accuracy of coral reef health status estimation. Maintaining coral diversity and structure is critical to maintaining resilience towards disturbances (Ferrigno et al. 2016). Coral reefs' health status on Tambolongan and Polassi Island is classified as very low with medium and nearly low diversity for coral and medium to high diversity for reef fish (Tabel 4 and 5). Despite their being classified as degraded, some coral reef ecosystems on both islands still support relatively high diversity for fish due to their characteristic habitat. The rationale for this may be because the loss of the reef fish community may not happen directly after the occurrence of coral degradation. According to Rogers et al. (2017), fishery productivity on progressively degraded coral reefs may still ensue for a short or medium term, after which a decline in fisheries productivity of around 50% may be observed when all structure is lost. Therefore, restoration may be necessary before the coral reefs of Tambolongan and Polassi reach total habitat loss due to continued unregulated fishing activities and cause the decline of reef fish.

The findings of this study may suggest that, based the condition of coral reefs, the restoration process may be strongly suggested to prevent total damage and loss. As an example by a study from Fox and Caldwell (2006), corals may take 5-10 years to recover from a single explosion, rubbles from blast effect can persist for many years, and coral resilience takes several decades to centuries from intense physical disturbance. McClanahan et al. (2012) evaluated and explored factors that affect the scale of coral reef resilience. It was noted that the resistance of each coral type might be affected by several abiotic and non-abiotic factors, such as: seawater temperature, level of pollution and sedimentation, diversity of corals, herbivore biomass, physical human impact, coral disease, macroalgae, coral recruitment and fishing pressure. The succession process needs to be through appropriate and long-term management so that coral reefs can recover. To support the improvement of reef health, increasing the complexity of coral reefs and fisheries regulation for Scaridae may be necessary. Increasing benthic coral complexity followed by the increased diversity of reef fish is a suitable condition for large Scaridae fish so that the role of Scaridae fish in controlling algal turf can be optimal.

The required measures for the management of coral habitats in the area can also be synchronized to the existing conservation or management programs initiated by local stakeholders. For instance, management strategies that put focus on conservation effort, such as no-take zones, may be implemented in areas where recovery of corals are considered feasible. In addition, programs that put focus on restoration, such as coral transplantation, may be implemented in areas that are severely damaged (such as Location 1). In the area of Taka Bonerate Kepulauan Selayar biosphere reserve, coral transplantation programs have been implemented particularly in the national park area, which forms the core zone of the biosphere reserve (e.g., Tinabo Island, Jinato Island) (Taka Bonerate National Park 2017, KSDAE 2018). Such programs have been shown to successfully revitalize the coral reefs ecosystem in the area (Kurniawan 2020), and thus provide an opportunity for its application in the area of this study.

The results of this study, although do not provide longitudinal time-series marine biodiversity conditions in the area, are still useful to understand the extent of pressures towards the quality of marine habitats in the area and can be used as baseline data for future monitoring programs. Such information can provide inputs for local policymakers in formulating sustainable coastal and marine planning in the biosphere reserve.

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