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Health status of coral reef at Moramo Bay Marine Conservation Area, Southeast Sulawesi, Indonesia

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Abstract. *Oetama D, Hakim L, Lelono TD, Musa M. 2024. Health status of coral reef at Moramo Bay Marine Conservation Area, Southeast Sulawesi, Indonesia. Biodiversitas 25: 1454-1464.* Moramo Bay is one of the regional Marine Conservation Areas (MCA) in Indonesia which is categorized as a Marine Tourism Park based on the Decree of the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia Number 22 of 2021. This bay is located in Southeast Sulawesi Province and has an area of 21,902.34 ha, consisting of a core zone, limited-use zone, and other zones. The ecosystems found in Moramo Bay include coral reefs, mangroves, and seagrass. The coral reef ecosystem in this area covers 2,528.19 ha with good visual conditions of the reef. The present study aims to provide detailed information concerning the condition of live hard corals and reef fishes, including abundance, diversity, evenness, dominance, and water quality by using point intercept transect (PIT) and underwater visual census (UVC) methods. The study was carried out at 7-10 meters of seawater depth in May-October 2023, focusing on both the core and limited-use zones and consisting of three study stages: field observation, data collection, and data analysis. Data collection covered identifying coral growth through literature study before performing descriptive analysis. The study revealed the percentage of live hard coral cover of 53%, referred to as a good category, and other variable percentages including dead coral (4%), dead coral with algae (9%), soft coral (4%), fleshy seaweed (1%), rubble (17%), sand (8%), silt (1%) and sponge (2%). Furthermore, 25 families of reef fishes were found, belonging to 48 genera, 102 species, and 2,364 individuals, with an ecological index of abundance of 1.05 ind.m^{-2}, diversity (2.86), evenness (0.83), and dominance (0.10). The coral reef health data issued by the present study implies that Moramo Bay MCA may be preserved as an alternative area for coral reef studies associated with global issues, for instance, climate changes. Protecting and increasing the sustainability of coral reefs is an absolute entity that must be considered by a local government.

Keywords: Abundance, coral cover, diversity, dominance, evenness, reef fish

Abbreviations: MCA: Marine Conservation Area, PIT: Point Intercept Transect, UVC: Underwater Visual Census

INTRODUCTION

Indonesia belongs to an archipelagic country where two-thirds of its territory is marine areas with high biodiversity. Protection of marine resources must be given priority to prevent damage and destruction of marine life (Djunarsjah and Putra 2021). Approximately 75% of the world's hard coral species can be found in Indonesian coastal waters, covering around 18% of the total coral reef area in the world (Hadi et al. 2020). In addition, such coastal waters also contain plentiful fisheries and microbial resources for biotechnology applications (Hutomo and Moosa 2005). Conversely, Indonesia's biodiversity is under pressure due to human activities. Accordingly, efforts must be made to ensure that the current use of marine resources can be sustainable for future generations. Conservation is a must for this purpose. To implement the vision of marine conservation, accelerating marine development through expanding the maritime economy needs to be pursued for improving community welfare (Bennett et al. 2021).

Moramo Bay is one of the Marine Conservation Areas (MCA) in Indonesia, located in Southeast Sulawesi Province which is administratively covered by three sub-districts, i.e., Moramo, North Moramo, and Laonti, in South Konawe District. The designation of this bay as an MCA is based on the Decree of the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia Number 22 of 2021 concerning Conservation Area in Moramo Bay, Southeast Sulawesi Province. According to this regulation, Moramo Bay MCA is divided into 3 conservation zones, including the core zone of 2,242.82 ha, the limited-use zone (19,168.91 ha), and other zones (40.61 ha), covering a total area of 21,902.34 ha. The core zone is a protection area for important biota to be preserved. This is a specifically designated area for protecting biological and genetic resources, a natural habitat for fish resources to spawn and feed, and cultural heritage protection area, while the limited-use zone is developed for capturing fisheries, cultivation, and tourism areas.

Marine resources in MCA need to be managed and protected sustainably to conserve and restore critical species, fisheries, or coral reef habitats (Cinner et al. 2016; Selig and Bruno 2010; Soler et al. 2015). A conservation area also aims to prevent or limit human-induced fishing pressure in that area (Emslie et al. 2015). The Moramo Bay MCA has a complete ecosystem, including coral reefs, mangroves, and seagrass (Oetama et al. 2023). Coral reef ecosystems have high biodiversity (Brandl et al. 2019) and have an ecological function as a home for species of fish and biota that are linked to each other (Richardson et al. 2020). Such coral reef ecosystems in particular have experienced a lot of pressure from both anthropogenic and natural factors, governed by changes in extreme climate conditions (Sweet and Brown 2016; Woodhead et al. 2019; Burt et al. 2020) and human practices in the exploitation of marine resources. The pressure on this ecosystem is mostly caused by the character of coral reefs which are sensitive to environmental changes (Soares et al. 2021).

Most of the people who are living on the coast of Moramo Bay MCA primarily work as fishermen and seaweed farmers. The high level of human activity that depends on the availability of marine resources for their livelihoods has a significant impact on damage to coral reef ecosystems (Schulte et al. 2015; Ngoc 2017; Guldberg et al. 2019). Some anthropogenic activities that are often found damaging the marine environment are the use of explosive fishing and the exploitation of marine resources in MCA (Katikiro and Mahenge 2016; Belhabib et al. 2019). It is also important to note that the increase in population and industrial activities around Moramo Bay (Armid et al. 2021) can contribute to a decline in seawater quality which may affect the health of coral reefs. Apart from that, the increase in surface seawater temperature (SST) as an effect of global warming currently has a large contribution to the ability of corals to survive (Lachs et al. 2023). Therefore, this study aimed to determine and analyze the health condition of coral reef ecosystems at the core zone and limited-use zone in the Moramo Bay MCA. Coral reef health data is imperative to identify as a consideration for local governments in sustainable marine development.

MATERIALS AND METHODS

Study area

The study was performed from May to October 2023 in the core zone and limited-use zone of Moramo Bay MCA. As specific zones prepared to protect marine biological/genetic resources and tourism activities, the abundance of coral reefs in Moramo Bay MCA is only well-preserved in these two zones. Observations were carried out at 9 stations at sea depths of 7-10 meters (Figure 1, Table 1). The observation stations were determined based on the existence and representation of the coral reef ecosystem in the Moramo Bay MCA.

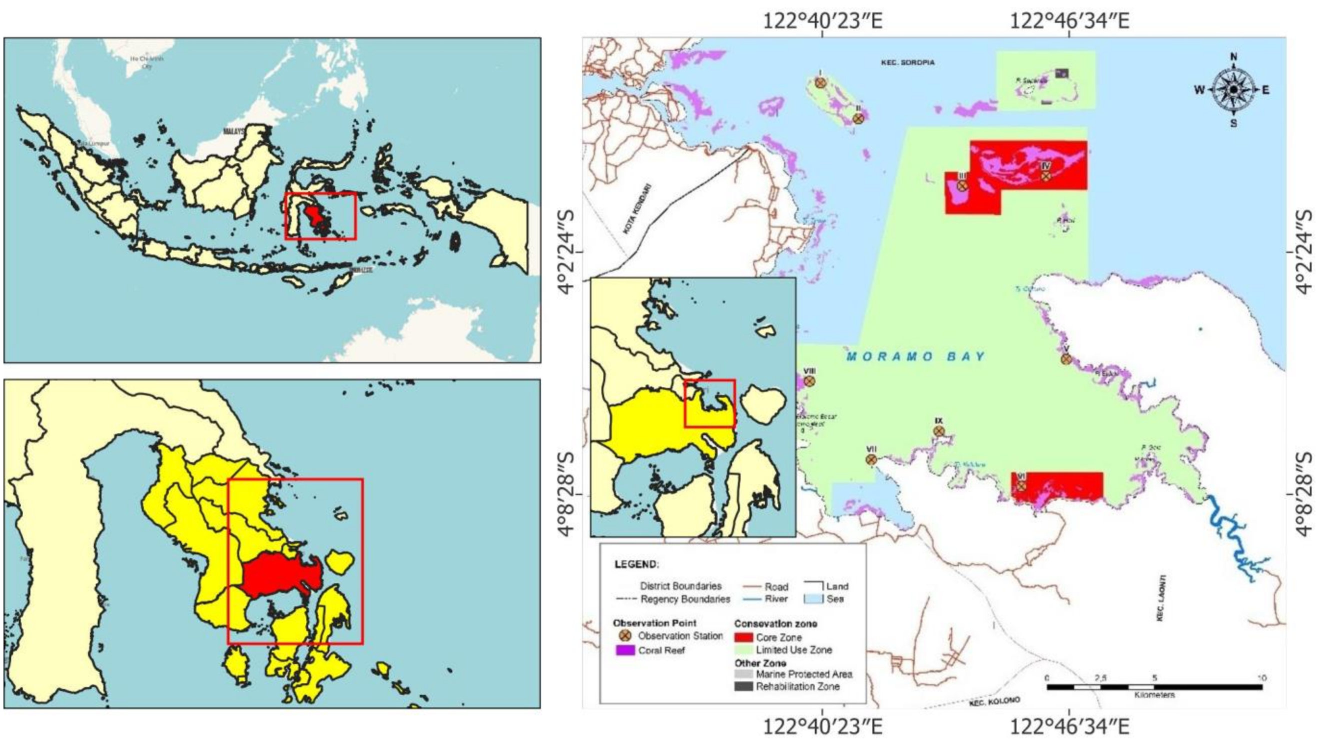

Figure 1. Moramo Bay MCA map of South Konawe, Southeast Sulawesi, Indonesia, showing nine coral reef observation stations

Table 1. Observation stations of coral reef in Moramo Bay MCA, Southeast Sulawesi, Indonesia

Station	Location	Zone*)	Geographic coordinates	
			E	S
I	Pasi Jambe 1	Limited-use zone	122º40'29.54"	3º58'34.82"
II	Pasi Jambe 2	Limited-use zone	122º41'26.75"	3º59'28.74"
III	Hari Island 1	Core zone	122º44'3.66"	4º01'11.17"
IV	Hari Island 2	Core zone	122º46'10.26"	4º00'56.34"
V	Labotaone	Limited-use zone	122º46'40.55"	4º05'34.05"
VI	Rumbi-Rumbia	Core zone	122º45'32.87"	4º08'47.61"
VII	Panambea Barata Cape	Limited-use zone	122º41'46.24"	4º08'6.42"
VIII	Lara Island	Limited-use zone	122º40'12.90"	4º06'7.26"
IX	Wawosunggu Island	Limited-use zone	122º43'28.51"	4º07'23.16"

Note: *) According to the Decree of the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia Number 22 of 2021 concerning Conservation Area in Moramo Bay, Southeast Sulawesi Province

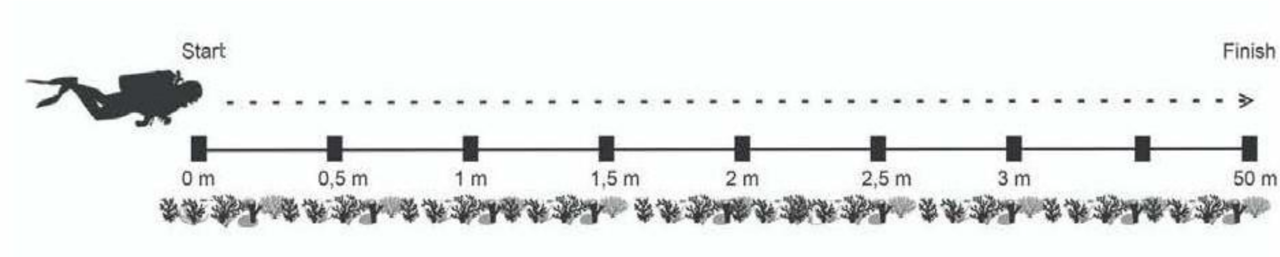

Figure 2. Sampling illustration for live corals, other biota, and basic coral reef substrate by a PIT method

Sampling

The data in this study was collected by direct observations in the field and by literature studies. The Point Intercept Transect (PIT) method (Facon et al. 2016) was used to observe coral cover. PIT is a method developed by the Reef Check Foundation to monitor the condition of seawater's bottom substrate, which can quantify the parameter percentages of live coral, dead coral, damaged coral, and other biotas associated with the coral reef ecosystem. The use of this method to determine the condition of coral reefs is relatively efficient and can cover large areas with a short time allocation (Hill and Wilkinson 2004). Figure 2 shows an illustration of direct data collection of live corals, other biota, and basic coral reef substrate by a PIT method. Observations at all 9 stations in Moramo Bay MCA were carried out during daylight (clear weather) in the dry season, and involved 3-4 divers per station. In its implementation, the PIT method used a line transect with a roll meter parallel to the coastline along 50 m at a predetermined depth. Each coral life form was observed in intervals ranging from 0.5 m to 50 m (Figure 2). All data observed and below-the-line transect points were recorded and identified quickly (Manuputty and Djuwariah 2009; Montilla et al. 2019; Kuo et al. 2022; Smith et al. 2022). It has to be noted that the entire parameter percentage did not have to be equal to 100% and the total number of recording points per station was 50 points. The component category and recording code for each type of biota/component in the PIT method are tabulated in Table 2.

Observations of reef fish abundance were carried out at the same transect line location as coral reef observations by an underwater visual census (UVC) method. An UVC is a method to observe the abundance of reef fish. This method is used worldwide in shallow water environmental surveys and is utilized to create decisions on reef fish varieties associated with coral reef and fisheries management (English et al. 1997; Bacheler et al. 2017). In execution, reef fishes were observed along the 50 m transect line, 2.5 m to the right side and 2.5 m to the left side of the transect line, covering a total area of 5 × 50 m^2 (Figure 3). It should be noted that all observations were conducted evenly among all stations, both PIT and UVC methods.

Table 2. Category and code for recording biota/component using the PIT method

Component category	Code	Description
Biotic	*AC*	*Acropora* coral
	NA	Non- *Acropora* coral
Abiotic	*DC*	Dead coral, i.e., that whose color is still white
	DCA	Dead coral with algae, i.e., that whose color has changed since overgrown with filamentous algae
Biotic	*SC*	Soft coral
	FS	Freshy seaweed, e.g., *Sargassum*, *Turbinaria*, *Halimeda*.
Abiotic	*R*	Rubble, i.e., dead branching coral fractures
	RK	Rock, i.e., hard bottom substrate
	S	Sand
	SI	Silt, i.e., fine muddy sand

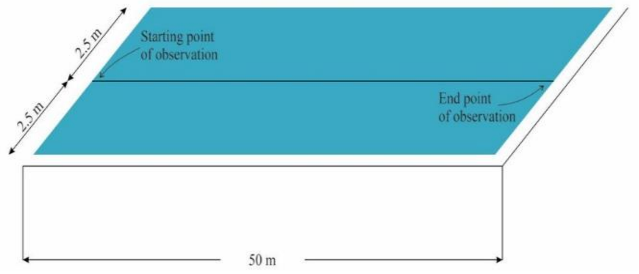

Figure 3. Transect layout scheme (5 × 50 m^2) for observing reef fish by an UVC method.

Table 3. Seawater quality standard (Indonesian Government Regulation No. 22 of 2021)

No.	Parameter	Unit	Threshold
1	Physical		
	Water brightness	meter	Coral: >5
	Temperature	°C	28-30
2	Chemical		
	pH	-	7-8.5
	Salinity	$^0/_{00}$	33-34

During sampling, seawater oceanographic parameters such as brightness, temperature, pH and salinity were measured directly, then compared with those of ideal seawater parameter data (thresholds) for coral reefs growth following Indonesian Government Regulation No. 22 of 2021 concerning the Implementation of Environmental Protection and Management as tabulated in Table 3.

Data analysis

Coral reef

Data of coral reef observations covering information concerning the component category and the number of biota/component (according to Table 2) were input into a table within MS Excel 2021 software. The percentage of coral reef cover was calculated using an equation (1) (Manuputty and Djuwariah 2009), as follows:

$$L_i = \frac{\sum \text{Component } i}{\sum \text{Total component}} \times 100\% \quad (1)$$

Where: L_i is the percent coral cover, Σcomponent *i* is the number of certain components found, and Σ total component is the number of all components in a 50 m transect.

The criteria for assessing the condition of coral reefs were based on the Decree of the Minister of Environment and Forestry of the Republic of Indonesia No. 4 of 2001 concerning Standard Criteria for Coral Reef Damage, as tabulated in Table 4.

Reef fish

Reef fish analysis includes several parameters, i.e., abundance, diversity, evenness, and dominance. Reef fish abundance is the number of fish found at a station per unit area of the observation transect. Fish abundance was calculated using an equation (2) below (Odum 1971):

$$X = \frac{X_i}{n} \quad (2)$$

where X is the abundance of reef fish (ind.), X*i* is the number of fish at the *i*th observation station and n is the area of the observation transect (5×50 m^2).

The diversity index is used to measure the level of diversity of reef fish species in a specific water area (McClanahan, 2019b; Ditzel et al. 2022). This index is also used as a parameter in determining the health of coral reef ecosystems (Morais et al. 2020). An equation (3) was used to quantify a diversity index, where H′ is a Shannon-Wiener diversity index, *s* is the number of reef fish species, P*i* is the population of each reef fish species; belongs to the ratio of the individual number of the *i*th species (n*i*) to the total number of individuals (N).

$$H' = \sum_{i=1}^{s} Pi \ln Pi \quad (3)$$

The evenness index expresses the balance of an ecosystem (Odum 1971). This index was measured by using an equation (4):

$$E = \frac{H'}{H'_{max}} \quad (4)$$

where E is the evenness index, H' is the balance of species (calculated Shannon-Wiener diversity), H_{max} is the maximum diversity index (= ln S, where S is the total number of species). The evenness index value ranges from 0 to 1.

The reef fish dominance index shows how dominant a particular species of fish is in the community (Odum 1971). This index is essential to know how the abundance is distributed between species of reef fish in the community. Dominance was calculated using the formula:

$$C = \sum_{i=1}^{n} Pi^2 \quad (5)$$

Where: C is the dominance index; P*i* is the proportion of the number of individuals in *i*th reef fish species. Similar with evenness, the dominance index value ranges from 0 to 1. Assessment of reef fish condition in Moramo Bay MCA based on the diversity, evenness, and dominance indices (Odum 1971) is tabulated in Table 5.

Table 4. Standard criteria for coral reef damage (Decree of the Minister of Environment and Forestry of the Republic of Indonesia No. 4 of 2001)

Parameter	Standard criteria for coral reef damage (%)		
Percentage area covered by living coral reefs	Damaged	Poor	0-24.9
		Moderate	25-49.9
	Preserved	Good	50-74.9
		Very good	75-100

Note: Percentage of live coral reef cover area that can be tolerated: 50-100%

Table 5. Assessment of reef fish condition based on diversity, evenness, and dominance indices (Odum 1971)

Ecology index	If	Description
Diversity (H')	H' ≤ 1	Low diversity, distribution, and community stability
	1 ≤ H' ≤ 3	Moderate diversity, distribution, and community stability
	H' ≥ 3	High diversity, distribution, and community stability
Evenness (E)	0 < E ≤ 0.4	Low evenness, depressed community
	0.4 < E ≤ 0.6	Moderate evenness, unstable community
	0.6 < E ≤ 1.0	High evenness, stable community
Dominance (C)	0 < C < 0.5	Low dominance
	0.5 < C ≤ 0.75	Moderate dominance
	0.75 < C ≤ 1.0	High dominance

Coral reef cover versus reef fish abundance

A simple regression analysis was applied to determine the relationship between coral cover and fish abundance at each station. This statistical analysis was carried out using a Minitab 21.4.1 statistical software at a confidence interval of 95% (or p <0.05), where the live hard coral cover was set up as an independent variable and the coral fish abundance as a dependent variable.

The simple regression analysis has a general equation of y = ax + b, where x is an independent variable, y is a dependent variable, a is the slope of the regression line which is the rate of change for y as x changes, and b is the y-intercept which is the expected mean value of y when all x variables are equal to 0; on the regression graph, it is the point where the line crosses the y axis. Whether the relationship between the x and y values is strong or not can be seen from the coefficient of determination (r^2) which ranges from 0 to 1. The closer it is to 1, the stronger the relationship between the two variables. Conversely, if the value is close to 0, the relationship between the two variables is getting weaker (Montgomery et al. 2021).

RESULTS AND DISCUSSION

Coral reef

In general, the coral reefs that grow and develop along the coast of the Moramo Bay MCA are the fringing reef type. This bay has a coral reef flat with a depth of 7-10 m and the distance between the shore and the tip of the reef varies in the range of ±50-200 meters. Furthermore, the tip of the reef has a reef slope with a moderate slope (45°) to quite steep (75°). Coral reefs exist at 1~35 m, with a basic substrate of sand and muddy sand.

Table 6 tabulates the percentage of live hard coral cover at 9 observation stations. The live hard coral cover in Moramo Bay MCA, as a basis for determining the quality and condition of coral reefs in a certain area, set up in the range of 23-75% (refers to the poor to very good category). During field observations, several spots of coral damage were still found in the Moramo Bay MCA. This damage was likely caused by fishermen's fishing practices using devices that were not environmentally friendly, for example by using of anesthesia/cyanide and explosives (Oetama 2023, unpublished data). The evidence obtained was the existence of dead coral fragments (rubble) and dead coral overgrown with algae in those spots.

Referring to the standard criteria for coral reef damage (Table 4), the coral condition in Moramo Bay MCA for Station I (Pasi Jambe 1; limited-use zone) was in the poor category (23%). The moderate category was found in several limited-use zones, specifically Station II (Pasi Jambe 2), Station VII (Panambea Barata Cape), and Station IX (Wawosunggu Island) with live hard coral covers of 42%, 45%, and 47%, respectively. Furthermore, the good categories were found in Station III (Hari Island 1; core zone), Station IV (Hari Island 2; core zone), Station V (Labotaone; limited-use zone), and Station VI (Rumbi-Rumbia; core zone). The very good category was only recorded at Station VIII which is located on Lara Island (limited-use zone) with a hard coral cover percentage of 75% (Table 6; Figure 4)

In general, the coral reef ecosystem along the coast of Moramo Bay MCA is still in relatively good condition with an average percentage of live hard corals of 53% (Table 6). Compared to other locations, a lower live coral cover of 24% was noticed in Tuburan, Cebu (Del Fierro et al. 2021), and Pulau Berhala, Pahang, Malaysia (45%) (Ismail et al. 2020), while higher live coral covers were discovered in the Northern Red Sea Islands, Egypt (84%) (Ghallab et al. 2020) and coral reefs in Lakshadweep Archipelago (64.5%) (Gopi et al. 2021).

Table 6. Percentage of hard coral coverage at each station in Moramo Bay MCA, Southeast Sulawesi, Indonesia

Station	Coverage (%)		
	Acropora coral	Non-Acropora coral	Total (live hard coral)
I	5	18	23
II	18	24	42
III	17	54	71
IV	29	44	73
V	18	32	50
VI	9	42	51
VII	12	33	45
VIII	36	39	75
IX	12	35	47
Average	17	36	53
			Good category

The percentage of coral cover shows the proportion of the seabed covered by live coral which is an important indicator of coral reefs' health. Table 6 further illustrates the investigation results of live hard coral cover (*AC* + *NA*) at depths 7-10 meters which are in the range of 5-54%. Such percentage of live hard coral cover based on *Acropora* and non-*Acropora* corals categories is more depicted in Figure 5. Station VIII has the highest hard coral cover (36% *Acropora* and 39% non-*Acropora*), while Station I has the lowest hard coral cover (5% *Acropora* and 18% non-*Acropora*).

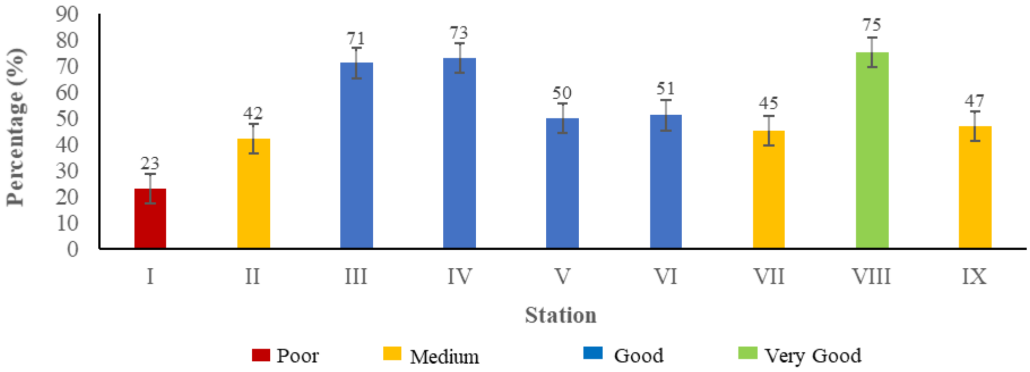

Figure 4. Live hard coral coverage in Moramo Bay MCA, Southeast Sulawesi, Indonesia (errors represent standard deviations, 2σ)

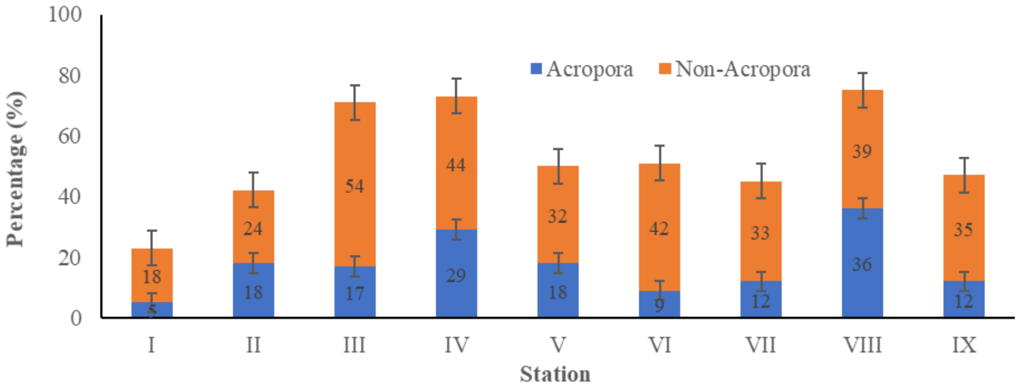

Figure 5. Acropora and non-Acropora corals coverages in Moramo Bay MCA, Southeast Sulawesi, Indonesia (errors represent standard deviations, 2σ)

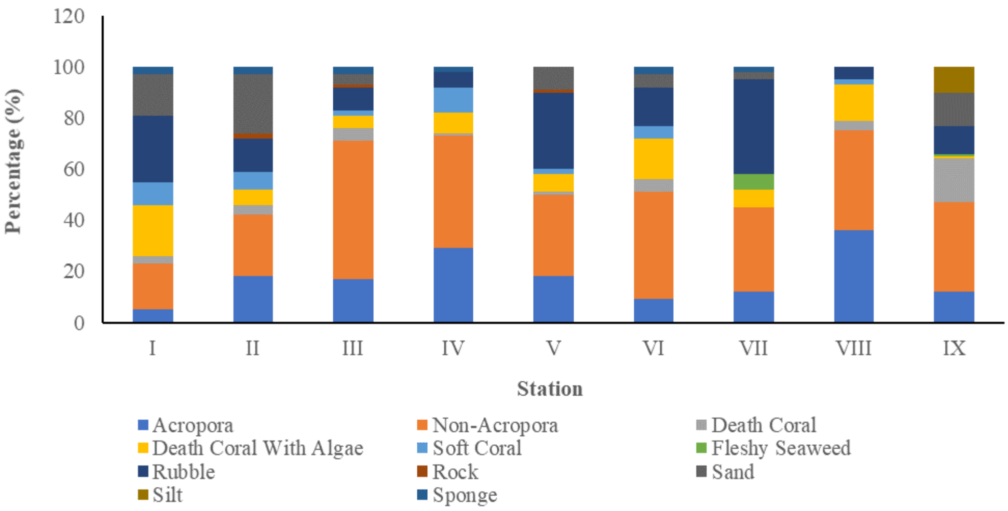

Figure 6. Cover percentage of biotic and abiotic components in Moramo Bay MCA, Southeast Sulawesi, Indonesia

Results of substrate observations (abiotic) and other biotic components at each station are shown in Figure 6. On average, live hard corals are still dominated by other substrates such as dead coral with algae (9%) and rubble (17%) at 9 observation stations. For the abiotic component, the highest cover percentage of dead coral with algae was found at a depth of 9 m at Stations I and VI. Furthermore, the highest coral fracture (rubble) was observed at a 10 m depth at Station VII and the lowest one at Station VIII (9 m depth).

Reef fish

The presence of reef fish in coral reef ecosystems constitutes an ecological indicator of coral reef health (Nash and Graham 2016). On the other hand, a decrease in the abundance and diversity of reef fish is a sign of a declining condition of the coral reef ecosystem. Hourigan et al. (1988) and Adrim et al. (2012) have emphasized that the existence of reef fish communities is an essential indicator of the health level of coral reef ecosystems. Coral reefs act as nurseries, feeding, and spawning grounds for various species of reef fish. Based on their role in the coral reef ecosystem, reef fish are divided into three groups, indicator fish, target fish, and major fish (McClanahan 2019a). Indicator fishes are those used as indicators of coral reef fertility, usually from the family Chaetodontidae. Target fishes are those have important economic value and are targeted by fishermen, for example, fishes from the families Seranidae, Lutjanidae, Kyphosidae, Lethrinidae, Acanthuridae, Mulidae, Siganidae, Labridae, and Haemulidae. Furthermore, major fishes are usually used as ornamental fishes in large numbers, such as the families Pomacentridae, Caesionidae, Scaridae, Pomacanthidae Labridae, and Apogonidae (Indonesian Coral Reef Foundation 2004). The results of the ecological parameters analysis of reef fish in Moramo Bay MCA are shown in Figure 7.

Abundance

Figure 7 shows that the abundance of reef fish ranged from 0.44 to 1.72 ind.m^{-2}. The highest fish abundance (1.72 ind.m^{-2}) was recorded at station III, which is the core zone in Moramo Bay MCA. The most common reef fish species discovered at this station was *Caesio teres* (100 individuals). This fish species is classified as a target fish (Corrales et al. 2015) and is often found in groups in the water column on reefs and shelf areas (Matley et al. 2017). Apart from these species, 50 individuals of the species *Atule mate* from the family Carangidae were verified, which is also a target fish. Furthermore, reef fishes from the family Chaetodontidae, which belong to the indicator fish of coral reef fertility, were found in 4 species (i.e., *Chaetodon octofasciatus*, *Chaetodon reticulatus*, *Chelmon rostratus*, and *Heniocus acuminatus*) totaling 20 individuals. The lowest fish abundance was obtained at Station I (limited-use zone) at 0.44 ind.m^{-2}. The fish species that are often found at this station were *Caesio cunning* (30 individuals) from the family Caesionidae. Only 2 species of fish from the family Chaetodontidae were acknowledged at Station I, i.e., *Chaetodon kleni* and *Chaetodon trifasciatus*, totaling 5 individuals. Overall, the total reef fish of the family Chaetodontidae identified at all observation stations were 3 genera (i.e., *Chaetodon*, *Chelmon*, and *Heniocus*), comprised of 7 species (i.e., *Chaetodon octofasciatus*, *Chaetodon reticulatus*, *Chaetodon kleinii*, *Chaetodon trifasciatus*, *Chaetodon Lunulatus*, *Chelmon rostratus*, and *Heniocus acuminatus*), with a total number of 69 individuals. In addition, the average abundance of reef fish in the Moramo Bay MCA was 1.05 ind.m^{-2}; suggesting a low category.

Diversity

The reef fish diversity index in Moramo Bay MCA ranged from 2.58 to 3.09 (Figure 7), with moderate to good category. Fish diversity in the good category was found at station IV (diversity index 3.09, the highest one) and station V (3.00). Ecologically, both stations have high distribution and stability of reef fish communities. At Station IV, 18 families, 27 genera, and 38 species of reef fish were identified, while Station V recorded the activity of 14 families, 20 genera, and 31 species of reef fish. Furthermore, the moderate category diversity index was recorded at station I (2.61), station II (2.58), station III (2.97), station VI (2.87), station VII (2.90), station VIII (2.83), and station IX (2.89) (Figure 7). The lowest diversity index was recorded at Station II with the number of reef fish found in 12 families, 17 genera, and 26 species. Overall, the average diversity index of all observation stations was 2.86, referring to the moderate category (Table 5).

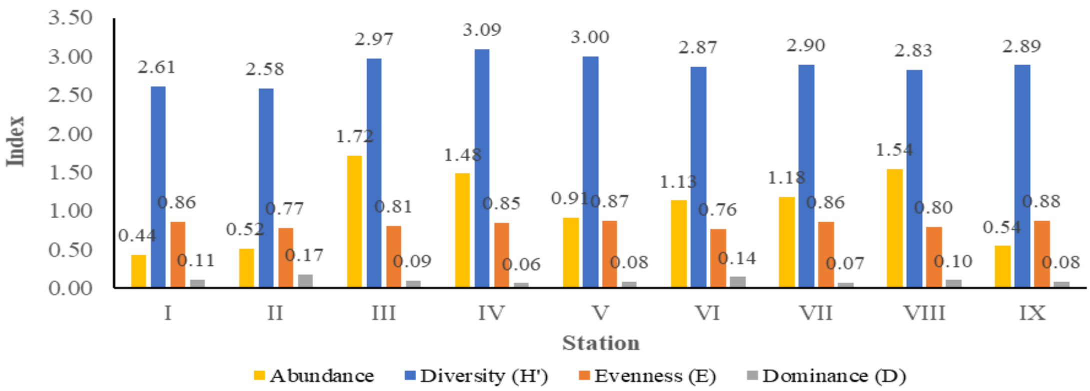

Figure 7. Ecological parameters (abundance, diversity, evenness, and dominance) of reef fishes in Moramo Bay MCA, Southeast Sulawesi, Indonesia

It has to be noted that field observations at all stations in the Moramo Bay MCA succeeded in identifying 25 families of reef fish, belonging to 48 genera, 102 species, and 2,364 individuals. By comparing those data with the presence of reef fishes in other overseas locations, the Malaysian South China Sea recorded 35 families and 86 species (Arai 2014); the Philippines Marine Protected Area verified 7 families and 12,352 individuals (Muallil et al. 2015); Cuba Marine Protected Area found 3 families, 19 species, and 16,070 individuals (Costa et al. 2020); while Brazilian coastal Marine Protected Area (MPA Costa dos Corais) documented 81 families and 325 species (Pereira et al. 2021).

Evenness and dominance

Figure 7 shows that the evenness index of reef fish at each observation station in Moramo Bay MCA does not show significant fluctuations. The lowest fish evenness index was recorded at Station VI (Rumbi-Rumbia, core zone) at 0.76, while the highest evenness was found at Station IX (Wawosunggu Island, limited-use zone) at 0.88. Taken as a whole, the average evenness value for reef fish in Moramo Bay MCA was 0.83 (high category; Table 5). A high evenness index reflects a stable fish community in a coral reef ecosystem with an even individual distribution (Ramírez-Ortiz et al. 2017).

Figure 7 further displays histograms of the reef fish dominance index at each station in Moramo Bay MCA. Based on the analysis results, it is known that the reef fish dominance index ranged from 0.06 (Station IV) to 0.17 (Station II). The average value of the fish dominance index was 0.10; implying a low category (Table 5). It is important to note that high evenness and diversity indices indicate low dominance of one species over other species.

Correlation between live hard coral cover and reef fish abundance

Figure 8 presents the results of linear regression analysis of the relationship between live hard coral cover and reef fish abundance at the Moramo Bay MCA. These two parameters are positively correlated, with a fairly high determination coefficient (r^2) of 0.7802 (p <0.05), indicating that the higher the percentage of live hard coral cover, the higher the abundance of reef fish in the coral reef ecosystem (Putra et al. 2019; Gustilah, 2018). The regression equation of $y = 0.0247x - 0.259$ means that every additional 1% of live hard coral cover will increase the abundance of reef fish by 0.025 individuals. As a comparison, a 1% increase in coral cover will raise the abundance of reef fish by 4 individuals in the marine waters of Taka Bonerate, South Sulawesi, Indonesia (Ghiffar et al. 2017).

The coral reef ecosystem is a source of biodiversity that ecologically has a role as a source of food, shelter, and spawning for marine biota, accordingly the condition of coral reefs plays an important role in multiplying productivity in the fisheries sector (Benkwitt et al. 2020; Mathon et al. 2022). As a dependent variable in such regression analysis (Figure 8), the abundance of reef fish is extremely influenced by the live hard coral cover (i.e., a dependent variable) in Moramo Bay MCA. This means that in order to increase reef fish resources, the condition of coral reefs requires full attention to be improved. Various efforts can be performed, for example by carrying out transplants, protecting coral reef areas, prohibiting destructive fishing activities, monitoring marine pollution, and advocating practices to increase public awareness of the importance of coral reefs existence.

Water quality

The results of water quality measurements in Moramo Bay MCA are presented in Table 7. The health condition and distribution of coral reefs in Moramo Bay MCA are significantly influenced by the quality of coastal waters. Based on the measurement results of water quality parameters, water temperature ranged from 26.36°C to 28.99°C, pH ranged 7.85-8.26, salinity level spread from 25.53 ppm to 34.94 ppm, and brightness was found to be 5.0-9.7 m. Comparing those parameter values to the Indonesian seawater quality standard for marine biota (coral reefs) (Table 3), all water quality parameters still support the life of coral reefs in Moramo Bay MCA. The water quality parameters data in this bay agree with the parameter values of several previous studies which concluded that coral reefs can grow at temperatures between 17-34°C with optimal temperature ranges of 23-29°C, pH 7.1-8.9, salinity 27-40 ppt, and water brightness above 5 m (Tomascik et al. 1997; Armid et al. 2011; Lough et al. 2011; Lu et al. 2020; Tuwo and Tresnati 2020; and Hancock et al. 2021). Decent coral growth will attract reef fish to breed in the coral reef ecosystem.

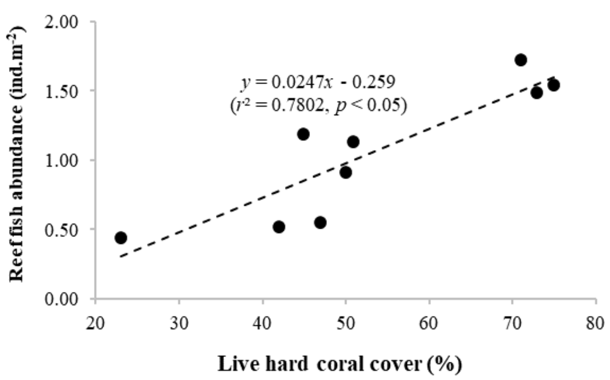

Figure 8. Correlation between live hard coral cover and reef fish abundance in Moramo Bay MCA, Southeast Sulawesi, Indonesia

Table 7. Water quality parameters in Moramo Bay MCA, Southeast Sulawesi, Indonesia

Station	T (°C)	pH	Salinity (ppt)	Brightness (m)
I	28.96	8.25	34.79	8.9
II	28.99	8.26	34.94	8.0
III	28.65	8.03	31.84	8.5
IV	28.80	7.96	31.11	9.7
V	27.02	7.87	30.26	5.1
VI	26.36	7.85	29.13	5.4
VII	27.04	7.93	25.53	5.2
VIII	27.30	7.96	27.12	5.5
IX	27.11	7.92	27.78	5.0

In conclusion, this study investigates the health status of coral reef ecosystems associated with ecological parameters of reef fish, i.e., abundance, diversity, evenness, and dominance, as well as assessing the water quality at 9 stations in the Moramo Bay MCA. The condition of coral reefs, reef fish, and water quality at the study location is relatively good, according to the Decree of the Minister of Environment and Forestry of the Republic of Indonesia No. 4 of 2001 concerning Standard Criteria for Coral Reef Damage and the Indonesian Government Regulation No. 22 of 2021 concerning the Implementation of Environmental Protection and Management. The percentage of live coral is dominated by *Acropora* and non-*Acropora*, with live hard coral cover of 53%. This study also identified 25 families of reef fish, comprising of 48 genera, 102 species, and 2,364 individuals in Moramo Bay MCA, which is a compilation of target and indicator fish groups. Effective conservation is an adaptive step to maintain and preserve coral reef ecosystems as well as active collaboration between communities and stakeholders in managing conservation areas. The coral reef ecosystem in Moramo Bay MCA can ultimately become a new economic growth area in the planning and management of Marine Protected Areas. This protection stage is of importance to increase the effectiveness of marine resource conservation, encourage sustainable use, and preserve biodiversity in the long term, such as through the utilization of ecologically based marine tourism activities and underwater educational laboratory according to the designated zone in the Moramo Bay MCA.

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