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ORIGINAL ARTICLE

The correlation of coral cover and reef fish density in the biggest archipelagos located in centre of Indonesia

Ernaningsih ERNANINGSIH*[1], Danial SULTAN[1], Asbar ASBAR[1], Budimawan BUDIMAWAN[2], Ma'ruf KASIM[3]

[1]Faculty of Fisheries and Marine Science, Muslim University of Indonesia, Jl. Urip Sumoharjo Km. 05, Makassar, Southeast Sulawesi, Indonesia.
[2]Faculty of Marine Science and Fisheries, Hasanuddin University.Jl. Perintis Kemerdekaan Km 10, Makassar 90245, Indonesia.
[3]Faculty of Fishery and Marine Science, Halu Oleo University, Jl. Mokodompit, Andounohu, Kendari, Southeast Sulawesi, Indonesia.

Correspondence
ernaningsih.aras@umi.ac.id

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Abstract
Live coral cover is a measure of the proportion of reef surface covered by live stony materials instead of sponges, algae, or other organisms. These stony corals are the main contributors to a reef's three-dimensional framework structure that provides critical habitat for many organisms. Therefore, this research aims to determine the relationship between the number of live coral cover and the presence of reef fish in one of the biggest archipelagos located in centre of Indonesia. The research method used for the determination of live coral cover was the point intercept transect, while the reef fish population were measured using the census technique. The results showed, that the average percentage of live coral cover in all stations including Sarappo, Lumulumu, and Langkai Island were 43.17, 52, 45.67%, respectively, and were classified into moderate and good. There were 149 reef fish species in 27 families found in the studied area during this research. The coral cover was negatively correlated with species diversity and the abundance of reef fish in archipelagos of Indonesia.

Keywords: Live coral cover, Diversity, Abundance, Archipelagos.

INTRODUCTION

Coral reefs are one of the underwater ecosystems carrying out marine biodiversity with various ecological functions, such as a place for marine organisms to breed, make shelter, feed, and maintain stability in ecological conditions, and also a habitat for a variety of marine animals (Maragos et al. 1996; Miththapala 2008, Gattuso et al. 2014). Coral reef ecosystems have high biodiversity and aesthetic value, such as a tourism area, for wave barriers and controlling coastal erosion (Gattuso et al. 2014). However, their ecosystems are very vulnerable to damage, which in turn affects the existence of organisms associated with corals. Also, the high access to the coral reef area increases its chance of degradation. The causes of such damage include the use of fishing gear that is not environmentally friendly, sedimentation, water pollution, sand mining, and severe tourism activities (Hartoni et al. 2012).

Coral reefs have a complex relationship with fish communities. The extent of coral reef exposure to various organisms provides a good opportunity and surface for various fish and more organisms to survive. Therefore, increasing populations and expanses of coral reef communities can provide sufficient food for reef fish. Several studies on the relationship between coral reefs and fish populations have been carried out, including research on the correlation between fish, environment, and biodiversity (Luiz et al. 2015; Harahap et al. 2019; Samoilys et al. 2022). Other studies were based on the effect of the percentage of coral cover on the structure of fish communities (Herawati et al. 2021). However, some studies did not find a significant correlation between the coral cover and the number of reef fish populations (Bell and Galzin. 1984; Samoilys et al. 2022). Several recent studies showed a positive correlation between coral cover and reef fish population, specifically the endemic fish (Philpott et al. 2012; Komyakova et al. 2018; Nugraha et al. 2020). However, the strength of each relationship depends on the organism's level and habitat type (Munday 2004). The habitat's resources

are also measured at the species level; this is necessary for further study (Andrew 1987). Habitat degradation impacts reducing the number of reef fish species, especially target fish species (Wilson et al. 2010). Russ (1991) explained that the most informative indicator of detecting the changes in the catch activity is the decrease of fish diversity through the scarcity of certain local species. Fishing activities affect the coral reef habitat by two methods: directly through destructive fishing and indirectly by increasing the grazing algae (Bouchon et al. 1985; Pet Soede 2000). The presence of reef fish in their habitats is directly affected by their health and population, which is associated with the availability of food, shelter, and spawning ground (Andamari et al. 2007).

Fish population growth is highly dependent on the environment. Suitable water conditions will affect good growth to the optimum population growth limit (Arteaga et al. 1997). However, the relationship between coral reef conditions and their populations is more specific to their living habitat. For this reason, this study will explore information related to the relationship between coral reef conditions and reef fish populations, particularly the relationship based on the area of living coral reefs and the species composition of reef fish.

MATERIAL AND METHODS

Study Sites: This research was conducted on three islands in Spermonde Archipelagos, South Sulawesi Province, in Indonesia, namely Sarappo, Lumulumu, and Langkai (Fig. 1). Each island had four stations representing the habitats of coral reefs. The coordinates of each station are given in Table 1.

Research Procedure: This study used primary data, and the coral reef observation was conducted based on the habitat condition using Point Intercept Transect (PIT) method, while reef fish was obtained using the belt transect technique (English et al. 1997). To determine the habitats' conditions, species diversity, and abundance, observations were carried out at three islands in Spermonde Archipelago, namely Sarappo, Lumulumu, and Langkai. The method used for the observation was the Point Intercept Transect (PIT) at 50 meters, 3-7m depth in a reef flat area.

The observations were carried out using a visual census method with a transect line (English et al. 1997) on each station and were repeated three times. The observations were made with a 50m transect line with visibility at a distance of 2.5m to the left and 2.5m to the right (the observer was in the middle). Specifically, reef fish found in the observed location were recorded according to their species, quantity, and estimated length. To identify the habitat characteristic grouping between the observed stations, a descriptive analysis was conducted, presenting the results in the form of graphs and images. Meanwhile, fish abundance was determined according to the method of Dartnall & Jones (1986). Reef fish can be categorized into three main groups (English et al. 1997): 1) target fish groups, 2) indicator fish, and 3) large fish groups. Fish identification was carried out using Kuiter (1992) and Matsuda & Allen (1987). The abundance of reef fish species is calculated in individual units/meter^2. The target fish groups are fish species that have economic value, are very important in their presence on coral reefs, and are targeted for fishing. This group of fish makes coral reefs as spawning grounds. The indicator fish group is a type of reef fish that usually lives in coral reef areas and is an indicator of the fertility of coral reef ecosystems. While the major fish groups are small fish, with sizes of 5-25cm, that had different colours. These fish are usually ornamental fish. This group of fish is generally found in large numbers and types and tends to be territorial.

Data Analysis: The data analysis for the coral cover was distinguished by the character of their habitats or their percentage population, while the dead and live form were calculated using the following formula. From the obtained percentage of lifeform cover, the quality of living coral in that area was determined. The criteria generally applied to

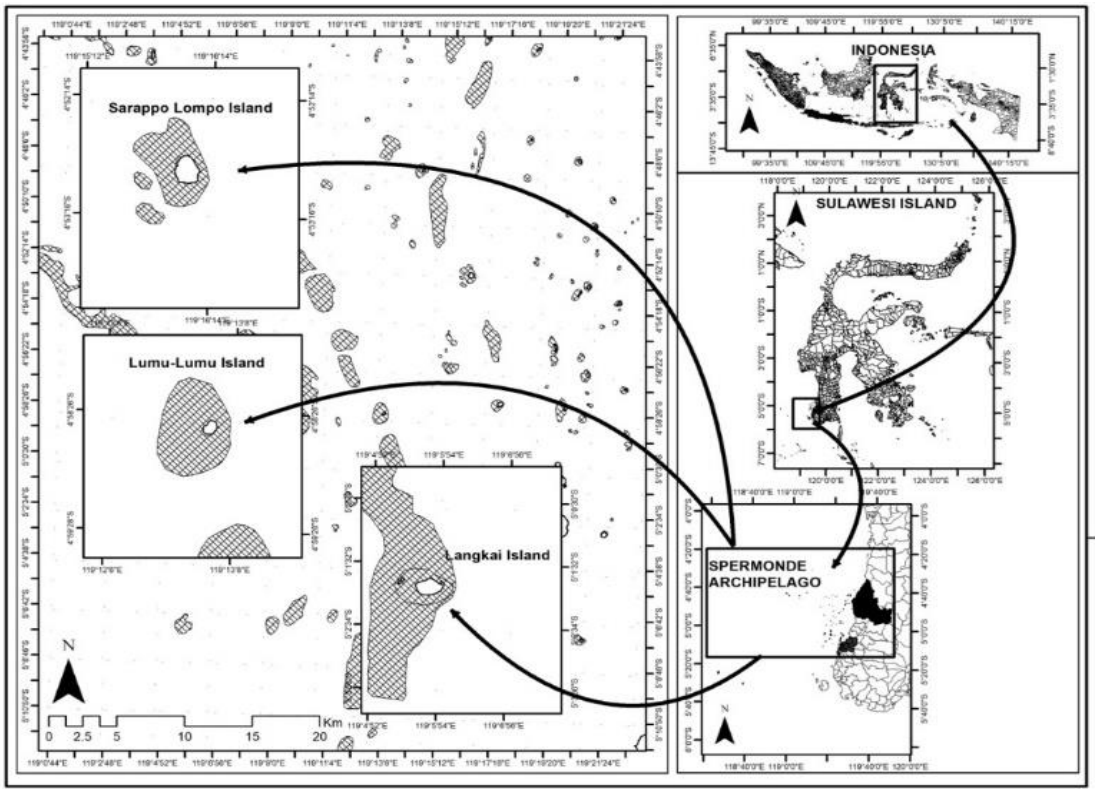

Fig.1. Study site during research in Spermonde Archipelagos, Indonesia.

Table 1. The coordinates of the research station.

No	Sampling station	Coordinate point
	Sarappo Lompo Island	
1.	Station 1	S5° 02.090' E119° 05.192'
2.	station 2	S4° 52.951' E119° 15.656'
3.	station 3	S4° 52.654' E119° 15.574'
4.	station 4	S4° 52.428' E119° 15.861'
	Lumulumu Island	
1.	station 1	S4° 58.435' E119° 13.028'
2.	station 2	S4° 58.143' E119° 12.791'
3.	station 3	S4° 58.158' E119° 12.640'
4.	station 4	S4° 58.402' E119° 12.512'
	Langkai Island	
1.	station 1	S5° 02.182' E119° 05.838'
2.	station 2	S5° 02.232' E119° 05.691'
3.	station 3	S5° 02.219' E119° 05.347'
4.	station 4	S5° 02.090' E119° 05.192'

determine the condition of coral reefs were divided into four categories (English et al. 1997), as follows:

- Damaged : 0-24,9%
- Moderate : 25-49,9%
- Good : 50-74,9%
- Very good : 75-100%

Statistical Analysis: To examine the relationship between live coral cover conditions and their abundance and density, Pearson's correlation was performed in SPSS software (version 24). The analysis results were tabulated in the table of the relationship between these factors.

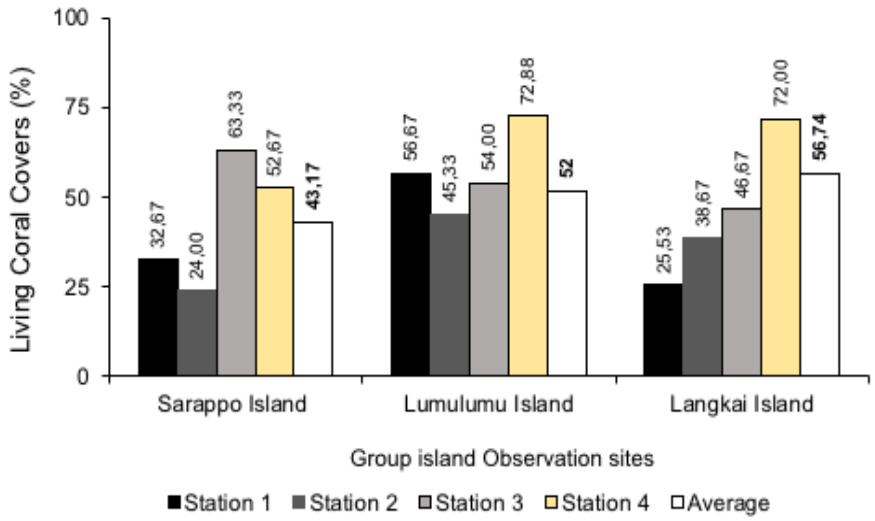

Fig.2. Live coral cover in each station at every island observation sites.

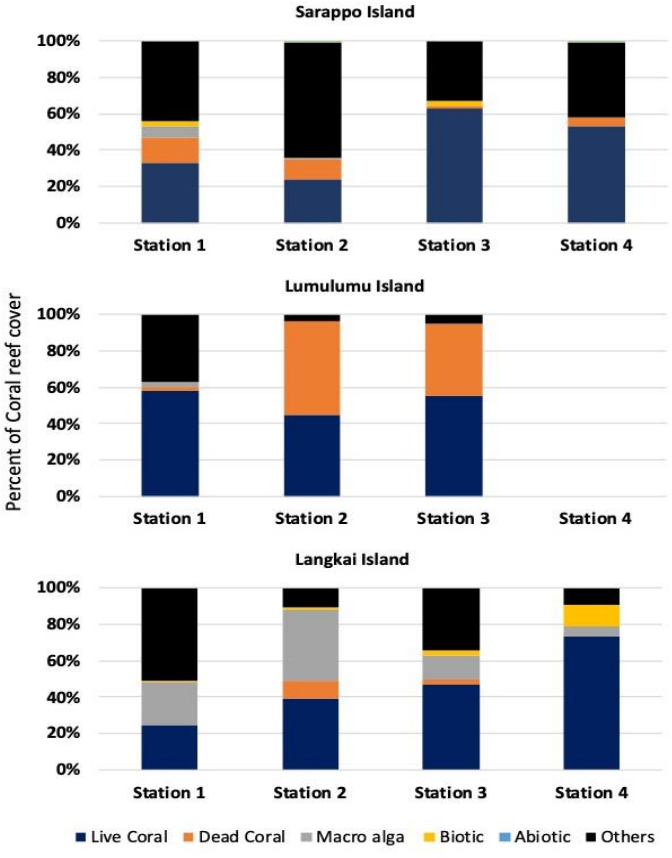

Fig.3. Average of living coral cover at each station in the research site (live coral are corals (soft corals and hard corals) that are found alive, Dead coral are corals (soft coral and hard coral) that are found in a non-living condition, marco algae is a group of seaweed found around coral reefs, Biotic is a population of living organisms other than corals and macroalgae, abiotic is a stretch of dead rock and coral, others is a stretch of sand and small rocks).

RESULTS

Coral reef condition: The living coral cover in three research sites (Sarappo Island, Lumulumu Island, and Langkai Island) was generally classified as moderate or good. The measurement results of the average percentage of coral cover in Sarappo, Lumulumu, and Langkai Islands were 43.17, 52, and 45.67%, respectively (Fig. 2).

The coral covers in these three studied sites were classified into moderate and good. The average coral cover also appeared to differ between the study sites. The highest percentage was around 72% on Langkai Island, especially at station 4. However, this condition was still moderate and good for all stations, with an average coral cover of 43%, 52%, and 45% for Sarappo, Lumulumu, and Langkai Island, respectively. Some striking stations with a deadly percentage (51%) were observed on Lumulumu Island. However, the percentage of dead coral appeared to be much lower, with an average of 8, 30, and 3% for Sarappo, Lumulumu, and Langkai Island, respectively (Fig. 3).

Reef Fish Diversity: The number of reef fish species in each location ranged from 39 to 66. The number and types of reef fish in each location are characterized by differences in size, behavior, and living characteristics. From the total population, there were 66 genera, 149 species, and 27 families

Table 2. Species abundance of reef fish at each island in genus level.

No	Genus Level	Sarapo Island				Lumu lumu Island			Langkai Island			
		St1	St2	St3	St4	St1	St2	St3	St1	St2	St3	St4
1	*Ablyglyphidodon*	*	*** *	*	*	*		**				
2	*Abudefduf*		*** **	*	****	******		*****				
3	*Acanthurus*			*	**	*	*	*	*	*	**	*
4	*Aeoliscus*				*	*		*				
5	*Amblyglyphidodn*	*								**		
6	*Amphiprion*						**	*		*	*	*
7	*Anampses*					*	*	**		*		
8	*Anyperodon*							*		*		
9	*Apogon*				*							
10	*Balistapus*							*			*	*
11	*Bodianus*	*										
12	*Caesio*	*	**									
13	*Canthigaster*						*					
14	*Carangichthys*											
15	*Centropyge*							*	*	*		
16	*Cephalopholis*	**	**	*		**				*	*	*
17	*Chaetodon*	**	**	*	**	**				*	**	
18	*Cheilinus*	*	*	*	*	*	*	*				
19	*Cheilodipterus*	*										
20	*Chlorurus*		*		*	*	*	**				
21	*Choerodon*		*	*				**				
22	*Chromis*	*	****					******		*****		*
23	*Chrysiptera*	*	*	*	****	*** *	*	***	***		*** *	*** *
24	*Cirrhilabrus*						*** *	*	*	*** **	*	
25	*Coris*				*							
26	*Cromileptes*	*										
27	*Ctenochaetus*					*						
28	*Dascyllus*	*								*		*
29	*Diproctacanthus*			*	*		*					
30	*Dischistodus*	*	*	*								
31	*Epibulus*	*	*					*	*	*		
32	*Epinephelus*							*	*		*	*
33	*Fistularia*											*
34	*Halichoeres*	*		*	**	*	**	*	**	*	*	*
35	*Hemigymnus*	*		*		*	*	*	*	*		
36	*Heniocus*							*				
37	*Labroides*	*	*	*	*		*		**		*	**
38	*Lethrinus*					*			*			
39	*Lutjanus*	*	*	*	*		*** *	*	*	*	*	
40	*Macropharyngodon*								*		*	*
41	*Monotaxis*					*		*				
42	*Naso*	*				*	*	*				
43	*Neoglyphidodon*	*	*	*		*	**	*		*		

Table 2. Continued.

No	Genus Level	Sarapo Island				Lumu lumu Island			Langkai Island			
		St1	St2	St3	St4	St1	St2	St3	St1	St2	St3	St4
44	*Neoniphon*									*		
45	*Neopomacentrus*		*	*								
46	*Odonus*							*			*	*
47	*Oxycheilinus*										*	
48	*Paracirrhites*	*	*	*	**	*	*					*
49	*Parupeneus*			*		*		*	*		*	*
50	*Pempheris*			*								
51	*Pentapodus*				*	*		*	*	*		
52	*Platax*						*					
53	*Plectorhincus*	*	*	*	*	*	*	**				
54	*Plectroglyphidodon*							**	*	*		*
55	*Plectropomus*		*			*						
56	*Pomacentrus*	***		****	****	***	***	***	****			
		***	**	*	*	**	**	***	**	***	**	*
57	*Pseudanthias*	*										
58	*Sargocentron*			*		*						
59	*Scarus*	*	*	*	*	*	*	*	**	*	*	
60	*Scolopsis*	*	**	*	*	*		*	**	*	*	*
61	*Siganus*		**	*	*	**	**	**	**	**	*	
62	*Stethojulis*			*	*							
63	*Taeniur*				*							
64	*Thalassoma*			*	**	*	*	*	**	*	*	*
65	*Zanclus*		*		*	*		*	*	*		*
66	*Zebrasoma*							*	**	*	*	*

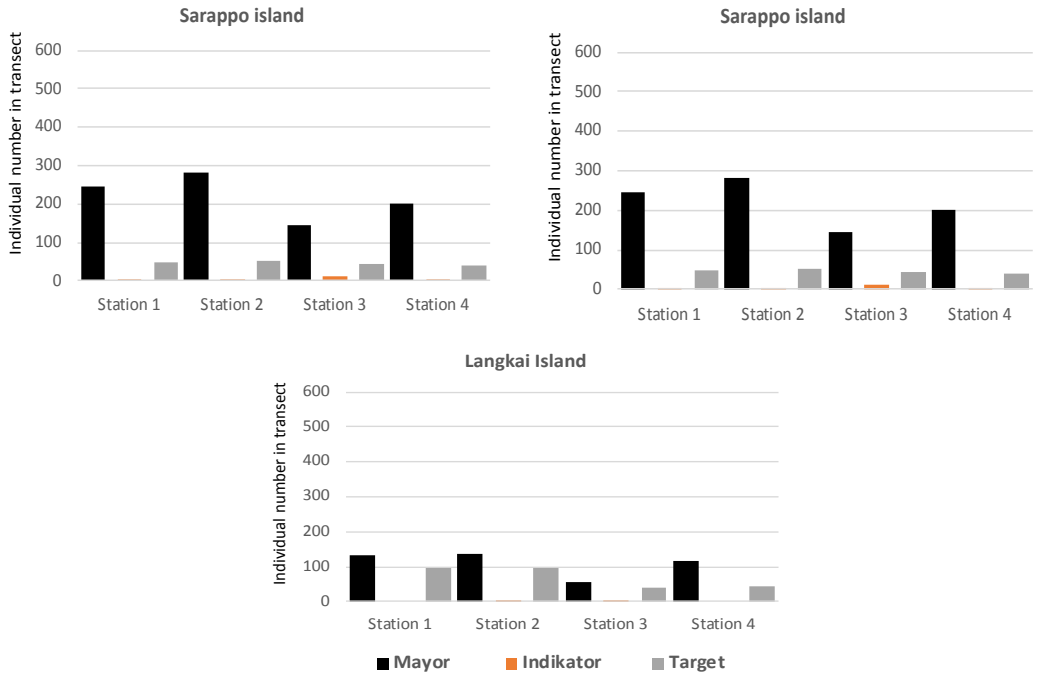

Fig.4. Number of reef fish in categories, namely major, indicator, and target fish.

Table 3. Correlation of live coral with species number and abundance of reef fish in all station.

	Abundance	Live Coral
Species Number	0.654*	-.314
Abundance		0.001
Live Coral		

*Correlation was significant at the 0.05 level (2-tailed).

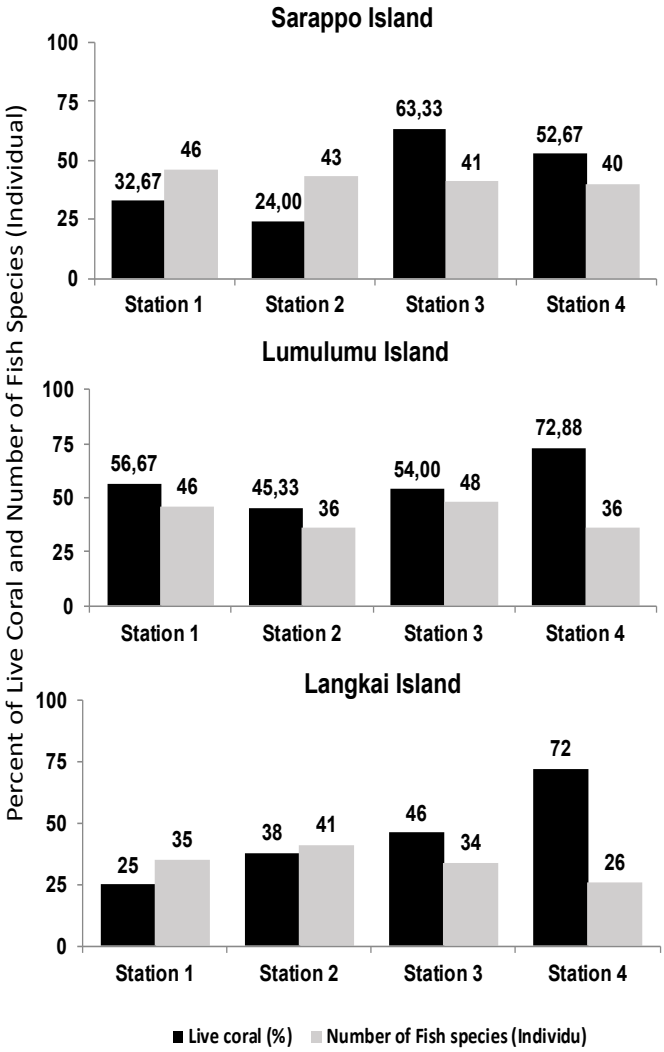

Fig.5. Correlation between live coral cover and diversity of reef.

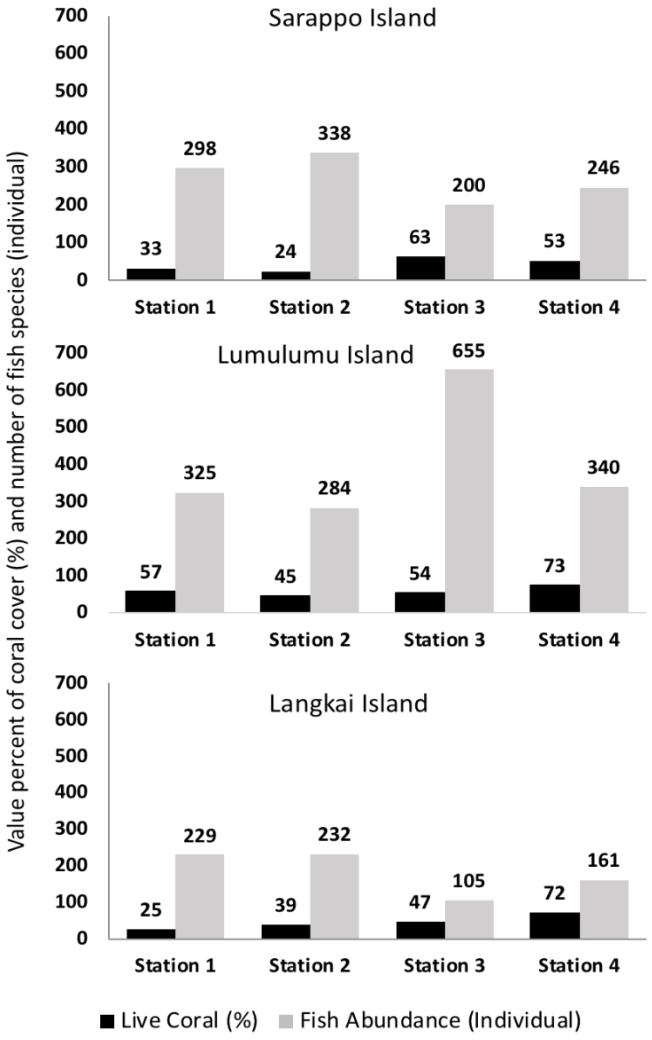

Fig.6. Corelation between live coral cover and abundance of reef fish.

(Table 2). All were classified into 3 groups: target, major, and indicator fish (English et al. 1997). The highest number of fish categories found at all stations was dominated by target fish. The highest number was found on the island of Sarappo (Fig. 4). **Correlation between coral cover and reef fish:** The correlation between coral cover with the diversity of reef fish in each observation site showed that Sarappo Island had a low coral cover of 32.67 and 24% at stations 1 and 2, with more fish diversity than 3 and 4, and coral cover of 63.33 and 52.67%, respectively (Fig. 5). The Pearson correlation showed that in Sarappo Island, coral cover negatively correlated with the diversity of fish species, i.e., an increase in coral cover was not followed by the rise in the diversity of fish species.

Meanwhile, live coral cover in Lumulumu and Langkai Island was negatively correlated with the diversity of fish species (Table 3).

Correlation between live coral cover with the abundance of reef fish: During the research, the high percentage of live coral cover was not significantly related to the number of reef fish species. On Lumulumu Island, the percentage of live coral cover was around 63% and had 41 individual fish species, while on Langkai Island, which had a live coral cover of about 72%, the number of reef fish was around 26 individuals. The correlation between live coral cover with the abundance of reef fish in Sarappo, Lumulumu, and Langkai Island was shown in Figure 5. In Sarappo Island, an increase in coral cover was not always followed by a rise in the abundance of fish. The Pearson correlation showed that the live coral cover on Sarappo Island was negatively correlated with the abundance of fish, while that of Langkai and Lumulumu Island were negatively related (Fig. 6). Generally, the diversity and density of reef fish were significantly associated with the complexity and their health. The discrepancies in the three islands are allegedly associated with the condition of the substrate as a shelter and feeding ground for fish, thereby affecting their existence in these places.

DISCUSSION

The percentage of live coral cover at the study site is quite high, up to 72%, although in some locations, it still looks quite low at around 43%. The presence of live coral is not correlated with the number of reef fish populations. This condition shows that high-lived coral cover has fewer reef fish. Riskiani et al. (2019) surveyed a location close to the study site and found that at a depth of 7m, the substrate cover was dominated by abiotic, with the highest percentage of 59.15%.

The condition of live coral cover consisted of Acropora and non-Acropora species. In general, coral cover was more of the Acropora species. The dominance of the abiotic substrate was due to the pressure on the corals, such as the use of bombs or poison when fishing; as a result, the condition of the living coral substrate changes drastically and then dies. In general, the percentage of live coral cover was relatively small compared to abiotic and dead (Hudatwi & Umroh 2018). In the population of coral reefs in Labuan Bajo, there is a striking difference in live coral cover between hard and soft coral groups, which is 81.25 and 15.625%, respectively. The most common coral genera found at this site were *Porites*, *Acropora, Pavona, Favites, Montipora*, and *Pocillopora,* in addition to the living non-coral and sponges. The condition of the corals in Labuhan Bajau was included in the group of coral reef communities and found to be very good since the cover percentage was high (82.875%) (Wisha et al. 2018).

The research conducted at Central Tapanuli, found 52 nest genera scattered in most locations, and about 90% of them had a distribution associated with live coral cover. While the waters of Mentawai and Bengkulu had more coral species than other locations, and the presence of certain species was associated with the stress on their environment (Siringoringo et al. 2019). The lowest coral diversity in Indonesia was probably along the west coast of Sumatra, with 48 genera, and after that was Togean Island, with 57 coral genera. Therefore, North Sulawesi had the highest coral genera (Hoeksema & Putra 2000). In another study, 386 species of coral genera were on the west coast of Sumatra (Veron et al. 2009).

Indonesia's highest number of coral reefs (574 species) was found in Raja Ampat Island, Papua (The Nature Conservancy 2002). The Indo-Australian islands were the best location to find the richest coral reef biodiversity in the world, covering northern Australia, Papua New Guinea, Solomon's, Indonesia, and the Philippines. However, the species richness decreased fivefold compared to the central Pacific region and decreased further in the east. A decrease in the number of species present in each family caused the decline in reef fish diversity Bell & Galzin (1984) found that the condition of living

coral strongly influenced the presence of fish. They recorded 115 fish species at 13 locations; moreover, 61 were observed on 250 transects and a further 37 and 17 were added by observation with 100m sections of coral reef. The results showed insufficient evidence; however, some species avoided dead coral areas. Then, 68% of the total species recorded were at sites with few live corals.

The number of live corals also influenced their distribution; for example, 29 out of 78 species were associated with only the 2 highest coral cover sites. In contrast, only 4 species (3%) were recorded exclusively from locations without live coral. Thirty-three species (29%) were recorded at sites with and without live coral. The presence of reef fish in the southern waters of Ambon Island was quite varied. In this location, 88 species of reef fish were found and the most dominant were *Balistapus undulatus, Chaetodon kleinii, Ctenochaetus striatus, C. strigosus, Labroides dimidiatus,* and *Paraupeneus multifasciatus* (Limmon et al. 2018). The abundance of fish in an area was often related to the condition of coral reefs. The existence of reef fish, which were generally solitary, and closely related to environmental changes, especially concerning the percentage of live coral cover (Feary et al. 2007). Chaetodontidae fish inhabit associated with coral reefs and are very sensitive to changes, such as the damage to coral reefs that greatly impact the existence of food and shelter for these fish species (Titaheluw 2011). The low percentage of coral reef cover resulted in a low population of fish living on them, and a decrease in the abundance of these fish occurred when there was damage to the coral reef.

Live coral was the most important component in coral reef populations; however, the lowest damage to the components of live coral impacted the abundance of fish populations and other organisms (Wilson et al. 2006). Fish inhabiting coral reefs were divided into the target, major, and indicator groups. These three groups were severely affected by the health and conditions of live coral cover (Madduppa et al. 2012). The decline in fish's physiological and reproductive activities on coral reefs was strongly associated with the coral cover conditions. The loss of several types of corals or their death had an impact on the nature and behaviour of the reef fish (Pratchett et al. 2004). Even over a long period, the continuing decline in the percentage of live corals impacted reef fish populations, particularly their diversity and abundance (Wilson et al. 2006). Coremap (2011) obtained live coral cover on Sarappo Island, Indonesia, which ranged between 48-76%, and 58-78%. Environmental factors, such as waves, coral disease, and climatic change, influenced these conditions. The same research found that live coral cover on Lumulumu and Langkai Island was 50.52 and 63.22%, respectively. Furthermore, Anwar (2011) reported that the decline in fish stocks in the waters of Makassar was also due to the use of bombs, toxic materials, gears such as seine, cantrang, and trawl when carrying out the fishing activity. The reduction in live coral cover in the three research sites from the previous years was due to high-intensity and destructive fishing.

Based on visual observations at the study sites, there were 149 species of reef fish from 27 families. Especially for grouper fish, as many as 7 species were found, namely *Cephalopholis boenack*, *C. micropion*, *C. miniata*, *C. sonnerati*, *Epinephelus aerolatus*, *E. merra*, and *Plectropomus maculatus*. Most fish living on the coral reef highly depend on protection and feeding. Therefore the number of individuals, both in species and composition, was influenced by their environmental conditions. Studies showed a positive correlation between the reef topography and its distribution and abundance. The indicator that showed the existence of the fish in the waters was the presence of living coral reefs (Sudirman & Yusri 2008). The diversity differences of reef fish species were closely related to the substrate's complexity (McClanahan 1994). The death of coral reef communities changed their restocking process (Davis 2007). Jones et al. (2004) suggested that there was often a strong positive relationship between the coral cover and the reef fish abundance. It was further explained that 75% of reef fish depended on live corals for various needs,

including feeding, shelter, and hiding. The fish living on coral reefs varied in their dependence, ranging from single to multiple (Mundai 2004; Pratchett et al. 2004). However, the effect of reduced coral abundance did not have an impact on fish populations. Corals vary depending on the level of changes in their compositions and structure. Also, the severe and widespread reduction in live coral cover resulted in large-scale disturbance to reef communities, impacting a wide range of fish species and causing a marked decrement in diversity (Wilson et al. 2006).

The spatial distribution of various reef fish was related to the condition of the bottom substrate. One of the causes of reef fish diversity was their habitat variation, as they were made up of coral, sand, bays, crannies, and algae meadows (Russel 1996). The habitat diversity explained the increased number of reef fish (Kasmi 2012), and their different environments influenced their variation (Maharbhakti 2009). The increased fish diversity, as well as the decline in coral cover, was a result of an increase in the heterogeneity of their habitat. Therefore, the reef, with a moderate level of coral cover, was due to the diverse mix of fish living on them compared to the sub-stratum-rock. However, the loss of coral (>60%) caused the decline in diversity due to the inability to compensate for the local extinction. However, there were some examples where a decrease in live coral cover disproportionately affects the local diversity of fish (Pratchett et al. 2011). The existence of coral cover was an important habitat for the different fish species since most of their populations hold direct recruitment on the stony material. In addition, many fish have the same needs, creating active competition between different or the same species (Friedlandera & Parrish 1998).

CONCLUSION

The average percentage of live coral cover in Sarappo, Lumulumu, and Langkai Island were 43.17±18,0, 52.00±5.9, 45.67±19.6%, respectively. Therefore, they were classified into the moderate group. There were 149 reef fish species belonging to 66 genera and 27 families. Therefore, the condition of the coral reefs classified as moderate did not have an impact on the decline in reef fish species. Furthermore, their average number and populations were moderate and even high in the three research islands. Also, their abundance was moderate or even high compared to coral fish populations in other areas in Indonesia. Therefore, live coral cover was negatively correlated with fish diversity.

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مقاله کامل

همبستگی تراکم ماهی پوشش و صخره مرجانی در بزرگترین مجمع‌الجزایر واقع در مرکز اندونزی

ارنانینگسه ارنانینگسه*[1]، دانیال سلطان[1]، اسبر اسبر[1]، بودیماوان بودیماوان[2]، معروف قاسیم[3]

[1]دانشکده شیلات و علوم دریایی، دانشگاه مسلمان اندونزی، ماکاسار، جنوب شرقی سولاوسی، اندونزی.

[2]دانشکده علوم دریایی و شیلات دانشگاه حسن الدین، پرینتیس کمردکان، ماکاسار، اندونزی.

[3]دانشکده شیلات و علوم دریایی، دانشگاه هالو اولئو، موکودومپیت، آندونوهو، کنداری، سولاوسی جنوب شرقی، اندونزی.

چکیده: پوشش مرجانی زنده، معیار نسبت سطح صخره‌ای است که به‌جای اسفنج‌ها، جلبک‌ها یا سایر موجودات زنده توسط مواد صخره‌ای زنده پوشیده شده است. این صخره‌های مرجان‌های حمایت‌کنندگان اصلی چارچوب ساختار سه‌بعدی صخره‌ها هستند که زیستگاه حیاتی را برای بسیاری از موجودات زنده فراهم می‌کند. از این‌رو، هدف این مطالعه تعیین رابطه بین تعداد پوشش زنده صخره‌های مرجانی و حضور ماهی‌ها در یکی از بزرگترین مجمع‌الجزایر واقع در مرکز اندونزی است. روش تحقیق مورد استفاده برای تعیین پوشش زنده مرجانی، برش عرضی نقطه‌ای بود، در حالی که جمعیت ماهیان با استفاده از تکنیک شمارشی اندازه‌گیری شد. نتایج نشان داد که میانگین درصد پوشش زنده مرجانی در تمامی ایستگاه‌ها شامل ساراپو، لومولومو و جزیره لانگکای به‌ترتیب ۴۳/۱۷، ۵۲، ۴۵/۶۷ درصد بوده و به دو دسته متوسط و خوب طبقه‌بندی می‌شوند. در این بررسی، ۱۴۹ گونه ماهی صخره‌ای در ۲۷ خانواده در منطقه مورد مطالعه یافت شد. پوشش مرجانی با تنوع گونه‌ای و فراوانی ماهی‌های صخره‌های مرجانی در مجمع‌الجزایر اندونزی همبستگی منفی داشت.

کلمات‌کلیدی: پوشش مرجانی زنده، تنوع زیستی، فراوانی، مجمع‌الجزایر.