

Community Structure of Coral Reef Ecosystem in Senoro-Toili Block

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Abstract. Research on coral reef biodiversity within oil and gas operational areas remains limited, as most previous studies have focused on coastal ecosystems adjacent to urban environments. This study aims to assess coral reef condition and reef fish community structure in the Senoro–Toili Block, as well as to examine the relationship between coral cover and reef fish abundance. Field data were collected using Manta Tow and Line Intercept Transect (LIT) methods for coral reef conditions, while reef fish data were obtained through the Underwater Visual Census (UVC) method. Coral reef observations included percentages of live hard coral, dead coral, algae, and abiotic substrates. Fish data comprised species composition and abundance, which were analyzed at the family level. The relationship between reef fish abundance and live coral cover was tested using Pearson correlation analysis. The study results indicated that dead corals dominated the Senoro-Toili Block coral community, ranging from 17.62 to 52.68%. Evaluation of coral reef conditions shows moderate to high levels of damage with a high mortality index, indicating that the health of the reef is significantly compromised and may negatively impact the associated reef fish populations. The reef fish community is composed of 195 species, which constitute 37 families. The abundance of reef fish ranges from 1605 to 3105 individuals/500 m². The Pearson statistics showed a correlation between the abundance of reef fish and the percentage of coral cover ($p < 0.05$). The diversity index was high, and the evenness index showed that the fish community was stable. This was backed up by a low dominance index. These conditions indicated that the reef fish community in the Senoro–Toili Block exhibits a relatively high level of ecological resilience in response to both natural and anthropogenic disturbances. These results highlight the necessity of continuous management interventions, especially coral transplantation initiatives executed in the study region.

Keywords: biodiversity, coral cover, reef fish

INTRODUCTION

Coral reefs as ecosystems with high biodiversity and primary productivity (Eviota et al., 2021; Iskandar et al., 2021), are currently facing severe threats both locally and globally (Brandl et al., 2019; Hoegh-Guldberg et al., 2019). The consequences of the coral reef's declining conditions

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are not only ecological but also economical due to the vast number of people's livelihoods that depend on this ecosystem (Morais et al., 2020; Morais & Bellwood, 2020) and in turns, it could affect food security.

Indonesia is located in the center of the coral reef triangle, making it the country with the highest coral diversity globally ~ 590 coral species (Purnomo, 2020). However, this condition is not in line with its coral reef conditions. Only 6.56% of coral reefs are in very good condition, 22.96% are good, 34.3% are sufficient, while 36.18% are categorized as poor (Hadi et al., 2018). Human activities such as mining and industries cause pollution (Maaty et al., 2021), which includes sedimentation (Limmon & Marasabessy, 2019), illegal fishing (Pelasula et al., 2021), and the high load of marine debris (de Carvalho-Souza et al., 2018), which all are triggers for the coral damage.

The damage to the reef ecosystems affects coral-associated fish diversity (Adrim et al., 2012; Harahap et al., 2019) because coral reef health and reef fish biodiversity are closely related. In healthy coral reef conditions, fish abundance is high; conversely, in a damaged coral reef condition, fish abundance is relatively low (Adiyoga et al., 2020; Edrus & Hadi, 2020). Furthermore, Hastuty et al. (2014) stated that healthy coral reef ecosystems support sustainable fishing activities because they provide suitable habitats for reef fish to lay eggs, forage, and nursery grounds for growth (Sektiana et al., 2022).

Central Sulawesi Province has a water area of 77,295.90 km² with a coastline of 6,653 km, and its coral reef ecosystem area consists of 187,766.71 Ha (Kementerian Kelautan dan Perikanan, 2018). In addition to the fisheries potential, Central Sulawesi waters also contain oil and gas reserves in the Senoro-Toili oil and gas block (Mansyur et al., 2019; Tis'in & Mansyur, 2016). The management of areas with overlapped fishery and oil and gas mining is highly challenging. Oil and gas exploration is a real threat to the sustainability of coral ecosystems (Maaty et al., 2021). Furthermore, Maaty et al. (2021) also stated that oil pollution in waters reduced the abundance of reef fish.

Currently, research on the biodiversity of coral reef ecosystems in oil and gas blocks has not been widely reported in the scientific literature. Studies conducted during the 2023–2025 period generally focused more on coastal areas adjacent to centers of human activity or urban areas, such as marine tourism areas (Prihadi et al., 2025), densely populated coastal zones (Putra, 2022), and conservation areas that have long served as sites for ecological monitoring (Shaadikin et al., 2025). Consequently, scientific information regarding the condition, species composition, and dynamics of coral reef ecosystems in marine areas associated with the oil and gas industry remains relatively scarce. This situation indicates a significant knowledge gap that needs to be addressed, particularly in understanding how the characteristics of coral reef ecosystems develop in marine areas managed by the extractive industry yet still possess ecological value. Based on these conditions, this study aims to evaluate the community structure of coral reef ecosystems through an analysis of coral cover percentage and reef fish diversity as indicators of coral reef ecosystem health in the Senoro-Toili oil and gas block area.

MATERIALS AND METHODS

The research was conducted in November 2022 in the Senoro-Toili oil and gas block. Three stations were established for observation which include: station TK-01 (Gosong Tiaka, 01° 50'

02.8" LS, 121° 59' 11.1" BT), station TK-02 (Gosong Tiaka, 01°50' 11.0" LS, 121° 59' 06.2" BT), and station TK-03 (Makakata Beach, 01° 17' 50.2" LS, 122° 33' 58.1" BT) (Figure 1). Gosong Tiaka is administratively part of North Morowali Regency and is located in the waters of Tolo Bay. Geographically, this location is about 12 nautical miles from the nearest mainland. Makakata Beach is administratively located in Sisipan Village, Batui District, Banggai Regency, Central Sulawesi. The stations represent the general condition of the coral reef ecosystem in the Senoro-Toili oil and gas block. At all three stations, there are also coral reef rehabilitation programs initiated by JOB Pertamina-Medco E&P Tomori Sulawesi (JOB Tomori), the operator of the Senoro-Toili oil and gas block.

Coral Cover Data Collection

A combination of Manta Tow survey (as a preliminary survey) and Line Intercept Transect (LIT) (English et al., 1997; Gomez & Yap, 1998) were employed to collect data on coral reef conditions. The transect was laid along 100 m at a depth of six to eight meters. The percentage of living hard coral cover was used to assess coral reef conditions and to enable the determination of the mortality index. Data were recorded on a data sheet and were categorized following English et al. (1994) the criteria.

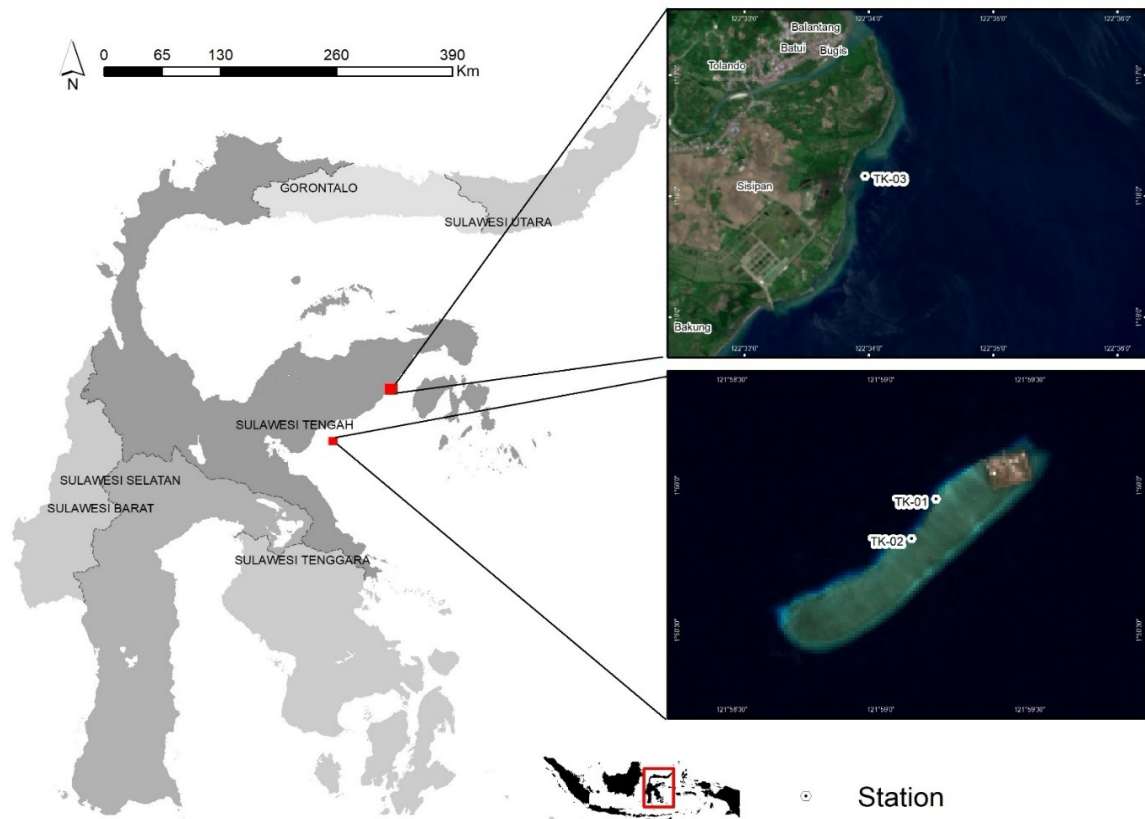


Figure 1. Research location in the Senoro-Toili Block

Reef Fish Data Collection

Reef fish data collection was carried out using the Underwater Visual Census (UVC) method

to assess the diversity index (H'), evenness index (E) and Dominance Index (D) at each station (Bürge et al., 2025). Reef fish were observed after coral reef observations. Fish sighted were classified based on fish groups (target, indicator, and significant), species, and the number of individual fish. The reef fish survey was carried out according to the following procedures (Farhana-Azmi et al., 2022): (i) installation of a 100 m transect which were adjusted to the coral reef observation's transect, and the observation was carried out simultaneously; (ii) census along the transect using SCUBA equipment were carried out alongside the LIT taking an area of observation of 2.5 meters to the left and right of the transect; (iii) identification of reef fish referring to Matsuda et al. (1984), Kuitert (1992), Lieske & Myers (1994) and Heemstra & Randall (1993).

Data Analysis

The percentage of coral cover was calculated using the following formula English et al. (1997):

$$N = \sum \frac{Li}{L} \times 100\%$$

Where N is percentage of coral cover (%), li is total length of the i th lifeform (cm), and L is total length of transect (cm). The data on coral reef cover conditions that were obtained were categorized as damaged (0 – 25%), moderate (26– 50%), good (51 – 75%), and very good (76 –100%). Index Coral mortality was calculated using the formula Gomez et al. (1994):

$$IM = \frac{DC}{DC + HC}$$

IM = mortality index, DC = dead coral cover, HC = living hard coral cover. Mortality index was categorized as low (0 – 0.24), moderate (0.25 – 0.49), high (0.50 – 0.74) and very high (0.75 - 100). The abundance of coral fish is calculated using the formula (Odum, 1971):

$$D = \frac{\text{number of individuals (Ind)}}{\text{observation area (m}^2\text{)}}$$

Ecological indices such as the Shannon-Weiner diversity index (H'), Pielou's evenness index (E), and the Dominance Simpson is calculated using the following formula Ludwig & Reynolds (1988) and Magurran (1998):

$$H' = \sum_{i=1}^s p_i \ln p_i$$

$$E = \frac{H'}{H_{\max}}$$

$$D = \sum_{i=1}^s (p_i^2)$$

H' = Shannon -Weiner diversity index, E = evenness index, D = Simpson dominance index, S = number of fish species, P_i = proportion of abundance of individuals of one i -th species (n_i/N), n_i = number of individuals of each type, N = total number, $H_{\max} = \ln S$.

The criteria for Shannon-Wiener diversity values are: (1) $H' < 1.0$: low diversity ; $1.0 < H' < 3.0$: moderate diversity ; and $H' > 3.0$: high diversity. The criteria for evenness values are: (1) $0.00 < E < 0.50$: stressed community ; (2) $0.50 < E < 0.75$: unstable community ; and (3) $0.75 <$

$E < 1.00$: stable community; whilst the criteria for Simpson's dominance index are : (1) $0.00 < D < 0.50$: low dominance; (2) $0.50 < D < 0.75$: moderate dominance; and (3) $0.75 < D < 1.00$: high dominance.

To determine the relationship between the abundance of reef fish and the condition of live coral cover, a Pearson correlation test was conducted using SPSS 16 software. If the value is positive and significant, this indicates the crucial role of healthy coral reef ecosystems in supporting fish populations.

RESULTS AND DISCUSSION

The condition of coral reef cover in the waters of Senoro-Toili Block is dominated by dead corals with a range of 17.62 - 52.68%. The largest living coral cover was found at station TK-03 (41.76 %) and the lowest at station TK-01 (14.88 %) (Figure 2a). Based on these results, stations TK-01 and TK-02 were categorized as damaged, while station TK-03 was in the moderate category. The condition of the coral reefs at each station is further explained based on the coral mortality index. The indices for Stations TK-01 and TK-02 were 0.82 and 0.80, respectively, falling into high mortality criteria, while at station TK-03, the index was 0.36, which made it moderate (Figure 2b). The mortality index shows the rate of change of living corals degradation into dead corals. This change agrees with the high percentage of dead coral cover at Stations TK-01 and TK-02. The changes include dead corals overgrown by algae, newly dead corals whose colors were bright white, and coral rubbles.

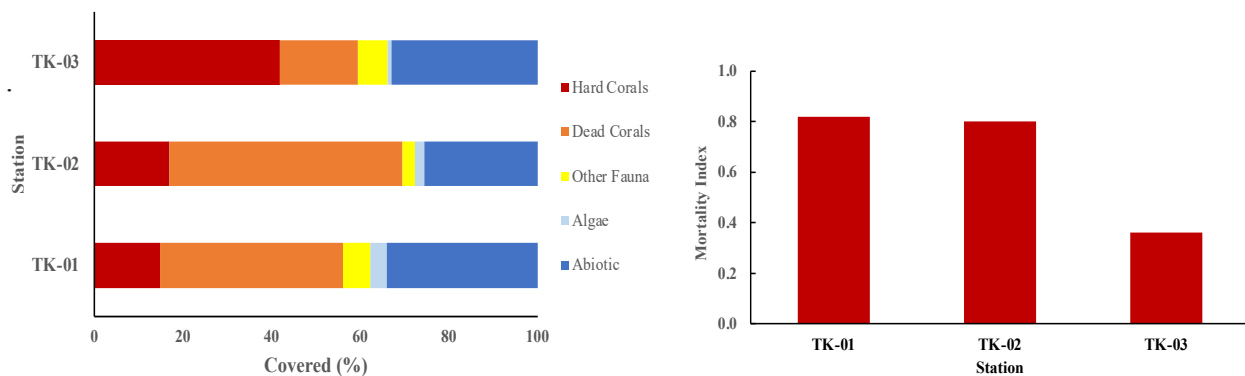


Figure 2. a. coral reef cover; b. mortality index

A total of 195 reef fish species belonging to 37 families were successfully identified across the three sampling stations (Table 1). The top four most abundant families are Pomacentridae (36), Scaridae (13), Acanthuridae (13), Chaetodontidae (12), and Serranidae (11) (Table 1). The abundance of reef fish ranged between 1,605 - 3,105 individuals/500 m², approximately 3 individuals/m² (Figure 3a). The composition of reef fish varies at each research station with the same trend, i.e., major groups dominate the communities (1,301 – 2,381 individuals/500 m²), the largest group found on all reef fish communities (79% of the total abundance). The target fish group contributes an average of 467 individuals/500 m² to the reef fish community (20% of the total abundance), while the indicator fish group is seen at an average of 27 individuals/500 m² (1% of the total abundance) (Figure 3b). The Pearson Bivariate correlation analysis results showed a correlation

between the abundance of reef fish and the percentage of coral cover (p -value<0.05; $r = 0.96$).

The Shannon-Wiener index of reef fish in the Senoro-Toili block shows high diversity ($H' = 4.097 - 4.586$) (Table 2). The evenness index indicates that the reef fish community is generally stable ($E = 0.871 - 0.875$). This value is also supported by the low index of dominance ($D = 0.015 - 0.022$). In other words, the reef fish community in the Senoro-Toili Block is a stable population, i.e., the community is not easily stressed when facing natural or anthropogenic disturbances. Also, the community is not under pressure due to the dominance of a particular species. This is indicated by the highly diverse reef fish, even though the corals are damaged.

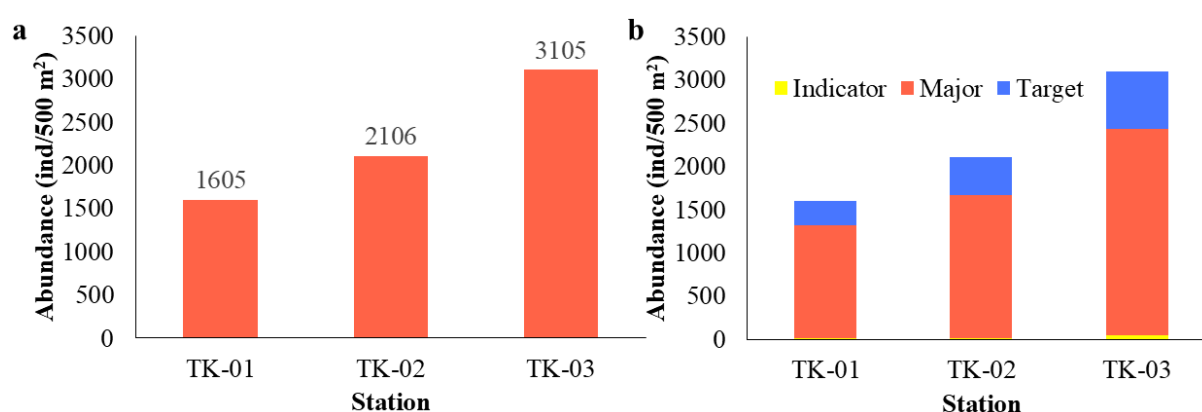


Figure 3. a. Abundance of reef fish; b. Abundance of target fish, indicator fish, and major fish

In general, the damage occurring in the Senoro-Toili Block is unrelated to the Tiaka Oil Field because, since 2016, this oil field was temporary shut in. Coral conditions in the Senoro Gas Field (station TK-03) is still categorized as moderate. This is supported by water quality data that still exceeds the environmental standards (Kasim Mansyur, unpublished data, 2021). Meanwhile, coral reef damage at stations TK-01 and TK-02 (Gosong Tiaka) was caused by two factors i.e., anthropogenic and natural factors (Mansyur et al., 2019). The anthropogenic impact is due to the arbitrary use of boat anchors by fishermen operating in the Gosong Tiaka, and the natural impact is caused by the coral predators, particularly the Crown of Thorns Starfish (COTS) (Kasim Mansyur, unpublished data, 2021).

The use of conventional anchors by fishing vessels and boats in the coral reef area has increased since the implementation of the temporary shut-in at the Tiaka Field. The frequency of fishing activities in the coral reef area has been observed to be quite high; however, patrol and surveillance efforts by security personnel previously assigned to the Tiaka Field have practically ceased since that period. According to Arafat et al. (2013) the percentage of coral reef damage due to anchorage in coral reef areas can reach 269.1 m²/year. The use of anchors in coral reef areas also results in a reduction in the reef fish abundance by up to 50% (Flynn & Forrester, 2019), detachments of coral colonies from their substrates, and structural coral damage, especially those in branching lifeforms (Giglio et al., 2017). In addition, researchers believe that blast fishing also contributes to the reef damage. This is proven by the many abiotic components in the form of dead coral fragments (rubble) found at all stations. According to Rizal et al. (2021), the presence of coral fragments and seafloor that form craters between coral reefs is an indication that the area has been exposed to explosives (Hamuna et al., 2019).

COTS outbreak also triggers the coral reef damage in Gosong Tiaka (Mansyur, unpublished data, 2021). Mansyur et al.

Table 1. Diversity of reef fish (families and number of species)

No	Family	Number of Species		
		TK-01	TK-02	TK-03
1	Chaetodontidae	4	5	12
2	Apogonidae	5	7	9
3	Aulostomidae	-	-	1
4	Balistidae	3	4	6
5	Belonidae	-	-	1
6	Blenniidae	1	1	3
7	Cirrhitidae	2	3	3
8	Dasyatidae	-	-	1
9	Diodontidae	-	1	2
10	Fistularidae	-	-	1
11	Gobiidae	4	4	6
12	Holocentridae	4	5	5
13	Labrididae	8	7	9
14	Malacanthidae	-	-	1
15	Microdesmidae	2	3	3
16	Monacanthidae	1	1	1
17	Mullidae	2	3	5
18	Pempheridae	-	-	1
19	Pinguipedidae	1	1	2
20	Pomacanthidae	2	4	8
21	Pomacentridae	29	30	36
22	Pseudochromidae	-	-	4
23	Scaridae	4	4	13
24	Scorpaenidae	1	-	3
25	Syngnathidae	-	-	1
26	Synodontidae	1	1	1
27	Tetraodontidae	2	1	2
28	Acanthuridae	10	11	13
29	Caesionidae	1	2	3
30	Carangidae	-	-	1
31	Haemulidae	-	1	3
32	Kyphosidae	-	1	-
33	Lethrinidae	6	6	6
34	Lutjanidae	4	5	7
35	Nemipteridae	3	4	4
36	Siganidae	1	1	3
37	Serranidae	4	5	11
∑ Family		25	27	36
∑ Species		105	121	191

data, 2021). In general, COTS prefer coral reef areas with high coral cover, while juvenile COTS prefer protected places by hiding under coral boulders or coral fragments (Moran, 1990). The coral types whose mortality was highest due to COTS population explosions are *Acropora*, *Pocillopora*, and *Porites* (Kayal et al., 2011). Coral reef damage due to COTS predation (Kroon et al., 2021) is one of the most serious problems in coral reef conservation (Kayal et al., 2012). In some waters, COTS could eliminate half of the living coral population (Plass-Johnson et al., 2015). According to Moran (1990), an adult COTS individual can prey on 5 - 6 m² of coral colonies/year. COTS will cause no harm to a coral community if the population size is normal. Under this normal condition, COTS helps to maintain ecological balance in the ecosystem. The natural population size of COTS under normal conditions is less than 14 individuals/1000 m². Corals are threatened if the population is more than 14 individuals/1000 m² (Fahreza et al., 2013). Information on the abundance of COTS in Gosong Tiaka was reported by Syakir et al. (2015), where in 2017 and 2018, the fishermen group managed to lift 1160 and 1278 COTS individuals, respectively. Therefore, the high COTS population has caused the decline in coral reef conditions in Gosong Tiaka.

Table 2. Ecological indices of coral reefs

Ecological Index	Station			Category
	TK-01	TK-02	TK-03	
Diversity Index (H)	4.097	4.197	4.586	High
Evenness Index (E)	0.880	0.875	0.871	Stable
Dominance Index (D)	0.022	0.020	0.015	Low

COTS is a coral predator (Kamya et al., 2014; Putra et al., 2022), but that does not mean that the animal does not have predators for itself. Natural predators of COTS are fish from the *Lethrinidae*, *Lutjanidae*, *Serranidae*, and *Labridae* families, more specifically, the species *Lethrinus miniatus*, *L. nebulosus*, *Plectropomus* spp., and *Variola* spp. (Kroon et al., 2021). Due to intensive and environmentally harming fishing activities, these species that are identified as target fish are rarely found in the Senoro-Toili Block. The decline in the target fish population is assumed to be a factor causing the uncontrolled abundance of COTS. Therefore, controlling natural COTS predators by regulating fishing activities of economically important fish from the *Lethrinidae*, *Lutjanidae*, *Serranidae* and *Labridae* families is necessary.

In general, major fish, target fish for consumption, and indicator fish are present in an unusual composition, namely 79% major group, 20% target group, and 1% indicator group (Figure 3), while the composition found in healthy coral reef areas has a major ratio composition of 55%, 34% target, and 11% indicator (Lelloltery et al., 2018). The change in the fish composition is a response to the declining condition of coral cover. Reef fish have a close relationship with coral reefs as their habitat, i.e., if the percentage of dead coral is high, the number of species and individuals will be low (Madduppa et al., 2012; Sukandar et al., 2022; Tony et al., 2021). Changes in the structure of the reef fish community can also caused by global warming and overfishing (Samoilys et al., 2022).

Interestingly, in this study, many herbivorous fish from the *Acanthuridae*, *Scaridae*, and *Siganidae* families were found at station TK-03, which correlated with the low algae cover at the station (0.86%, Figure 2a). The *Acanthuridae*, *Scaridae*, and *Siganidae* families play an important

role in coral recruitment because their herbivorous diet changes the coral surface by peeling off algae to provide a place for new coral larvae to attach (Afandy et al., 2019; Madduppa et al., 2020). Algae are the main competitors of planula (cnidarians larvae) in competing for the substrate, the algae clearance by herbivorous fish allows planula to attach to the substrate (El-Haddad et al., 2022). The grazing activities of the three families of fish is thought to be the reason for the better condition of living coral that cover station TK-03 compared to stations TK-01 and TK-02.

Overall, reef fish in the Senoro-Toili Block are dominated by Pomacentridae, categorized as major fish group. Pomacentridae are the most abundant and are resident fish that exhibit territorial behavior. They rarely wander far from food sources and shelters (Farghal et al., 2021). The most crucial criterion in measuring the health of coral reefs in the Senoro-Toili Block is the presence of indicator fish (Iskandar et al., 2021) from the Chaetodontidae family. The existence of these fish is an indication that there has been a decline in coral conditions at stations TK-01 and TK-02 because these fish respond quickly to changes in coral substrate cover and have distinctive feeding behavior patterns; they are opportunistic omnivores and corallivores (coral polyp eaters) (Sektiana et al., 2022; Tony et al., 2020). The difference in the number of species in the Chaetodontidae family between stations TK-01 and TK-02 with TK-03 shows that the Chaetodontidae population at station TK-03 is growing due to the high live coral cover indicates the condition of the coral reefs in the area is better than the other two stations.

In population distribution statistics, the diversity of coral reef fish communities is related to the number of species present to form the community (Edrus & Hadi, 2020). In this study, H' fish species are classified as high, E as stable, and D as low. Stable E with low D indicates that the habitat provides equal opportunities for all populations to develop. This implies no dominant population in the coral reef fish community (Hamuna et al., 2022). These results indicate that the Senoro-Toili Block waters are a suitable habitat for coral reef fish.

Although the condition of live coral cover is poor, the metrics of diversity, evenness, and dominance of reef fish are good. These good metric values may be influenced by other factors, such as habitat connectivity, which enables the recruitment of reef fish from different populations (Faricha et al., 2020) to the waters of the Senoro-Toili Block. When compared to H' and E of reef fish in other areas on Sulawesi Island such as Wakatobi National Park (H' = 2.89 - 2.93; E = 0.71 - 0.72) (Yuliana et al., 2022) and Taka Bonerate National Park (H' = 2.95 - 3.33; E = 0.73 - 0.81) (Wulandari et al., 2022) then H' and E in the waters of the Senoro-Toili Block is better and this is correlated with a much higher number of species and families than the other two areas.

The description of the condition of the coral reef ecosystem in the waters of the Senoro-Toili Block shows worrying conditions at stations TK-01 and TK-02 because they are categorized as damaged. Efforts that can be taken to prevent further damage to the coral reef ecosystem in the Senoro-Toili Block are through a coral transplantation program. The three research stations are suitable for designated coral transplant areas because the coral conditions are categorized as damaged and moderate.

In addition, from a topographical perspective, the waters of the Senoro-Toili block are also suitable as a protected area because the West-Northwest side of Gosong Tiaka directly faces the mainland of Sulawesi which has a sloping water base and is relatively protected from the effects of the large waves. These waters also have several reef spots that can provide protection to shore by stabilizing the substrate on the seafloor during turbulence by currents and waves. The physicochemical parameters of the waters also show that the waters of the Senoro-Toili Block

can still support coral growth. The diversity of reef fish at the research location is also very high, indicating that the waters of the Senoro-Toili Block are suitable for the reef fish community. Therefore, rehabilitation of the coral reef ecosystem is vital to maintain the reef fish community in the area. However, monitoring the COTS population while rehabilitating the corals is essential.

CONCLUSION

The condition of coral reefs in the waters of the Senoro-Toili Block falls into the category of damaged and moderate, as indicated by the high number of incidents of living coral cover that turn to dead corals. On the other hand, the high diversity index and relatively stable evenness index of reef fish, supported by a low dominance index, indicate that the reef fish community has the same opportunity to develop and no dominant population exists. Through coral transplantation program, efforts can be taken to prevent further damage to the coral reef ecosystems. These efforts can also contribute to maintaining the existence of the reef fish community in the waters of the Senoro-Toili Block.

AUTHOR CONTRIBUTION

The contributions of each author included conceptualization, methodology, conducting the research, data analysis, and manuscript preparation. **K.M., A.R., M.T., and M.S.N.** contributed to conceptualization. **K.M., A.R., S.N.A., E.P.N., C.M., and A.H.S.** contributed to methodology. **K.M., A.R., M.T., and M.S.N.** conducted the research. **K.M., A.R., M.T., M.S.N., S.N.A., E.P.N., C.M., and A.H.S.** contributed to data analysis and writing the original draft of the manuscript.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES

- Adiyoga, D., Hartati, R., & Setyati, W. A. (2020). Fluktuasi Ikan Karang di Kawasan Konservasi Laut Daerah Gili Sulat dan Gili Lawang, Lombok Timur. *Journal of Marine Research*, 9(2), 175–180. DOI: <https://doi.org/10.14710/jmr.v9i2.26894>
- Adrim, M., Harahap, A. S., & Wibowo, K. (2012). Community Structure of Coral Reef Fishes at Kendari Waters Coral. *ILMU KELAUTAN: Indonesian Journal of Marine Sciences*, 17(3), 154–163. DOI: <https://doi.org/10.12912/27197050/190639>
- Afandy, Z., Damar, A., & Agus, S. B. (2019). Coral Recruitment Spatial Distribution in its Relation With Coral Cover and Herbivorous Fish Abundance Within Conservation Area. *ILMU KELAUTAN: Indonesian Journal of Marine Sciences*, 24(2), 91. DOI: <https://doi.org/10.14710/ik.ijms.24.2.91-98>

- Arafat, Y., Gurning, R. O. S., & Pitana, T. (2013). Penilaian Risiko Labuh Jangkar Kapal Terhadap Kerusakan Terumbu Karang Dengan Simulasi Monte Carlo di Wilayah Kepulauan Raja Ampat – Papua Barat. Seminar Nasional Pascasarjana XI – ITS.
- Brandl, S. J., Rasher, D. B., Côté, I. M., Casey, J. M., Darling, E. S., Lefcheck, J. S., & Duffy, J. E. (2019). Coral reef ecosystem functioning: eight core processes and the role of biodiversity. *Frontiers in Ecology and the Environment*, 17(8), 445–454. DOI: <https://doi.org/10.1002/fee.2088>
- Bürigi, K., Bouveyron, C., Lingrand, D., Derijard, B., Precioso, F., & Sabourault, C. (2025). Towards a fully automated underwater census for fish assemblages in the Mediterranean Sea. *Ecological Informatics*, 85, 102959. DOI: <https://doi.org/10.1016/j.ecoinf.2024.102959>
- de Carvalho-Souza, G. F., Llope, M., Tinôco, M. S., Medeiros, D. V., Maia-Nogueira, R., & Sampaio, C. L. S. (2018). Marine litter disrupts ecological processes in reef systems. *Marine Pollution Bulletin*, 133, 464–471. DOI: <https://doi.org/10.1016/j.marpolbul.2018.05.049>
- Edrus, I. N., & Hadi, T. A. (2020). Struktur Komunitas Ikan Karang di Perairan Pesisir Kendari Sulawesi Tenggara. *Jurnal Penelitian Perikanan Indonesia*, 26(2), 59. DOI: <https://doi.org/10.15578/jppi.26.2.2020.59-73>
- El-Haddad, K. M., Mohammed, S. Z., Ali, A. H. A. M., Abdel-Rahman, M. S., & Temraz, T. A. (2022). Herbivorous Reef Fishes of South Sinai Marine Protected Areas (Gulf of Aqaba, Egypt): Influence of Fisheries Management and Protection Status. *Egyptian Journal of Aquatic Biology and Fisheries*, 26(5), 681–705. DOI: <https://doi.org/10.21608/ejabf.2022.264541>
- English, S., Wilkinson, C., & Baker, V. (1994). *Survey Manual for Tropical Marine Resources*. Australian Institute of Marine Science.
- English, S., Wilkinson, C., & Baker, V. (1997). *Survey Manual of Tropical Marine Resources*. 2nd Edition, Australian Institute Resources.
- Eviota, M. P., Cuadrado, J. T., & Adlaon, M. S. (2021). Species composition of coral reef fish in the nonoc island, philippines. *AACL Bioflux*, 14(5), 2820–2825.
- Fahreza, A. D., Purnomo, P. W., & Hendarto, B. (2013). Kelimpahan Serta Predasi *Acanthaster planci* di Perairan Tanjung Kelayang Kabupaten Belitung. *Management of Aquatic Resources Journal*, 2(3), 212–218. DOI: <https://doi.org/10.14710/marj.v2i3.4217>
- Farghal, T. K., Zaid, M. M. A., & Fouda, M. M. (2021). Abundance, diversity and distribution of coral reef fish families in the Egyptian Red Sea, at Hurghada, Egypt. *Egyptian Journal of Aquatic Biology and Fisheries*, 25(1), 541–554. DOI: <https://doi.org/10.21608/EJABF.2021.147328>
- Farhana-Azmi, N., Manjaji-Matsumoto, B. M., Maidin, N., John, J., Bavoh, E., & Saleh, E. (2022). Checklist of coral reef fishes of Darvel Bay, Sabah, Malaysian Coral Triangle, with a note on the biodiversity and community structure. *Biodiversity Data Journal*, 10: e79201. 1-24. DOI: <https://doi.org/10.3897/BDJ.10.e79201>
- Faricha, A., Edrus, I. N., Utama, R. S., Dzumalex, A. R., Salatalohi, A., & Prayuda, B. (2020). Hubungan Antara Komposisi Ikan Target dan Presentase Tutupan Karang Hidup di Kepulauan Kei Kecil, Maluku. *Jurnal Penelitian Perikanan Indonesia*, 26(3), 147–157. DOI: <https://doi.org/10.15578/jppi.26.3.2020.147-157>
- Flynn, R. L., & Forrester, G. E. (2019). Boat anchoring contributes substantially to coral reef degradation in the British Virgin Islands. *PeerJ*, 7, e7010. DOI: <https://doi.org/10.7717/peerj.7010>

- Giglio, V. J., Ternes, M. L. F., Mendes, T. C., Cordeiro, C. A. M. M., & Ferreira, C. E. L. (2017). Anchoring damages to benthic organisms in a subtropical scuba dive hotspot. *Journal of Coastal Conservation*, 21(2), 311–316. DOI: <https://doi.org/10.1007/s11852-017-0507-7>
- Gomez, E. D., Aliño, P. M., Yap, H. T., & Licuanan, W. Y. (1994). A review of the status of Philippine reefs. *Marine Pollution Bulletin*, 29(1–3), 62–68. DOI: [https://doi.org/10.1016/0025-326X\(94\)90427-8](https://doi.org/10.1016/0025-326X(94)90427-8)
- Gomez, E. D., & Yap, H. T. (1998). *Monitoring Reef Condition*. In *Coral Reef Management Hand Book*. UNESCO, Regional Office for Science and Technology for South East Asia.
- Hadi, T. A., Giyanto, G., Prayudha, B., Hafizt, M., Budiyanoto, A., & Suharsono, S. (2018). *Status Terumbu Karang Indonesia 2018*. Pusat Penelitian Oseanografi – Lembaga Ilmu Pengetahuan Indonesia.
- Hamuna, B., Dimara, L., & Alianto, A. (2022). Reef Fish Diversity in Jayapura City, Indonesia: A Preliminary Study. *Journal of Tropical Biodiversity and Biotechnology*, 7(3), 73094. DOI: <https://doi.org/10.22146/jtbb.73094>
- Hamuna, B., Kalor, J. D., & Rachmadani, A. I. (2019). Assessing the Condition of Coral Reefs and the Indicator Fish (Family: Chaetodontidae) in Coastal Waters of Jayapura City, Papua Province, Indonesia. *European Journal of Ecology*, 5(2), 126–132. DOI: <https://doi.org/10.2478/eje-2019-0020>
- Harahap, Z. A., Gea, Y. H., & Susetya, I. E. (2019). Relationship between coral reef ecosystem and coral fish communities in Unggeh Island Central Tapanuli Regency. *IOP Conference Series: Earth and Environmental Science*, 260, 012113. DOI: <https://doi.org/10.1088/1755-1315/260/1/012113>
- Hastuty, R., Yonvitner, Y., & Adrianto, L. (2014). Tutupan karang dan komposisi ikan karang didalam dan luar kawasan konservasi pesisir timur Pulau Weh, Sabang. *Depik*, 3(2), 99–107. DOI: <https://doi.org/10.13170/depik.3.2.1468>
- Heemstra, P. ., & Randall, J. (1993). *FAO Species Catalogue. Vol. 16. Groupers of the world (family Serranidae, subfamily Epinephelinae). An annotated and illustrated catalogue of the grouper, rockcod, hind, coral grouper and lyretail species known to date*. Food and Agriculture Organization of the United Nations.
- Hoegh-Guldberg, O., Pendleton, L., & Kaup, A. (2019). People and the changing nature of coral reefs. *Regional Studies in Marine Science*, 30, 100699. DOI: <https://doi.org/10.1016/j.rsma.2019.100699>
- Iskandar, R., Soemarno, S., Kusuma, Z., & Wiadnya, D. G. R. (2021). Association between Coral Community Coverage with Coral Reef Fish Communities at Samber Gelap Island, South Kalimantan, Indonesia. *Egyptian Journal of Aquatic Biology and Fisheries*, 25(3), 861–881. DOI: <https://doi.org/10.21608/ejabf.2021.182968>
- Kamya, P. Z., Dworjanyn, S. A., Hardy, N., Mos, B., Uthicke, S., & Byrne, M. (2014). Larvae of the coral eating crown-of-thorns starfish, *Acanthaster planci* in a warmer-high CO₂ ocean. *Global Change Biology*, 20(11), 3365–3376. DOI: <https://doi.org/10.1111/gcb.12530>
- Kayal, M., Lenihan, H. S., Pau, C., Penin, L., & Adjeroud, M. (2011). Associational refuges among corals mediate impacts of a crown-of-thorns starfish *Acanthaster planci* outbreak. *Coral Reefs*, 30(3), 827–837. DOI: <https://doi.org/10.1007/s00338-011-0763-1>
- Kayal, M., Vercelloni, J., Lison de Loma, T., Bosserelle, P., Chancerelle, Y., Geoffroy, S.,

- Stievenart, C., Michonneau, F., Penin, L., Planes, S., & Adjeroud, M. (2012). Predator Crown-of-Thorns Starfish (*Acanthaster planci*) Outbreak, Mass Mortality of Corals, and Cascading Effects on Reef Fish and Benthic Communities. *PLoS ONE*, 7(10), e47363. DOI: <https://doi.org/10.1371/journal.pone.0047363>
- Kementerian Kelautan dan Perikanan. (2018). Potensi Usaha dan Peluang Investasi Kelautan dan Perikanan Povinsi Sulawesi Tengah.
- Kroon, F. J., Barneche, D. R., & Emslie, M. J. (2021). Fish predators control outbreaks of Crown-of-Thorns Starfish. *Nature Communications*, 12, 6986. DOI: <https://doi.org/10.1038/s41467-021-26786-8>
- Kuiter, R. H. (1992). *Tropical reef-fishes of the western Pacific Indonesia and adjacent waters*. Gramedia Pustaka Utama.
- Lelloltery, H., Pudyatmoko, S., Fandelli, C., & Baiquni, M. (2018). Study of coral reef for marine ecotourism development based on region suitability and carrying capacity in Marsegu Island Nature Tourism Park, Maluku, Indonesia. *Biodiversitas Journal of Biological Diversity*, 19(3), 1089–1096. DOI: <https://doi.org/10.13057/biodiv/d190342>
- Lieske, E., & Myers, R. (1994). *Coral Reef Fishes*. Collins Pocket Guide Haper Collins Publishers.
- Limmon, G. V., & Marasabessy, A. M. (2019). Impacts of sedimentation on coral reefs in Inner Ambon Bay, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 339(1), 012035. DOI: <https://doi.org/10.1088/1755-1315/339/1/012035>
- Ludwig, J. A., & Reynolds, J. F. (1988). *Statistical Ecology: A Primer on Methods and Computing*. Wiley-Interscience Pub.
- Maaty, M. M., Azab, A. M., & Desouky, M. G. (2021). Distribution, abundance and diversity of reef fishes in waters of some cities along the northern Egyptian Red Sea coast, Egypt. *Egyptian Journal of Aquatic Biology & Fisheries*, 25(5), 901–918. www.ajas.uoanbar.edu.iq
- Madduppa, H. H., Farhan, A. R., & Suhendra, D. (2012). Fish biodiversity in coral reefs and lagoon at the Maratua Island, East Kalimantan. *Biodiversitas Journal of Biological Diversity*, 13(3), 145–150. DOI: <https://doi.org/10.13057/biodiv/d130308>
- Madduppa, H. H., Koropitan, A. F., Damar, A., Subhan, B., Taufik, M., Minsaris, L. O. A., Taurusman, A. A., Ramli, A., & Purwanto, A. B. (2020). Ecological Vulnerability of Coral Reef Ecosystem in Wakatobi National Park During Indian Ocean Dipole Event. *HAYATI Journal of Biosciences*, 27(1), 57–70. DOI: <https://doi.org/10.4308/hjb.27.1.57>
- Magurran, A. E. (1998). *Ecological Diversity and Its Measurement*. Princeton University Press.
- Mansyur, K., Rizal, A., Tis'in, M., Saleh Nurdin, M., & Susanti, N. (2019). Pertumbuhan dan Sintasan Karang Hasil Transplantasi di Lapangan Minyak Tiaka, Teluk Tolo, Sulawesi Tengah. *Prosiding Simposium Nasional Kelautan dan Perikanan VI*, 167–176.
- Matsuda, H., Amaoka, K., Araga, C., Uyeno, T., & Yoshino, T. (1984). *The Fishes of the Japanese Archipelago*. Tokai University Press.
- Morais, R. A., & Bellwood, D. R. (2020). Principles for estimating fish productivity on coral reefs. *Coral Reefs*, 39(5), 1221–1231. DOI: <https://doi.org/10.1007/s00338-020-01969-9>
- Morais, R. A., Connolly, S. R., & Bellwood, D. R. (2020). Human exploitation shapes productivity–biomass relationships on coral reefs. *Global Change Biology*, 26(3), 1295–1305. DOI: <https://doi.org/10.1111/gcb.14941>
- Moran, P. J. (1990). *Acanthaster planci* (L.): biographical data. *Coral Reefs*, 9(3), 95–96. DOI:

<https://doi.org/10.1007/BF00258218>

- Odum, E. P. (1971). *Fundamentals of Ecology (Third Edition)*. W.B. Saunders Co.
- Pelasula, D. D., Alik, R., Ruli, F., Hukum, F. D., La Pay, & Hehuat, J. (2021). A coral reef health study and its problem in Leti, Moa and Wetar Island, Mollucas Province. *IOP Conference Series: Earth and Environmental Science*, 777(1), 012003. DOI: <https://doi.org/10.1088/1755-1315/777/1/012003>
- Plass-Johnson, J. G., Schwieder, H., Heiden, J., Weiland, L., Wild, C., Jompa, J., Ferse, S. C. A., & Teichberg, M. (2015). A recent outbreak of crown-of-thorns starfish (*Acanthaster planci*) in the Spermonde Archipelago, Indonesia. *Regional Environmental Change*, 15(6), 1157–1162. DOI: <https://doi.org/10.1007/s10113-015-0821-2>
- Prihadi, D. J., Harahap, S. A., Parasibu, B., Pamungkas, W., & Simbolon, F. Y. (2025). Exploring Coral Reef Distribution and Health at Post 1, West Bali National Park. *Egyptian Journal of Aquatic Biology and Fisheries*, 29(3), 1–9. DOI: <https://doi.org/10.21608/ejabf.2025.425696>
- Purnomo, T. (2020). Biodiversity and Existing Condition of Coral Reef Ecosystem in Kondang Merak Beach Malang. *Advances in Computer Science Research*, 95, 28–33. DOI: <https://doi.org/10.2991/miseic-19.2019.7>
- Putra, R. D., Abrar, M., Siringoringo, R. M., Purnamsari, N. W., Agustina, P., & Islam, M. J. (2022). Marine Biodiversity of Coral Reef Fishes in Pieh Marine Recreational Park After Bleaching and *Acanthaster* Outbreaks. *Jurnal Ilmiah Perikanan dan Kelautan*, 14(1), 48–70. DOI: <https://doi.org/10.20473/jipk.v14i1.30133>
- Putra, S. A. (2022). The essentiality of coral reef ecosystems in urban areas. *Jurnal Oase Nusantara*, 1(2), 105. Retrieved from <https://ejurnal.kptk.or.id/oase/article/view/17>
- Rizal, A., Siagian, H., & Farahdita, W. (2021). Sebaran dan Kondisi Terumbu Karang di Kepulauan Kangean. *Jurnal Kelautan Nasional*, 16(3), 235–246. DOI: <https://doi.org/10.15578/jkn.v16i3.9890>
- Samoilys, M., Alvarez-Filip, L., Myers, R., & Chabanet, P. (2022). Diversity of Coral Reef Fishes in the Western Indian Ocean: Implications for Conservation. *Diversity*, 14(2), 102. DOI: <https://doi.org/10.3390/d14020102>
- Sektiana, S. P., Abdillah, A. A., Alam, M. J., Isoni, W., Dewi, N. N., Kim, H. W., & Andriyono, S. (2022). Diversity of the Tabuhan Island coral reef fish revealed by DNA barcoding and implication on conservation strategy in Banyuwangi, Indonesia. *Biodiversitas Journal of Biological Diversity*, 23(9), 4844–4851. DOI: <https://doi.org/10.13057/biodiv/d230953>
- Shaadikin, R., Hasan, R., & Ridwan, M. (2025). An Analysis of the Sustainability of the Coral Reef Ecosystem in the Marine Protected Areas Of Waetuno and Kabita Villages, Wakatobi Regency. *BHARASUMBA: Jurnal Multidisipliner*, 4(3), 225–244. DOI: <https://doi.org/10.62668/bharasumba.v4i03.1625>
- Sukandar, Samuel, P. D., Dewi, C. S. U., Pratiwi, I. D., Anam, M. C., Beno, J. E., & Fatmawati, R. (2022). Current status of the coral reef ecosystem in Gresik Regency, East Java. *AACL Bioflux*, 15(4), 1692–1702. <http://www.bioflux.com.ro/aacl>
- Syakir, M., Mansyur, K., Yusuf, S., Syam, D., & Aini, N. (2015). Pembelajaran Pengelolaan Terumbu Karang di Sekitar Lokasi Pengeboran Minyak dan Gas Lapangan Tiaka, Tomori Sulawesi Tengah. *Torani (Jurnal Ilmu Kelautan dan Perikanan)*, 25(2), 88–95. ISSN: 0853-4489

- Tis'in, M., & Mansyur, K. (2016). Studi Pendahuluan Kondisi Terumbu Karang Yang Memiliki Jarak Lokasi Berbeda Dari “Flare Produksi” Lapangan Minyak Tiaka. *Jurnal Agrisains*, 17(2), 78–84.
- Tony, F., Soemarno, S., Wiadnya, D. G. K., & Hakim, L. (2021). Habitat biodiversity as a determinant of fish community structure on coral reefs in Halang Melingkau Island, Kotabaru, South Kalimantan, Indonesia. *Egyptian Journal of Aquatic Biology and Fisheries*, 25(1), 351–370. DOI: <https://doi.org/10.21608/EJABF.2021.149758>
- Tony, F., Soemarno, S., Wiadnya, D. G. R., & Hakim, L. (2020). Diversity of reef fish in Halang Melingkau Island, South Kalimantan, Indonesia. *Biodiversitas Journal of Biological Diversity*, 21(10), 4804–4812. DOI: <https://doi.org/10.13057/biodiv/d211046>
- Wulandari, P., Sainal, S., Cholifatullah, F., Janwar, Z., Nasruddin, N., Setia, T. M., Soedharma, D., Praptiwi, R. A., & Sugardjito, J. (2022). The health status of coral reef ecosystem in Taka Bonerate, Kepulauan Selayar Biosphere Reserve, Indonesia. *Biodiversitas Journal of Biological Diversity*, 23(2), 721–732. DOI: <https://doi.org/10.13057/biodiv/d230217>
- Yuliana, E., Winata, A., Adimu, H. E., Hewindati, Y. T., & Djatmiko, W. A. (2022). Reef Fish in the Mudflats of Kaledupa Island in Wakatobi National Park, Indonesia. *HAYATI Journal of Biosciences*, 29(2), 245–254. DOI: <https://doi.org/10.4308/hjb.29.2.245-254>