TPM Vol. 32, No. 4, 2025
ISSN: 1972-6325
https://www.tpmap.org/

THE EFFECT OF BIOTIC AND ABIOTIC FACTORS ON THE DIVERSITY OF REEF FISH IN THE BATU ANJIR CORAL REEF ECOSYSTEM

FRANS TONY[1], RINA ISKANDAR[2], SUPANDI[3], YUDHA HADIYANTO EKO SAPUTRA[4], DWI PUTRI AGUSTINA[5]

[1] DEPARTMENT OF MARINE SCIENCE, FACULTY OF FISHERIES AND MARINE SCIENCE, LAMBUNG MANGKURAT UNIVERSITY, SOUTH KALIMANTAN, INDONESIA
[2] DEPARTMENT OF FISHERIES, FACULTY OF AGRICULTURE, ACHMAD YANI UNIVERSITY, BANJARMASIN, SOUTH KALIMANTAN, INDONESIA
[3] HSE DIVISION HEAD PT BORNEO INDOBARA, TANAH BUMBU REGENCY, INDONESIA
[4,5] ENVIRONMENTAL REHABILITATION & COMPLIANCE DEPARTMENT, PT. BORNEO INDOBARA, TANAH BUMBU REGENCY, INDONESIA

*Corresponding Author: Rina.oriens@gmail.com

Abstract
Coral reef ecosystems are important habitats for reef fish, whose existence is strongly influenced by the interaction of biotic and abiotic factors. Changes in environmental conditions such as temperature, salinity, and water quality, as well as food availability and interspecific competition, can determine the level of reef fish diversity. The purpose of this study was to analyze the influence of biotic and abiotic factors on the level of reef fish diversity in the Batu Anjir Coral Reef ecosystem, thus providing a basis for conservation efforts and sustainable management of marine resources. This study used qualitative methods by analyzing satellite imagery, water quality measurements, and marine biota surveys to assess the influence of biotic and abiotic factors on the Batu Anjir coral reef ecosystem. The results showed a significant decrease in live coral cover, water quality that largely met quality standards but with indications of mild pollution, and moderate reef fish diversity with the dominance of several species. PCA analysis confirmed that optimal physical-chemical environmental conditions play a significant role in supporting biota abundance, although other factors such as habitat complexity and human activities also influence. The results of the study indicate that the condition of the Batu Anjir coral reef ecosystem experienced a 33.88% decline in live coral cover between 2015, 2020, and 2025, shifting the ecosystem status to the "Moderate" category. Reef fish diversity is still classified as moderate, with a total of 40 species from 15 families (4,257 individuals), dominated by plankton-eating fish, invertebrates, and predatory fish. PCA analysis showed that most environmental factors, such as pH, DO, salinity, brightness, and depth, were positively related to fish diversity, while current speed contributed negatively.
Keywords: Abiotic, Biotic, Reef fish, Diversity, Coral reefs

1. INTRODUCTION

Coral reef ecosystems are among the most complex and biodiverse marine ecosystems. Coral reefs not only serve as primary habitats for reef fish but also play a crucial role in maintaining the balance of the marine ecosystem. Reef fish themselves perform various ecological roles, including herbivores that control algae growth, carnivores that maintain the food chain, and planktivores that contribute to the ocean's energy cycle. This complexity demonstrates that the existence of reef fish is significantly influenced by the environmental conditions in which they live (Nabilla & Anggriyani, 2024).
Biotic factors, such as food availability, interspecific interactions, and live coral cover, significantly influence the abundance and diversity of reef fish. For example, corallivorous fish depend on the availability of live coral, while herbivorous fish are closely linked to algal cover (Vincentius & Erfin, 2025). Furthermore, abiotic factors such as temperature, salinity, water clarity, currents, and bottom substrate conditions also play a significant role. Small changes in abiotic factors can significantly impact the structure of reef fish communities and the overall balance of the ecosystem (Erdana et al., 2022).
The coral reef ecosystem in Batu Anjir is a coastal area with high potential for reef fish diversity. However, this ecosystem also faces pressures from human activities, such as unsustainable fishing practices, pollution, and changes in coastal planning, as well as from natural factors such as large waves and climate change (Mubarak et al., 2024). Therefore, research on the influence of biotic and abiotic factors on reef fish diversity in this area is crucial to provide a comprehensive picture of the ecosystem's condition. Research results can inform conservation efforts, sustainable management, and preservation of marine resources in Batu Anjir.

Previous research by Ayorbaba et al. (2021) explained that in the seagrass ecosystem on Batu Island, Ambai Islands District, biotic and abiotic components are interdependent to maintain ecosystem balance. Therefore, proper protection and management of seagrass ecosystems are crucial to ensure the survival of the organisms living within them and prevent environmental damage that could threaten human survival.

Andrimida & Hardiyan (2022) recorded 721 individual reef fish belonging to 76 species and 25 families, with the Chaetodontidae, Pomacentridae, and Labridae families being the most abundant. Tiga Warna Beach showed the highest abundance of carnivorous, detritivorous, herbivorous, and omnivorous fish, while Kondang Buntung Beach was more dominant in the benthic invertivorous, corallivorous, and planktivorous groups. High live coral cover at Tiga Warna Beach was associated with the abundance of corallivorous fish, although the relationship between the two was relatively weak ($R^2 = 0.2045$). Conversely, the relationship between herbivorous fish abundance and algal coral cover was very strong ($R^2 = 0.9843$), while detritivorous fish showed a high negative correlation with sediment ($R^2 = 0.7119$). These findings confirm that in addition to natural factors and human activity pressures, variations in seabed substrate cover play an important role in determining the abundance and distribution of reef fish at certain trophic levels in a location.

The most fish compositions are from the POMACENTRIDAE (2 Species with 562 Individuals), LUTJANIDAE (2 Species with 215 Individuals), HAEMULIDAE (2 Species with 206 Individuals), NEMIPTERIDAE (2 Species with 152 Individuals), HOLOCENTRIDAE (2 Species with 35 Individuals), CHAETODONTHIDAE (2 Species with 30 Individuals), SERRANIDAE (1 Species with 27 Individuals), POMACANTHIDAE (1 Species with 11 Individuals), EPHIPPIDEE (1 Species with 7 Individuals) and CARANGIDAE, DIODONTIDEE, SCYLIORHINIDAE with 1 Species and Individuals each . Of all the fish families found at the study site, there were 7 similar families from 19 families which were also found on Halang Melingkau Island, Kotabaru Regency, South Kalimantan Province, namely POMACENTRIDAE, CHAETODONTHIDAE, HAEMULIDAE, LUTJANIDAE, SERRANIDAE, HOLOCENTRIDAE, and POMACANTHIDAE (Tony F. et al, 2021).

Arifin & Nasruddin (2022) explain that coral reefs play a vital role as habitat providers, food sources, and natural protectors for various marine biota, yet these ecosystems are highly vulnerable to damage. At Ngurblot Beach, Southeast Maluku Regency, coral reef damage is influenced by natural factors such as large waves, warming sea temperatures, and tropical storms that can trigger coral bleaching. Furthermore, human factors such as fishing with explosives, the use of poisons, mining activities, and land-based pollution also accelerate ecosystem degradation. The impacts are evident in the decline in biodiversity, the decline in economically valuable reef fish populations, and the decline in coastal protection from abrasion. To address this problem, efforts that can be taken include law enforcement against destructive practices, coral reef rehabilitation programs through transplantation or the installation of artificial media, and community-based coastal management with a sustainable conservation approach. Environmental education and local community involvement are also important to create collective awareness in maintaining the sustainability of coral reef ecosystems.

Research on coral reef fish diversity is generally conducted in large coral reef areas such as Bunaken, Raja Ampat, or Wakatobi, while specific studies on the Batu Anjir Coral Reef are still very limited. The novelty of this research lies in its focus on analyzing the relationship between biotic factors, such as food availability and interspecific interactions, and abiotic factors, such as temperature, salinity, and water quality, on coral reef fish diversity at that location. The aim of this study is to identify and analyze the influence of biotic and abiotic factors on coral fish diversity in the Batu Anjir Coral Reef ecosystem, so that the results can serve as a scientific reference in the sustainable management and conservation of marine resources.

2. METHOD

This research method was qualitative, using a combination of spatial analysis, in-situ measurements, and marine biota surveys. Analysis of bottom substrate cover was conducted using Sentinel-2 satellite imagery using the method *unsupervised classification* ISODATA through ENVI software, utilizing blue, green, red, and NIR bands to map changes in live coral cover, dead coral, and sand from 2015, 2020 and 2025. Abiotic factors were measured directly in the field through surveys and deployed with water quality parameters including temperature, pH, DO, salinity, brightness, depth, and current, then processed using Surfer 16 and ArcGIS 10.8 to produce distribution maps. Biotic factors were observed through reef fish surveys using the method *underwater visual census* (UVC) at two transplant stations and plankton identification at five stations with calculations of abundance, diversity, evenness, and dominance. The data obtained were then analyzed using ecological indices (Shannon-Wiener, Simpson, and Evenness) and *Principal Component Analysis* (PCA) to examine the relationships between biotic and abiotic factors. This integrative approach allows for comprehensive mapping of ecosystem conditions and identification of the relationship between environmental quality and reef fish biodiversity.

3. RESULT

3.1 Classification of Changes in the Bottom Substrate Cover of the Anjir Rock Reef Cluster in 2015, 2020, and 2025 Using Satellite Imagery

Classification of seabed substrate in the Anjir Rock Reef Cluster was carried out using Sentinel-2 imagery with the method unsupervised classification ISODATA in ENVI software. This method groups pixels based on spectral similarity without training data, making it effective for areas without detailed substrate maps. The analysis uses Bands 2 (Blue), 3 (Green), 4 (Red), and 8 (NIR), which are commonly used for shallow water studies (Istriani et al., 2024). The classification results show a total area of 8.89 hectares with details as in Table 1.

Table 1. Percentage of Coral Reef Area in 2015, 2020 and 2025

INFORMATION	2015 (Ha)	2020 (Ha)	2025 (Ha)	CHANGE 2015 – 2025 (Ha)	PERCENTAGE CHANGE (%)
Living Coral	6,05	4,70	4,0	-2,05	-33,88%
Dead Coral	3,77	3,66	3,7	-0,07	-1,86%
Sand	2,04	1,77	1,2	-0,84	-41,18%
Grand Total	**11,86**	**10,13**	**8,9**	**-2,96**	**-24,95%**

(*Source*: Data Analysis, 2025)

The graph of the trend of changes in the basic substrate cover of the Batu Anjir coral cluster can be seen in the following image;

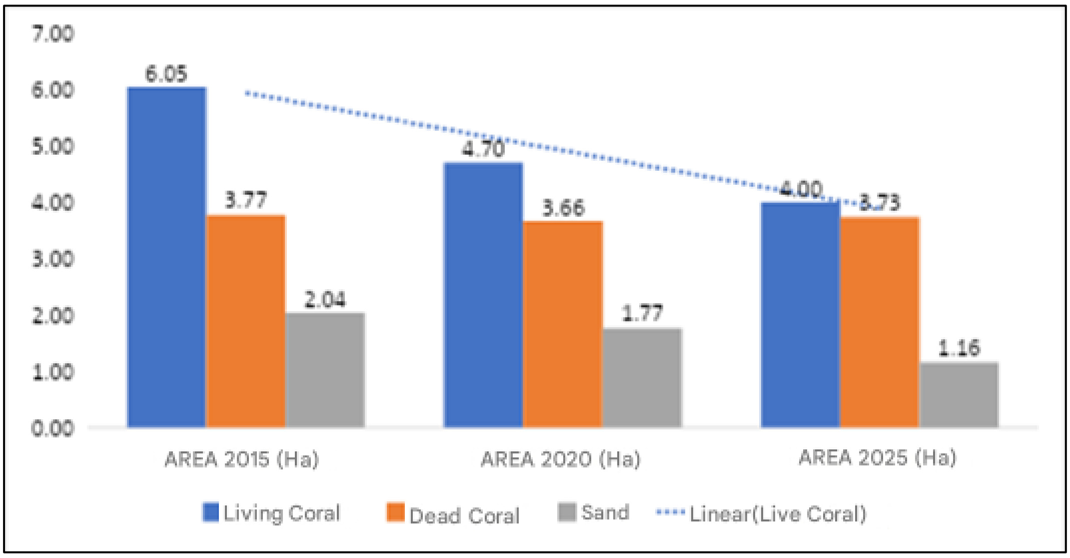

Figure 1. Graph of Changes in Bottom Substrate Cover of Anjir Reef Basin in 2015, 2020 and 2025

Analysis of the bottom substrate area of the waters in 2015, 2020, and 2025 shows variations in the composition of coral cover. Live coral cover was recorded at 6.05 ha (51.00%) in 2015, then to 4.70 ha (46.40%) in 2020, and 4.00 ha (44.99%) in 2025, with an accumulated area change of 2.05 ha, equivalent to 33.88%. Meanwhile, the dead coral category showed a relatively constant condition, while the sand substrate experienced a decreasing trend. Based on Ministerial Decree No. 4/2001, this change in proportion indicates a shift in ecosystem status, from the "Good" category (>50%) in 2015 to the "Moderate" category (25–49.99%) in the 2020 and 2025 periods.

3.2 Abiotic Factor Conditions

Abiotic factors, especially water quality, are the main determinants of the survival of coral reef ecosystems (Isdianto & Luthfi, 2020). In this study, seven main parameters were measured, namely temperature, salinity, pH, dissolved oxygen (DO), depth, current, and brightness. The observation results were obtained from surveys and *deploy* in May and July 2025.

Table 2. Water Quality Parameter Measurement Results Data

Parameter	Station										Baku Stop
	1		2		3		4		5		
	S	D	S	D	S	D	S	D	S	D	
pH	7.86	7.89	7.9	8.13	8.7	8.9	7.92	8.9	8.01	8.7	7,0–8,5
DO (ppm)	8.5	6.9	6.4	6.7	7.5	6.7	7.9	6.1	6.3	4.8	>5 mg/
Salinity (PPT)	28.5	28.6	28.6	28.4	28.7	28.5	28.6	28.5	29.1	28.5	coral: 33-34 ‰
Brightness (m)	4	7	2	3	1.5	3.5	5	1.5	3.5	2	Coral >5 m
Depth (m)	4	8.5	2	3	1.5	3.5	7.5	1.5	3.5	2	-

Temperature (°C)	29.7	30.2	30	30.9	30.5	30.2	30.1	30.5	29.6	32.4	28–30 °C
Current Speed	0.127	0.063	0.158	0.042	0.209	0.043	0.160	0.077	0.182	0.104	-

Ket: S=Survey, D=Deploy. Minister of Environment Decree No. 51 of 2004 concerning Seawater Quality Standards for Marine Biota.

Water quality data were obtained through field measurements and spatially processed using Surfer 16 and ArcGIS 10.8, producing a distribution map of each parameter. Water temperature ranged from 27.8–29.1°C, still within the normal threshold, although the highest values in the east and south potentially reflect shallow waters and are affected by anthropogenic activities. The pH value of 7.84–7.94 (average 7.9) is still within quality standards, but the trend towards the lower limit may indicate increased CO_2 and light pollution. DO concentrations of 4.7–6.5 mg/L, with two stations below the minimum threshold, indicate the possible presence of organic pollutants and high levels of organic matter decomposition.

Salinity of 27.5–28.5 ppt is considered lower than the ideal range, possibly due to freshwater input that can cause osmotic stress on the biota. Clarity at 1.5–3 m is below the ideal threshold, indicating high turbidity due to sediment and shipping activity, which can potentially inhibit zooxanthellae photosynthesis. The depth of 2–7 m still supports coral growth, although shallower waters are more susceptible to physical disturbances and environmental fluctuations. Current velocities of 0.116–0.385 m/s are classified as weak to moderate, sufficient to maintain oxygen circulation and diffusion, but limited in transporting sediment, thus risking increased turbidity and disrupting coral growth.

3.3 Biotic Factors: Diversity of Coral Fish and Plankton

Reef fish are an important component of the reef ecosystem that lives permanently in various microhabitats, so that damage to the reef will have a direct impact on their existence (Najeeb et al., 2025). Observations at two transplant stations showed 40 species of reef fish from 15 families with a total of 4,257 individuals. The initial survey recorded 63 major fish, 172 target fish, and 116 indicator fish. At Station 1, 579 major fish, 907 target fish, and 324 indicator fish were found, while Station 2 recorded 1,033 major fish, 831 target fish, and 232 indicator fish. The number of fish at both stations was higher than the initial survey, with target fish dominating at Station 1 and major fish at Station 2.

The abundance of fish based on the coral fish groups, major fish groups, target fish and indicator fish is shown in Figure 2 below.

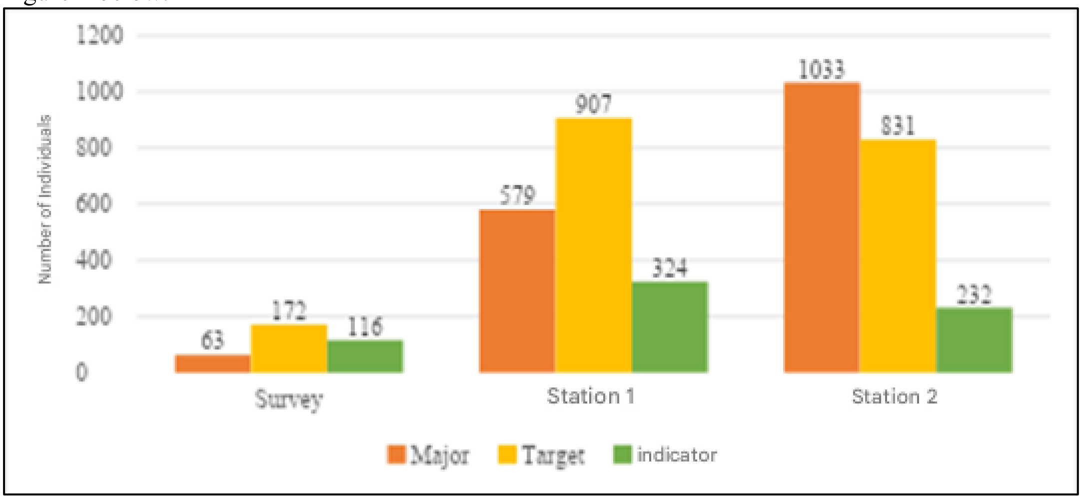

Figure 2. Fish Abundance Based on Reef Fish Groups

Based on Figure 2, the highest abundance of major fish was recorded at Station 2 (1,033 individuals/m²), target fish at Station 1 (907 individuals/m²), and indicator fish also at Station 1 (324 individuals/m²). Conversely, the lowest abundance was found in the initial survey with 63 individuals/m² for major fish, 172 individuals/m² for target fish, and the lowest abundance for indicator fish. Major fish dominate because they are the largest group of coral reef inhabitants, which generally live in groups (schooling).

For the results of diversity, uniformity, and dominance in Angsana waters, the results obtained are presented as below.

Table 3. Observation results of Diversity, Uniformity, and Dominance

Index	Survey	Station 1	Station 2
Diversity (H')	2,69	2,93	2,49
Uniformity (E)	0,93	0,82	0,73
Dominance (C)	0,05	0,08	0,13

Observations show that the coral fish diversity index (H') in Angsana waters is in the moderate category (2.49–2.93), the evenness index (E) is high (0.73–0.93), and the dominance index (C) is low (0.05–0.13), indicating that no species dominates. Of the total 672 individuals identified, the most dominant species was Apogon cookii (17.41%), followed by Diplogramma bifasciatum (12.20%), Apogon sudakateenia (9.52%), Notolabrus fucicola (8.33%), and Heniochus acuminatus (7.89%), while Gymnothorax favaejianus was recorded as the least abundant (0.15%). This composition indicates that the water conditions are still quite supportive of the sustainability of the coral fish community, although they are still influenced by water quality factors, food availability, and ecological pressures due to human activities.
Besides reef fish, another biotic factor is plankton. Plankton observations at five stations in Angsana waters indicate a dominance of phytoplankton from the Bacillariophyceae class, a group of diatoms that are tolerant of environmental variations and capable of rapid reproduction in nutrient-rich waters. This dominance reflects high primary productivity and potential water fertility that can lead to eutrophic conditions. Therefore, although supporting the ecosystem, continued monitoring is still necessary to maintain ecological sustainability. Plankton composition as an indicator of water quality in Angsana waters of the Batu Anjir coral reef cluster can be seen in Table 4 below.

Table 4. Plankton Composition in Angsana Waters, Batu Anjir Coral Reef Cluster

No	Class	Type	Survey					Deploy					Jlh
			Station					Station					
			1	2	3	4	5	1	2	3	4	5	
Phytoplankton													
1	*Bacillariophyceae*	*Bacteriastrum varians*	-	-	-	-	-	-	-	-	114	-	114
		Chaetoceros sp	-	-	-	-	-	1216	950	114	570	-	2850
		denticle	-	-	38	38		76	-	-	-	-	152
		Diatoma sp	608	76	-	38	38	152	76	76	-	-	1064
		Dytilium sol	-	-	-	-	-	-	38	-	-	76	114
		Gyrosigma	-	-	-	-	-	76	-	-	38	38	152
		Boats	-	-	-	38	-	-	-	-	-	-	38
		Nitzschia	38	-	-	38	38	-	-	-	-	-	114
		Rhizosolenia alata	-	-	-	-	-	-	190	38	76	76	380
		Stephanodiscus	-	-	-	38	38	-	114	38	38	-	266
		Surirella	-	-	-	-	-	-	-	38	-	-	38
		Synedra	38	-	38	-	38	-	38	-	-	114	266
		Tabular	76	-	-	38	-	-	-	-	-	-	114
		Thallasionema nitzschioides	-	-	-	-	-	-	304	836	646	570	2356
2	*Chlorophobes*	*Gonatozygon*	38	38	-	38		-	38	-	114	-	266
		Micractinium	-	-	-	570							570
Zooplankton													
1	Ciliates	*Tintinopsis radix*	-	-	-	-	-	-	-	-	76	-	76
2	Dinoflagellates	*Ceratium*	-	-	-	-	-	-	76	-	-	-	76
3	Crustacea	*Nauplius*	-	-	-	-	-	-	-	-	76	-	76
Amount			798	114	76	836	152	1520	1824	1140	1748	874	9082
Body			5	2	2	8	4	4	9	6	9	5	

Plankton analysis results at five Angsana water stations showed differences in composition between the initial survey and the time of transplantation media deployment. In the initial survey, the phytoplankton community was dominated by Bacillariophyceae, especially Tabellaria and Diatoma sp. (22.77% each), followed by Gonatozygon (17.82%) and Micractinium (14.85%). During deployment, the community was more diverse, dominated by Chaetoceros sp. (41.44%) and Thalassionema nitzschioides (34.25%), as well as the emergence of zooplankton such as Nauplius, Ceratium, and Tintinnopsis radix (33.33% each). These differences indicate changes in environmental conditions and higher primary productivity, and the emergence of zooplankton indicates the development of a more complex food chain in the transplantation habitat. For more clarity on the abundance of plankton in the Angsana waters of the Batu Anjir coral reef cluster, see the following figure;

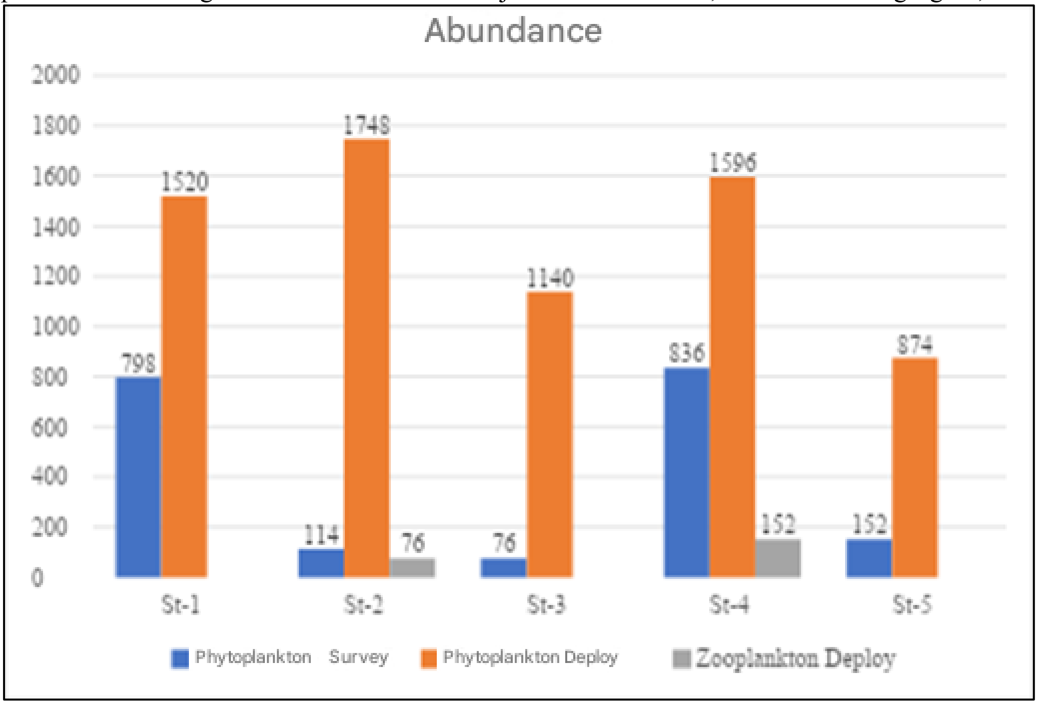

Figure 3. Plankton Abundance Index Value found in the Angsana waters of the Batu Anjir coral reef cluster

Plankton diversity index analysis showed that in the initial survey, H' values ranged from 0.54 to 1.00, reflecting a relatively balanced community and even species distribution. Upon deployment, phytoplankton diversity decreased to 0.51 to 0.75, while zooplankton diversity was lower (0 to 0.43), indicating dominance by certain species due to environmental pressures such as fluctuations in temperature, nutrients, light, and currents. This difference suggests that a more stable environment supports high diversity, while ecological pressures reduce plankton diversity and lead to the dominance of adaptive species.

3.4 Analisis PCA (Principal Component Analysis)

Two-dimensional biplot PCA analysis showed a clear positive relationship between environmental and biotic variables on coral reefs, where coral cover, fish abundance, pH, salinity, DO, brightness, depth, and plankton tended to increase simultaneously in the direction of adjacent vectors.

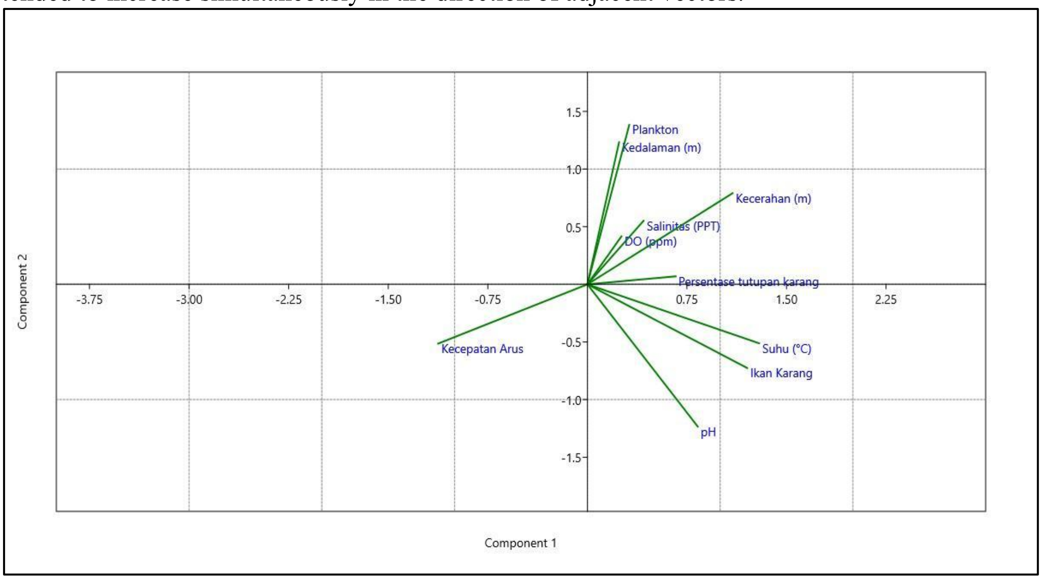

Figure 4. Analysis Chart *Principal Component Analysis* (PCA) between Biota and Water Quality Parameters

PCA analysis showed significant positive correlations between most environmental and biotic variables, including coral cover, fish abundance, pH, salinity, DO, brightness, depth, and plankton, indicating that optimal physical-chemical environmental conditions support biotic productivity (Tupper et al., 2017; Madduppa et al., 2020). Conversely, current velocity negatively impacted community structure, especially when it exceeded the optimal range. However, the correlation between coral cover and fish abundance was weak, suggesting the influence of other factors such as habitat complexity, food availability, water quality, predation, and fishing pressure. These findings are important for conservation planning and management of coral reef ecosystems, given that reef fish play a key role in trophic networks (Tony et al., 2021).

4. DISCUSSION

An evaluation of the coral reef ecosystem in the Karang Batu Anjir area shows significant degradation over the past decade (2015, 2020, and 2025). Live coral area decreased from 6.05 hectares in 2015 to 4.00 hectares in 2025, a 33.88% decrease, while dead coral remained relatively stable and sandy substrate declined sharply. The shift in substrate dominance from live coral to dead coral and sand impacts habitat complexity, which in turn affects biotic diversity (Komala et al., 2024; Isdianto et al., 2025).

Water quality factors also played a role in this decline. Water temperatures of 27.8–29.1°C are still within the tolerance range of tropical corals, but the temperature peak at Station 4 has the potential to cause thermal stress. Low DO (4.7 mg/L at Station 4 and Station 5) can trigger mild hypoxia. Water pH of 7.84–7.94 is near the lower optimal limit, risking inhibiting calcification. Salinity of 27.5–28.5 ppt is slightly below the ideal range, while low transparency (1.5–3 m) limits light penetration and reduces the photosynthetic efficiency of zooxanthellae.

A depth of 2–7 m is still ideal, but the combination of deteriorating water quality and weak currents (0.116–0.385 m/s) causes sedimentation that covers coral surfaces, reduces light penetration, and accelerates the shift from live to dead substrate. Declining coral cover impacts reef fish abundance, as complex habitats serve as shelter, feeding, and spawning grounds (Riansyah et al., 2018). PCA analysis showed a significant positive correlation between coral cover, fish abundance, water quality, depth, and plankton, while currents contributed differently, suggesting that certain physical factors may limit community structure if they are outside the optimal range (Madduppa et al., 2020).

However, the condition of Anjir Rock Reef is relatively better than Halang Melingkau Island, which in 2021 only had a cover of 1.43–53.71% (Tony et al., 2021), and Tanjung Seloka in 2025 with a cover of 26.76–52.76% (Iskandar et al., 2025). The decline in coral cover has implications for reduced habitat complexity, which affects the distribution and abundance of reef fish, in line with the findings of Riansyah et al. (2018) that fish abundance follows the level of live coral cover and habitat structure.

Currently, restoration efforts through artificial substrate transplantation such as Bioreef_block and iron domes are showing positive results, with an additional 2,000 m² of live coral cover by 2025. However, cumulatively only 1.02 hectares or 11.47% of the target 8.89 hectares have been restored, leaving 88.53% of the area untouched. This situation emphasizes the need for an integrated strategy, including monitoring coastal industrial activities, active restoration, water quality monitoring, and community participation to support sustainable ecosystem recovery.

Observations show that the gradual degradation of Anjir Rock Reef demonstrates the need for comprehensive ecosystem restoration, where physical, chemical, and biotic factors interact. Ecosystem-based approaches and adaptive zoning are key to long-term success, with a combination of mitigating anthropogenic pressures, improving water quality, and expanding active restoration as key strategies.

5. CONCLUSION

Research in the Batu Anjir ecosystem shows that biotic (reef fish, plankton, live coral cover) and abiotic (pH, DO, salinity, brightness, current, depth, water quality, sedimentation) factors influence reef fish diversity. Between 2015, 2020, and 2025, live coral cover experienced a 33.88% change in composition, which resulted in a shift in ecosystem status to the "Moderate" category. A total of 4,257 individuals of 40 reef fish species from 15 families were identified, dominated by plankton-eating fish, invertebrates, and predatory fish. PCA analysis showed that most environmental variables were positively correlated with fish diversity, except for current velocity, which had a negative impact.

Restoration efforts through artificial substrates such as *Bioreef block* and iron domes have successfully increased live coral cover, but only cover 11.47% of the target area, thus limiting the effectiveness of restoration. These findings emphasize the need for an integrated coral reef management strategy that considers the interaction of biotic and abiotic factors and mitigates anthropogenic pressures. This study's recommendations include accelerating restoration with broader coverage, providing adequate technical and funding support, and ensuring strict monitoring of human activities on the coast. Community participation through education and empowerment is also considered crucial for strengthening collective awareness of ecosystem protection. For future development, long-term studies with more detailed spatial-temporal monitoring and bioeconomic and social-ecological analyses are recommended to obtain a comprehensive picture of ecosystem dynamics and the effectiveness of management policies.

Acknowledgment

The author would like to thank PT. Borneo Indobara, South Kalimantan, for supporting and facilitating this research. The author would also like to thank the Dean of the Faculty of Fisheries and Marine Sciences, Lambung Mangkurat University, Ahmad Yani University, Banjarmasin, the Tanah Bumbu Regency Government, South Kalimantan Province, and all colleagues who have provided support so that this research can be completed.

REFERENCES

3. Andrimida, A., & Hardiyan, F. Z. (2022). Trophic structure of reef fish and its relationship to the condition of the bottom substrate in the Sempu Strait, Indonesia.Journal of Fisheries and Marine Research, 6(1), 41–54.
4. Arifin, A. N., & Nasruddin. (2022). Marine Environmental Damage to Coral Reef Ecosystems in Southeast Maluku Regency Due to Natural Factors and Human Activities (Physico Natural Features Environmental Analysis): Environmental Damage, Marine Ecosystems, Coral Reefs.Multidisciplinary Research Journal, 1(2), 56–60. https://doi.org/10.58705/jpm.v1i2.53
5. Ayorbaba, R., Beroperai, R., Bonai, H., & Rahanra, R. (2021). Biotic & Abiotic Components of the Seagrass Ecosystem on Batu Island, Ambai Islands District.UNES Journal of Scientech Research, 6(2), 130-138. Retrieved from https://ojs.ekasakti.org/index.php/UJSR/article/view/357
6. Erdana, R., Pratikto, I., Suryono, C. A., & Suryono, S. (2022). Relationship between Percentage of Live Coral Cover and Fish Abundance in the Koon Island Marine Conservation Area, East Seram Regency, Maluku Province.Journal of Marine Research, 11(2), 145-155. https://doi.org/10.14710/jmr.v11i2.32164
7. Tony, F., Iskandar, R., & Khasanah, R. I. (2021). Effectiveness of Bioreef_Block Technology on Reef Fish Diversity in Marine Waters of Sungai Cuka Village at Kintap District, Tanah Laut Regency of South Kalimantan, Indonesia. https://doi.org/10.18551/rjoas.2021-07.24
8. Isdianto, A., & Luthfi, O. M. (2020). The Relation of Water Chemical Quality to Coral Reef Ecocsystems in Damas. Journal of Environmental Engineering and Sustainable Technology, 7(2), 26-34. http://dx.doi.org/10.21776/ub.jeest.2020.007.02.3
9. Isdianto, A., Wibowo, R. A., Kudrati, A. V., Aliviyanti, D., Asadi, M. A., Dewi, C. S. U., ... & Pratiwi, D. C. (2025). Impact of Coral Recruitment on Ecosystem Sustainability in Sempu Island Nature Reserve, Indonesia.Journal homepage: http://iieta. org/journals/ijdne, 20(1), 73-82. https://doi.org/10.18280/ijdne.200108
10. Iskandar, R., Tony, F., Muhammad, M. M., & Firzatullah, M. (2025). Analysis of Coral Reef Community Structure and Coral Cover in Tanjung Seloka Village, Pulau Laut Selatan District, Kotabaru District, South Kalimantan Province, Indonesia.Asian Journal of Fisheries and Aquatic Research, 27(5), 33-41.. https://doi.org/10.9734/ajfar/2025/v27i5918
11. Istriyani, I. K., Hidayah, Z., & Wiyanto, D. B. (2024). Estimation of Total Suspended Solids in the Ujung Pangkah Estuary Using Multi-Temporal Sentinel-2 Satellite Imagery.Journal of Tropical Marine Science and Technology, 16(3), 293-306. https://doi.org/10.29244/jitkt.v16i2.53244
12. Komala, R., Noer, M. I., Miarsyah, M., Widyartini, D. S., & Handayani, H. (2024). Assess the level of damage to the coral reef ecosystem based on substrate coverage on Bira Island, Kepulauan Seribu, Indonesia. Biodiversitas Journal of Biological Diversity, 25(3). https://doi.org/10.13057/biodiv/d250309
13. Madduppa, H., Zamani, N. P., & Subhan, B. (2020). Multivariate analysis of coral reef health and its relation to environmental parameters in Indonesian waters. Biodiversitas Journal, 21(4), 1678–1688.
14. Mubarak, N., Hasyim, M. A., Rozy, M. F., Ilayas, M. H., & Anggara, A. (2024). Diversity of coral reefs at Tiga Warna Beach, Clungup Mangrove Conservation (CMC) Area, Malang Regency.Journal of Biotropical Research and Nature Technology, 2(2). https://doi.org/10.36873/borneo
15. Nabilla, N., & Wahyu Anggriyani, F. C. (2024). Environmental Damage Due to Human Activities in Coral Reef Ecosystems. service, 2(2), 169–172. Retrieved from https://ejournal.edutechjaya.com/index.php/khidmat/article/view/894
16. Najeeb, S., Khan, R. A. A., Deng, X., & Wu, C. (2025). Drivers and consequences of degradation in tropical reef island ecosystems: strategies for restoration and conservation. Frontiers in Marine Science, 12, 1518701. https://doi.org/10.3389/fmars.2025.1518701
17. Riansyah, A., Hartono, D., & Kusuma, A. B. (2018). Butterflyfish (Chaetodontidae) as bioindicators of damage to the coral reef ecosystem of Tikus Island.Jurnal scientific, 35(2), 103-110.
18. Tony, F., Iskandar, R., & Khasanah, R. I. (2021). Effectiveness of Bioreef_Block Technology on Reef Fish Diversity in Marine Waters of Sungai Cuka Village at Kintap District, Tanah Laut Regency of South Kalimantan, Indonesia. https://doi.org/10.18551/rjoas.2021-07.24
19. Tupper, M., Asif, F., Garces, L. R., & Pido, M. D. (2017). Reef fish diversity and biomass in relation to water quality parameters in Southeast Asia. Marine Pollution Bulletin, 124(1), 482–489.
20. Vincentius, A., & Erfin. (2025). Diversity of coral fish in the marine conservation area of Palue Island, Sikka Regency, East Nusa Tenggara Province.Aquanipa: Journal of Marine and Fisheries Sciences, 7(2).