BIODIVERSITAS
Volume 25, Number 12, December 2024
Pages: 4781-4789

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d251214

Environmental determinants of reef fish community structure in Sempu Strait, East Java, Indonesia

ANDIK ISDIANTO[1,2,♥], KHALIL GIBRAN[2], ADE YAMINDAGO[1,2], SYARIFAH HIKMAH JULINDA SARI[2], ADI TIYA YANUAR[2], DESY SETYONINGRUM[2], ARIEF SETYANTO[1,2], LISA NUR HIDAYAH[2], KRISTINA MARSELA[2], MUCHAMAD FAIRUZ HAYKAL[2], AULIA LANUDIA FATHAH[3], BERLANIA MAHARDIKA PUTRI[4], SUPRIYADI[5], OKTIYAS MUZAKY LUTHFI[6], DWI CANDRA PRATIWI[7]

[1]Coastal Resilience and Climate Change Adaptation Research Group, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia. Tel.: +62-341-553512, Fax.: +62-341-557837, ♥email: andik.isdianto@ub.ac.id

[2]Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia

[3]Graduate Program of Environmental Management and Development, Postgraduate School, Universitas Brawijaya. Jl. MT Haryono 169, Malang 65145, East Java, Indonesia

[4]Graduate Program of Environmental Sciences, Postgraduate School, Universitas Gadjah Mada. Jl. Teknika Utara, Sleman 55284, Yogyakarta, Indonesia

[5]Doctoral Program of Ocean Resource and Environmental Changes, National Taiwan Ocean University. Keelung City 202, Taiwan (R.O.C)

[6]Institute of Marine and Environmental Sciences, University of Szczecin. Mickiewicza 16a, Szczecin, 70-383, Poland

[7]Department of Earth and Atmospheric Sciences, University of Alberta. 1-26 Earth Sciences Building Edmonton, Alberta, T6G 2E3, Canada

Manuscript received: 28 September 2024. Revision accepted: 9 December 2024.

Abstract. *Isdianto A, Gibran K, Yamindago A, Sari SHJ, Yanuar AT, Setyoningrum D, Setyanto A, Hidayah LN, Marsela K, Haykal MF, Fathah AL, Putri BM, Supriyadi, Luthfi OM, Pratiwi DC. 2024. Environmental determinants of reef fish community structure in Sempu Strait, East Java, Indonesia. Biodiversitas 25: 4781-4789.* The Rumah Apung located in Sempu Strait, Malang District, East Java, Indonesia, is home to diverse coral reef ecosystems that provide vital ecological services and support local livelihoods. However, these ecosystems face significant threats from both natural environmental changes and anthropogenic activities. Understanding how environmental factors influence reef fish communities is critical to inform effective conservation strategies. This study investigated the influence of environmental factors on the community structure of coral reef fish in the Sempu Strait waters, East Java, using Underwater Visual Census (UVC) and Principal Component Analysis (PCA). Conducted from August 2023 to May 2024 at the Sempu Strait Floating House Station, this study aimed to assess the impact of water quality, substrate type, and food availability on the diversity and abundance of coral reef fish. The main results revealed a significant correlation between the community structure of coral reef fish and environmental variables such as water clarity, salinity ($r = 0.65$, $p<0.01$), pH ($r = 0.55$, $p<0.05$), dissolved oxygen ($r = 0.70$, $p<0.01$), and sediment type. Seasonal variations significantly affected water quality, with cold nutrient-rich water during the east monsoon increasing fish biomass by about 30%. Human activities, especially recreational diving and fishing activities, were correlated with a 20% decline in coral reef fish populations, highlighting the anthropogenic pressure on this ecosystem. PCA provides insight into the complex interdependencies within coral reef ecosystems, illustrating how multiple environmental factors combine to influence reef fish dynamics. The study concludes that effective management and conservation strategies, such as establishing marine protected areas, implementing community-based monitoring programs, and promoting sustainable tourism practices, are essential, supported by regular environmental monitoring, are essential to maintain the biodiversity and ecological integrity of coral reefs in the Sempu Strait. These strategies should address both natural environmental changes and anthropogenic impacts to mitigate their adverse effects on coral reef ecosystem conditions.

Keywords: Coral reefs, ecological analysis, principal component analysis, reef fish diversity, underwater visual census

INTRODUCTION

Reef fish are a diverse group of the marine species that inhabit coral reef areas and rely on them for breeding, shelter, and foraging (Luthfi et al. 2020; Tony et al. 2021). The presence of diverse fish species not only increases total biomass but also plays a crucial role in ecological functions like herbivory, which helps regulate macroalgae that could otherwise hinder coral recovery after disturbances. The structure and presence of reef fish communities serve as vital indicators of coral reef ecosystem health, as these fish rely on reefs for essential life processes. Healthy and diverse fish populations indicate a well-functioning ecosystem, whereas declines in fish numbers and diversity can signal environmental degradation (Topor et al. 2019; Gress et al. 2023). Reef fish are categorized into three main types indicator, target, and major fish each contributing uniquely to the coral reef ecosystem (English et al. 1998). Indicator fish, such as butterflyfishes and herbivores, serve as essential bioindicators of coral reef health, reflecting overall environmental conditions and offering insight into ecosystem status, with their abundance closely linked to coral health and signaling a healthy reef when present in notable numbers (Edrus and Lestari 2020; Iskandar et al. 2020). Target fish species are essential for assessing fish stock availability, as they directly influence the sustainability and management of fisheries (Bergseth et al. 2016). Major fish, typically ornamental species, add further diversity to the ecosystem. The distribution and abundance of these fish depend on several environmental factors such as water quality and seasons, both of which are essential for reef fish growth and survival (Fadli et al. 2022).

Environmental factors such as water quality, substrate type, and food availability have been recognized as important determinants of the distribution and abundance of coral reef fish (Gilby et al. 2016; Morais and Bellwood 2020; Hadj-Hammou et al. 2021). Coral reefs as coastal ecosystems play an important role in the life of coral reef fish; high diversity of coral reefs in waters as habitat variation increases the number of coral fish. The high diversity of coral reefs in a body of water, as a habitat variation, increases the number of reef fish (Ditzel et al. 2022; Najmi et al. 2023).

Beside environmental factors, human activities such as snorkeling, diving, and fishing add notable pressure to coral reefs, affecting their biodiversity. These activities can lead to physical damage to the reefs and alter the structure of the reef fish communities (Sangkhaduang et al. 2023). In addition to human-induced impacts, seasonal variations such as nutrient-rich cold water during the easterly season affect water quality and reef fish habitats. These seasonal changes can lead to increased fish abundance and diversity by providing essential resources for their growth (Suriya et al. 2023). Moreover, the proximity of fishing ports and high fishing activity in these waters intensify anthropogenic pressure, further threatening coral reef biodiversity and the reef fish populations (Bintoro et al. 2023). Therefore, it is very important to identify and manage the impacts of anthropogenic and natural environmental changes on coral reefs and reef fish communities.

Despite numerous studies on reef fish communities, there is still a notable gap in understanding how specific environmental factors shape these communities in the Sempu Strait, Malang District, East Java, Indonesia. Many previous studies have generalized ecological impacts across wider regions, often neglecting the unique conditions and species interactions present in this specific area. This research aims to bridge that gap by offering detailed empirical data on the connections between water quality, coral cover, and reef fish community dynamics in the Sempu Strait. By concentrating on this geographically and ecologically distinctive region, the study seeks to reveal patterns that may not be evident in broader regional analyses. Through an integrated approach and comprehensive data analysis, this research contributes to the scientific literature and supports conservation efforts by providing essential information for effective marine resource management and sustainable conservation strategies in Indonesia. The findings are expected to serve as a foundation for policy formulation and decision-making aimed at the preservation and sustainable use of natural resources.

MATERIALS AND METHODS

Research station

The data collection location was conducted around the waters of Sempu, Malang District, East Java, Indonesia, specifically at the Rumah Apung Station (Figure 1). Data collection was conducted in August 2023, November 2023, and May 2024. This data collection is in accordance with the seasonal differences in the eastern region, specifically the transition seasons II and I. The selection of the research location in the Rumah Apung area was based on the influence of anthropogenic activities in the region. This location is close to an estuary and coastal settlements, which potentially generate domestic waste, as well as fishing activities that may affect the quality of the aquatic environment. Additionally, its proximity to boat traffic increases the risk of disturbances to the coral ecosystem through oil pollution, sedimentation, and potential physical damage to coral structures. However, the geographical position of this area, sheltered by the surrounding land, provides relatively stable environmental conditions, which are presumed to support coral growth and serve as a habitat for various types of reef fish.

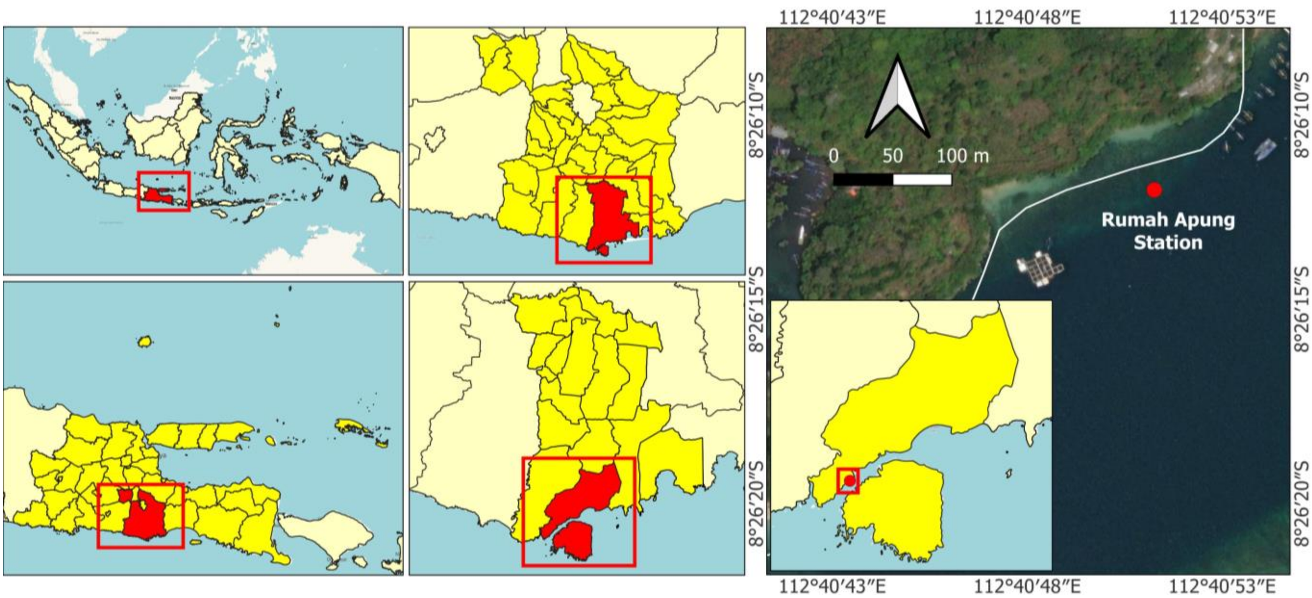


Figure 1. Location of Rumah Apung Station, Sempu Strait, Malang District, East Java, Indonesia

Data collection

Water quality parameters

Data parameters of the water were collected at the Rumah Apung Station. The parameter data was conducted, including temperature, Dissolved Oxygen (DO), pH, salinity, turbidity using Aquatic Analyzer AAQ Rinko (Moira et al. 2020). Meanwhile water current were measured using a current meter based on the Eulerian method at a fixed location in a body of water using a current measuring device (Röhrs et al. 2015; Sugianto et al. 2017). The currents were categorised as weak (<0.4 m/s), moderate (0.4-1 m/s), and strong (>1 m/s) (Putra et al. 2023). The water clarity was measured using secchi disc, which was lowered into the water until it disappeared from view. The depth at this point was recorded as D1. The disc was then slowly raised until it became visible again, and this depth was noted as D2. Water clarity was determined by averaging these two depths, D1 and D2. For sediment data sampling, sediment traps were deployed near coral reef and observation area. The sedimentation rates obtained were classified into three categories: low (1-10 mg/cm^3/day), medium (10-50 mg/cm^3/day), and catastrophic (50 mg/cm^3/day) (Pastorok and Bilyard 1985). The collection of nitrate and phosphate data were also collected using the Salifert Test Kit with bottles to collect samples.

Reef fish monitoring

Data collection of fish using the Underwater Visual Census (UVC) method (Figure 2) with using line transect 100 m for observation area. The visual method is an effective and environmentally friendly approach for the management of coral reef fish in particular. Before data collection, the location, depth, and topography of the water should be determined. The depth for data collection is set around 4-6 meters, depending on the presence of coral reefs. Data were collected using a transect that is 100 meters long and 5 meters wide on each side. A waiting period of about 5-10 minutes at the established transect is needed to allow the fish that may have moved away to return to their original area. Observations are recorded on a board, noting the types and abundance of fish within the designated 500 m^2 area (Giyanto et al. 2014). Documentation is also necessary to facilitate the identification of fish within the imaginary area.

Data analysis

Reef fish community structure

The coral fish community structure is assessed by measuring abundance, diversity, and evenness, which are then aligned with the corresponding category values (Table 1).

Abundance

The abundance of fish is obtained by counting the number of individuals present in a body of water divided by the area of the observation transect conducted. The formula for the abundance of coral reef fish can be seen as follows:

$$Abundance = \frac{Total\ of\ Individuals}{Transect\ Area}$$

Diversity

Biodiversity is a parameter aimed at biota to compare aquatic biota communities. The Diversity Index (H') was used according to the Shannon-Wiener Diversity Index (Krebs 2014).

$$H' = (pi \ln pi), pi\ defined\ as\ \frac{ni}{N}$$

Where :
H' : Shannon-Wiener Diversity Index
ni : Total of individuals (i)
N : Total of all individuals

Uniformity

Uniformity is an index used to describe the number of individuals per species within each coral reef fish community. The results of the uniformity scores of reef fish are then classified into three categories: stressed, unstable, and stable (Krebs 2014).

$$E = \frac{H'}{Hmax}$$

Where :
E : Uniformity Index
H' : Diversity Index
Hmax : Maximum of Diversity Index

Dominance

Dominance is an index of the number of species that dominate a body of water (Loiseau and Gaertner 2015). The dominance index has a range of values that describes the tendency of each individual to dominate, with a value range of 0-1.

$$C = \sum_{i=1}^{s} pi^2 = \sum_{i=1}^{s} \left[\frac{ni}{N}\right]^2$$

Where :
C : Dominance Index
ni : Number of individuals of species i
N : Total number of individuals of all species
pi : Proportion of individuals of species i
s : Number of reef fish species found

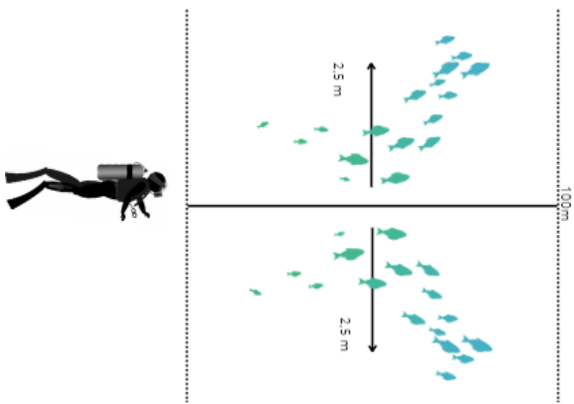


Figure 2. Underwater photo transect

Table 1. Structure community categories

Abundance	Criteria	H'	Criteria	E	Criteria	C	Criteria
0.55-1.54	Low	H' < 1	Low	0<E<0.4	Depressed	0<C<0.5	Low
1.55-2.53	Moderate	1<H'<3	Moderate	0.4<E<0.6	Unstable	0.5<C<0.75	Moderate
2.54-3.54	High	H'>3	High	0.6<E<1	Stable	0.75<C<1.0	High

Principal Component Analysis (PCA)

In this study, Principal Component Analysis (PCA) was employed to identify the primary factors contributing to the variability in reef fish abundance, coral reef structure, and water parameters. PCA was used to transform the original variables into a smaller set of uncorrelated components, which capture the most significant patterns in the data for further analysis. The analysis considered the reef fish community structure as the x variable, while coral cover and water parameters were designated as the y variables. The PCA method was employed to determine which variables were most appropriate for further analysis in subsequent stages of the research. The relationships between the variables were categorized as either positively or negatively correlated. Positively correlated variables were represented by vectors forming an angle of less than 90°, whereas negatively correlated variables were indicated by vectors forming an angle greater than 90°. PCA processing using IBM SPSS Statistics 26 software.

RESULTS AND DISCUSSION

Water quality parameters

Based on the data processing, the average temperature is 25.4°C, the average salinity is 34.4‰, the average pH is 7.4, the average DO is 6.7 mg/L, the average water clarity is 5.7 m, the average current is 0.3 m/s, the average sedimentation rate is 84.3 mg/cm²/day, the average nitrate is 0.9 mg/L, and the average phosphate is 0.048 mg/L (Table 2).

The average temperature at the Rumah Apung Station is around 25.4°C, which is below the threshold limit. Temperature drops can occur during the eastern season, particularly in Southern Java, due to the upwelling process. Research indicates that the cooling associated with upwelling can alter the reproductive dynamics of fish species. For instance, sea surface temperature closely influences the timing of spawning and hatching, often leading to delayed hatching times for fish eggs (Baldé et al. 2019). During Transitional Season 2, there is a peak in sea surface temperature warming (Ramadlanie et al. 2023). Research shows that rising temperatures cause physiological stress in reef fish, reducing growth rates and altering behaviour due to increased metabolic demands. As ectothermic animals, reef fish are particularly sensitive to temperature fluctuations, impacting their ability to regulate body heat (Munday et al. 2017; Morais and Bellwood 2018).

The average salinity value overall in the waters of the Sempu Strait is 34.4‰. Reef fish have a salinity tolerance range of 25-40‰ (Tony et al. 2020). The salinity values observed during the study included those within normal ranges. During the east or dry season, when it does not rain and water keeps evaporating because of the sun, the salt concentration and salinity levels rise (Suhanda and Putra 2021).

The average overall pH value obtained over three months is 7.4, which falls within normal conditions. Generally, the pH of seawater tends to be alkaline, but marine organisms are relatively well-adapted to such conditions. However, a decrease in pH was observed in November, coinciding with the rainy season. The lower pH during this transitional period is influenced by the increased rainfall. Higher rainfall impacts seawater chemistry by diluting salinity and alkalinity, which in turn lowers pH levels. The influx of freshwater reduces seawater's buffering capacity against acidification, especially in coastal areas experiencing heavy rainfall, thereby exacerbating the effects of ocean acidification (Carstensen and Duarte 2019). Acidification-induced physiological stress can elevate metabolic rates and energy demands, potentially leading to slower growth and reduced reproductive success in fish populations (Ern et al. 2017; Rummer and Munday 2017).

The DO results at the Rumah Apung Station are considered optimal because they exceed the standard quality threshold. Research shows that reef fish adjust their behaviour in response to different levels of dissolved oxygen, especially in areas with low oxygen (hypoxia). For example, reef fish have been observed migrating to shallower waters where oxygen levels are higher, altering their distribution over time in response to decreasing oxygen levels (Meyer-Gutbrod et al. 2021). This habitat displacement increases their vulnerability to predation and capture (Kim et al. 2023). Research from Ern et al. (2017) showed that reef fish can tolerate high temperatures as long as oxygen levels remain above 35 mmHg or ±2.06 mg/L, with their thermal tolerance largely unaffected. However, when oxygen levels fall below 35 mmHg (severe hypoxia), their ability to endure high temperatures decreases significantly, making them more vulnerable to heat stress. Dissolved oxygen in a body of water can reach elevated levels due to the diffusion of atmospheric oxygen into the water column.

The average water clarity over the three months studied is 5.7 m, which falls within the normal category. However, the reduced water clarity observed in November is attributed to the rainy season, which temporarily causes fish to relocate in search of food and habitats to support their mobility (Edrus and Setiawan 2016). The average current speed recorded over the same period is 0.3 m/s, classifying it as a weak current (Putra et al. 2023). Currents play a significant role in transporting oxygen, zooplankton, and nutrients. The influence of currents affects fish habits, particularly regarding spawning grounds, nursery grounds, and feeding grounds (Eggertsen et al. 2016).

Table 2. Water quality parameters

Parameters	Month			Average	Status	Threshold
	August	November	May			
Temperature (°C)	24.1	27.6	24.7	25.4	Low	28-30[a]
Salinity (‰)	34.3	34.3	34.4	34.4	Optimal	33-34 [a]
pH	7.5	7.0	7.8	7.4	Optimal	7-8.5 [a]
DO (mg/L)	6.9	6.5	6.8	6.7	Optimal	>5 [a]
Water clarity (m)	5.1	4.8	7.2	5.7	Optimal	>5 [a]
Current (m/s)	0.2	0.4	0.4	0.3	Low	<0.4 (low)[b] 0.4-1 (moderate) >1 (strong)
Sedimentation (mg/cm^2/day)	95.0	75.3	82.6	84.3	Severe-catastrophic	1-10 slight-moderate[c] 10-50 moderate-severe >50 severe-catastrophic
Nitrate (mg/L)	0.90	1.0	0.90	0.90	High	0.06 [a]
Phosphate (mg/L)	0.054	0.048	0042	0.048	High	0.015 [a]

Source: Indonesia Government No.22/(2021)[a], Putra et al. (2023)[b], Pastorok and Bilyard (1985)[c]

Table 3. Community structure

Month	Abundance	Diversity (H')	Uniformity (E)	Dominance (C)
August	0.804	1.977	0.771	0.182
November	0.704	1.767	0.711	0.205
May	0.896	1.980	0.714	0.177

In weak currents, sediment accumulates at the bottom of the water, whereas strong currents can cleanse coral polyps of attached particles. The average sedimentation rate recorded during the three months is 84.3 mg/cm^2/day, categorized as "catastrophic" according to the sedimentation rate category of >50 (Pastorok and Bilyard 1985). Sedimentation at the seabed arises due to weak currents, which inhibit coral growth and indirectly affect the presence of reef fish (Edrus and Setiawan 2016).

The average nitrate level in the waters of the Sempu Strait over the three months was 0.92 mg/L, which is considered high. The good nitrate level for marine biota is 0.008 mg/L. Furthermore, the upwelling of nutrient-rich bottom waters significantly enhances surface nutrient concentrations, as documented in various coastal regions (Martin et al. 2002; Kondratev 2015). The phosphate concentration varied across the study period, with 0.054 mg/L in August, 0.048 mg/L in November, and 0.042 mg/L in May. The standard quality for phosphate concentration in water is 0.015 mg/L. It can also be observed that the classification of water fertility ranges from 0.021 to 0.050 mg/L, indicating a moderately fertile condition. Higher phosphate levels with quality standards usually occur at the bottom of the water. The high concentration of phosphate at the bottom of these waters is caused by sediments acting as the main reservoir of phosphate that occurs in the marine cycle (Dar et al. 2017). Human activities, including residential waste and port operations near the Rumah Apung, further exacerbate nutrient input into the waters, impacting the local marine environment.

Community structure of reef fish

Based on the analysis of reef fish abundance data at the Rumah Apung Station, an abundance of 0.896 Ind/m² was recorded in May. The lowest reef fish abundance,0.704 Ind/m², was observed in November. The highest reef fish diversity, recorded in May, was 1.980, while the lowest, recorded in November, was 1.767, both of which are categorised as "moderate." The highest reef fish uniformity, 0.771, was recorded in August, whereas the lowest, 0.711, occurred in November. The highest reef fish dominance, 0.205, was observed in November, while the lowest, 0.177, occurred in May, both categorised as "low" (Table 3).

A total of 402 fish in May, 352 fish in August, and 448 fish in November were recorded, representing the three months of study. The most commonly encountered families are Pomacentridae and Acanthuridae. The abundance of reef fish is influenced by two factors: local and regional. Local factors include habitat conditions and the direct or indirect impacts of human activities. The habitat condition at the Rumah Apung Station is categorised as "damaged." Live coral cover provides an essential habitat, offering protection and reducing competition for reef fish (Elston et al. 2020). In regional factors, such as variations during the east season also play a crucial role. The east season, often referred to as the dry season, is characterised by weak currents and clear waters, which promote species richness, diversity, and abundance of fish. These conditions enhance visibility and facilitate the free mobility of fish (Madduppa et al. 2012; Edrus and Setiawan 2016). The dry season is also the peak spawning time for reef fish, supporting increased reproduction and growth of fish in the marine environment (Donelson et al. 2010; Padios et al. 2016). In contrast, during the second transitional season, reduced water water clarity leads to a decline in the mobility. This decrease impacts their ability to forage and select habitats, as poor vivibility disrupts their vision (Caves et al. 2017).

Diversity categorised as "moderate" indicates that the number of individuals across species is relatively balanced, with no significantly dominance or pressure on the ecosystem (Marista et al. 2023). The decline in biodiversity on coral reefs is primarily driven by the reductions in live coral cover, substrate degradation, and poor water quality. These factors lead to an increase in algal substrates, which predominantly supports herbivorous fish functioningas algae controllers (Perevolotsky et al. 2020; Clements and

Hay 2021). During the rainy season, biodiversity tends to decrease due to reduced water clarity, which can trigger fish to migrate to alternative habitats (Day et al. 2018). Seasonal fluctuations further impacts habitats and food availability, influencing the complexity and diversity of coral reef fish communities (da Silva et al. 2021). For example, changes in water temperature and chlorophyll levels affect the availability of food resources, subsequently impacting the abundance and diversity of fish populations (Ghazilou et al. 2016; Shraim et al. 2017). The uniformity of reef fish at the Rumah Apung Station is in a "stable" condition. Stable uniformity indicates an even distribution of individuals across species, promoting the ecosystem balance. The presence of sulfficient food resources competition, supporting the life of reef fish (Nadia et al. 2021). Low uniformity also reflects minimal dominance of specific species.

The dominance criteria at the Rumah Apung Station indicate a dominance value away from 1, indicating "low" dominance. A low dominance value reflects an evenly distributed population, rather than concentration in specific spesies. However, intense competition in the intertidal zone near coral reefs, driven by the need for shelter from predators, often results in the disappearance of individuals, highlights ecosystem instability. This instability is reflected in a dominance index, which measures the extent to which one biota group dominates another. High competition for shelter in these zones further underscores ecosystem stress and vulnerability (Papadakis et al. 2016; Rizal et al. 2022).

Abundance of reef fish

Based on the data processing results, the trophic abundance of major fish was recorded at 56%, target fish at 28%, and indicator fish at 16% in August. Subsequent results showed the percentage of reef fish trophic categories in November, with major fish at 49%, target fish at 29%, and indicator fish at 22%. In May, the trophic abundance was recorded at 52% for major fish, 31% for target fish, and 17% for indicator fish. Among the three reefs fish trophic categories, the highest trophic abundance was found in major fish (Figure 3).

Based on the trophic percentage of reef fish, it can be seen that the percentage of major fish has the highest trophic percentage. The major fish families identified in August, November, and May include Pomacentridae, Labridae, Blennidae, Zanclidae, Tetraodontidae, Aulostomidae, Fistularidae, Centriscidae, Cirrhitidae, Pinguipidae, and Scorpionidae, representing a total of 11 families. The high abundance of major fish in the waters is a common occurrence, as these fish tend to dominate and are typically found in large quantities. This finding aligns with research of Bintoro et al. (2023), which reported that during the research period October 2021-May 2022, the type of fish that dominates the Rumah Apung is the major fish. Major fish are also classified as non-target species in the marine fisheries (Ulfah et al. 2020). They are also schooling fish that prefer to live among branching corals. Among major fish, the Pomacentridae family is the most frequently encountered. This family consists primary ofherbivorous fish which that utilise shallow waters for foraging algae, which grow on sand and contain detritus (Emslie et al. 2019; Hata et al. 2020). Previous research at the same location obtained 18 families of coral fish in the same location in 2023 (Isdianto et al. 2024). Overall, the families and genera of reef fish found at the Floating House station are presented in Table 4.

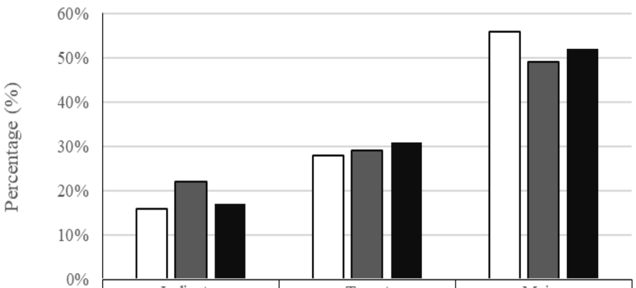
Table 4. Reef fish inventory in Rumah Apung, Sempu Strait, East Java, Indonesia

Family	Genus	Aug-23	Nov-23	May-24
Chaetodontidae (Butterfly fish)	*Chaetodon*	+	+	+
	Heniochus	+	+	+
Acanthuridae (Surgeon fish)	*Acanthurus*	+	+	+
	Ctenochaetus	+	+	+
	Zebrasoma	+	+	+
Scaridae (Parrot fish)	*Chlorurus*			+
	Scarus			+
Caesionidae (Yellow fin fish)	*Casio*			+
Balistidae (Trigger fish)	*Sufflamen*		+	
	Rhinnecantus			+
Holocentridae (Big eye fish)	*Myripristis*	+		
Haemulidae (Sweet lips fish)	*Plectorhinchus*	+	+	+
Ephippidae (Bat fish)	*Platax*	+		+
Pomacentridae (Damsel fish)	*Abudefduf*			
	Dascyllus	+	+	+
	Neoglyphidodon	+	+	+
	Plectroglyphidodon	+	+	+
	Pomacentrus	+	+	+
	Pycnochromis	+	+	+
	Chromis			+
Labridae (Wrasse fish)	*Anampses*			
	Coris	+	+	+
	Labroides	+	+	+
	Thalassoma	+	+	+
	Choerodon			+
	Gomphosus			+
	Halichoeres			+
	Hemigymus			+
Apogonidae (Cardinal fish)	*Pristiapogon*	+		
Blennidae (Blennis fish)	*Salarias*	+		
Zanclidae (Moorish idol)	*Zanclus*	+	+	+
Tetraodontidae (Puffer fish)	*Canthigaster*	+	+	+
	Arothron		+	
Aulostomidae (Trumpet fish)	*Aulostomus*	+	+	+
Centriscidae (Razor fish)	*Aeoliscus*		+	+
	Centriscus			+
Cirhitidae (Hawk fish)	*Cirrhitichthys*	+	+	+
	Paracirrhites			+
Pinguipidae (Sand perch)	*Parapercis*		+	+
Scorpionidae (Lion fish)	*Pterois*	+		

The relationship between water parameters and reef fish abundance

The relationship between water parameters and the abundance of reef fish can be observed through a scatter plot (Figure 4). The results of the principal component analysis on the relationship between abundance and water parameters show that the parameters that positively correlate with reef fish abundance are water clarity, salinity, pH, dissolved oxygen, and sediment. This is indicated by vectors forming angle of <90°, signifying positive correlations. Parameters that correlate positively with the abundance of reef fish can be interpreted as directly proportional, meaning that an increase in these parameters enhances reef fish abundance. Water clarity supports the vision of fish, aiding them in locating food and evading predators (Edrus and Setiawan 2016; Tony et al. 2020). Salinity is an important factor in aquatic ecology, influencing the osmotic pressure in the organism's body, requiring energy expenditure for adaptation through osmoregulation (Meylani et al. 2023). Value of pH affects the metabolism of fish in absorbing the nutritional needs that are essential for their growth. Extreme increases and decreases in pH can disrupt reproductive processes and abundance of fish (Moira et al. 2020). Dissolved oxygen also affects reef fish in supporting their activities; higher levels indicate increased sunlight and nutrient availability, promoting metabolic processes.

The metabolism of fish is supported by the respiration process, so low levels of Dissolved Oxygen (DO) make it difficult for fish to carry out metabolism, grow, and can lead to mortality. Sediment accumulation on the bottom of the water can cause coral death due to the covering of coral polyps, which can hinder the process of photosynthesis. The sedimentation rate category at the Rumah Apung Station falls into the "catastrophe" category (Pastorok and Bilyard 1985). This can enhance the growth of algae, which serves as a food source for herbivorous fish (Dell et al. 2020). In the parameters of current, temperature, nitrate, and phosphate, there is a negative linear relationship. Strong current challenge fish by disrupting their balance, requiring substantial energy expenditure to maintain stability (Eggertsen et al. 2016). Elevated temperatures affect fish in the metabolism processes and drive them to migrate to cooler waters, negatively impacting reproduction and growth processes of fish (McCosker et al. 2022). The increase in nitrates and phosphates in the water adversely affect coral reef fish habitats. Excessive nutrients lead to vulnerability in coral reefs, resulting in habitat degradation. Increases in nitrates and phosphates also affect the composition of reef fish species, causing some other species to decline and extinction. Consequently, reef fish seek suitable habitats to support their survival (Buckingham et al. 2022; Koester et al. 2023).



	Indicator	Target	Major
August	16%	28%	56%
November	22%	29%	49%
May	17%	31%	52%

Figure 3. Abundance of trophic groups in reef fish

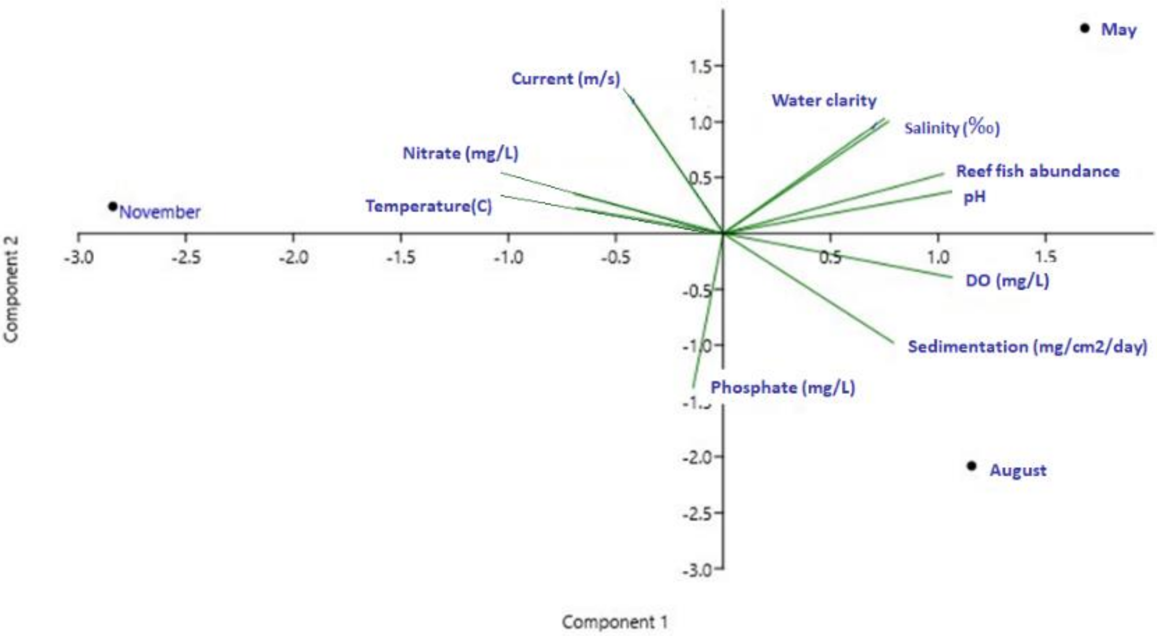


Figure 4. PCA between water quality and reef fish abundance

The conclusions of this study have provided important insights into the ecological dynamics affecting reef fish populations. Through the integration of UVC methods with PCA, this study reveals the impact of water quality, coral cover, and substrate type on reef fish diversity and abundance. The findings suggest that environmental factors such as water clarity, salinity, pH, dissolved oxygen, and sediment type play a crucial role in supporting reef fish communities, showing positive correlations between these factors and fish abundance. Seasonal variations, especially nutrient-rich waters brought by the east monsoon, markedly enhance food availability and benefit reef sih populations. However, human activities such as snorkeling, diving, and fishing have placed additional pressures on these ecosystems, indicating an urgent need for effective management and conservation strategies. The methodological approach using PCA allows for a detailed analysis of interactions within the coral reef ecosystem, offering new perspectives on the management and conservation of this critical habitat. Overall, this study has provided important data for the understanding and conservation of biodiversity and ecological health in the Sempu Strait waters, emphasizing the need for informed policies and conservation efforts to address both natural and anthropogenic impacts.

ACKNOWLEDGMENTS

This research has been conducted as an independent study, without any affiliation to any particular funding agency. Special thanks are due to all team members for their unwavering support and commitment throughout the research process. Their expertise and dedication were crucial in overcoming the challenges faced during the study both in the field and in the preparation of the research report and in achieving the in-depth results presented.

REFERENCES

Baldé BS, Döring J, Ekau W, Diouf M, Brehmer P. 2019. Bonga shad (*Ethmalosa fimbriata*) spawning tactics in an upwelling environment. Fish Oceanogr 28 (6): 686-697. DOI: 10.1111/fog.12451.

Bergseth BJ, Williamson DH, Frisch AJ, Russ GR. 2016. Protected areas preserve natural behaviour of a targeted fish species on coral reefs. Biol Conserv 198: 202-209. DOI: 10.1016/j.biocon.2016.04.011.

Bintoro G, Isdianto A, Harahab N, Kurniawan A, Wicaksono AD, Maharditha R, Fathah AL, Putri BM, Haykal MF, Asadi MA, Setyanto A, Lelono TD, Luthfi OM, Pratiwi DC. 2023. Reef fish monitoring as a coral reef resilience indicator in the Sempu Strait, South of East Java, Indonesia. Biodiversitas 24 (9): 4950-4959. DOI: 10.13057/biodiv/d240938.

Buckingham MC, D'Angelo C, Chalk TB, Foster GL, Johnson KG, Connelly Z, Olla C, Saeed M, Wiedenmann J. 2022. Impact of Nitrogen (N) and Phosphorus (P) enrichment and skewed N:P stoichiometry on the skeletal formation and microstructure of symbiotic reef corals. Coral Reefs 41: 1147-1159. DOI: 10.1007/s00338-022-02223-0.

Carstensen J, Duarte CM. 2019. Drivers of pH variability in coastal ecosystems. Environ Sci Technol 53 (8): 4020-4029. DOI: 10.1021/acs.est.8b03655.

Caves EM, Sutton TT, Johnsen S. 2017. Visual acuity in ray-finned fishes correlates with eye size and habitat. J Exp Biol 220 (Pt 9): 1586-1596. DOI: 10.1242/jeb.151183.

Clements CS, Hay ME. 2021. Biodiversity has a positive but saturating effect on imperiled coral reefs. Sci Adv 7 (42): eabi8592. DOI: 10.1126/sciadv.abi8592.

da Silva VEL, Dolbeth M, Fabré NN. 2021. Assessing tropical coastal dynamics across habitats and seasons through different dimensions of fish diversity. Mar Environ Res 171: 105458. DOI: 10.1016/j.marenvres.2021.105458.

Dar SA, Khan KF, Birch WD. 2017. Sedimentary: Phosphates. Reference Module in Earth Systems and Environmental Sciences. Elsevier, Amsterdam, The Netherlands. DOI: 10.1016/B978-0-12-409548-9.10509-3.

Day PB, Stuart-Smith RD, Edgar GJ, Bates AE. 2018. Species' thermal ranges predict changes in reef fish community structure during 8 years of extreme temperature variation. Divers Distrib 24 (8): 1036-1046. DOI: 10.1111/ddi.12753.

Dell CLA, Longo GO, Burkepile DE, Manfrino C. 2020. Few herbivore species consume dominant macroalgae on a Caribbean coral reef. Front Mar Sci 7: 676. DOI: 10.3389/fmars.2020.00676.

Ditzel P, König S, Musembi P, Peters MK. 2022. Correlation between coral reef condition and the diversity and abundance of fishes and Sea urchins on an East African coral reef. Oceans 3 (1): 1-14. DOI: 10.3390/oceans3010001.

Donelson JM, Munday PL, McCormick MI, Pankhurst NW, Pankhurst PM. 2010. Effects of elevated water temperature and food availability on the reproductive performance of a coral reef fish. Mar Ecol Prog Ser 401: 233-243. DOI: 10.3354/meps08366.

Edrus IN, Lestari P. 2020. Community structure and trophic status of reef fish in Natuna waters. Indones Fish Res J 26 (2): 69-82. DOI: 10.15578/ifrj.26.2.2020.69-82.

Edrus IN, Setiawan IE. 2016. The effect of sea water clarity on the structure of coral fish communities in Belitung Island Waters. Jurnal Penelitian Perikanan Indonesia 19 (2): 55-64. DOI: 10.15578/jppi.19.2.2013.55-64. [Indonesian]

Eggertsen L, Hammar L, Gullström M. 2016. Effects of tidal current-induced flow on reef fish behaviour and function on a subtropical rocky reef. Mar Ecol Prog Ser 559: 175-192. DOI: 10.3354/meps11918.

Elston C, Dallison T, Jones PR. 2020. Factors influencing the abundance patterns of reef fish functional guilds in two coastal bays, Philippines. Ocean Coast Manag 198: 105386. DOI: 10.1016/j.ocecoaman.2020.105386.

Emslie MJ, Logan M, Cheal AJ. 2019. The distribution of planktivorous damselfishes (Pomacentridae) on the Great Barrier reef and the relative influences of habitat and predation. Diversity 11 (3): 33. DOI: 10.3390/d11030033.

English SA, Baker VJ, Wilkinson CR. 1998. Survey Manual for Tropical Marine Resources. Second Edition. Australian Institute of Marine Science, Australia.

Ern R, Johansen JL, Rummer JL, Esbaugh AJ. 2017. Effects of hypoxia and ocean acidification on the upper thermal niche boundaries of coral reef fishes. Biol Lett 13 (7): 20170135. DOI: 10.1098/rsbl.2017.0135.

Fadli N, Damora A, Muchlisin ZA, Dewiyanti I, Ramadhaniaty M, Razy NM, Macusi ED, Siti-Azizah MN. 2022. Length-weight relationships and condition factors of three *Epinephelus* grouper (Epinephelidae) harvested in the Northern coast of Aceh, Indonesia. Intl J Des Nat Ecodynamics 17 (1): 119-124. DOI: 10.18280/ijdne.170115.

Ghazilou A, Shokri MR, Gladstone W. 2016. Coral reef fish assemblages along a disturbance gradient in the Northern Persian Gulf: A seasonal perspective. Mar Pollut Bull 105 (2): 599-605. DOI: 10.1016/j.marpolbul.2015.10.050.

Gilby BL, Tibbetts IR, Olds AD, Maxwell PS, Stevens T. 2016. Seascape context and predators override water quality effects on inshore coral reef fish communities. Coral Reefs 35: 979-990. DOI: 10.1007/s00338-016-1449-5.

Giyanto, Manuputty AEW, Abrar M, Siringoringo RM, Suharti SR, Wibowo K, Edrus IN, Arbi UY, Cappenberg HAW, Sihaloho HF, Tuti Y, Zulfianita D. 2014. Coremap CTI LIPI Coral Reef Health Monitoring 91. [Indonesian]

Gress E, Bridge TC, Fyfe J, Galbraith G. 2023. Novel interaction between a Rabbitfish and Black corals. Oceans 4 (3): 236-241. DOI: 10.3390/oceans4030016.

Hadj-Hammou J, Mouillot D, Graham NAJ. 2021. Response and effect traits of coral reef fish. Frontiers in Marine Science 8. DOI: 10.3389/fmars.2021.640619.

Hata H, Takano S, Masuhara H. 2020. Herbivorous damselfishes expand their territories after causing white scars on Porites corals. Sci Rep 10 (1): 16172. DOI: 10.1038/s41598-020-73232-8.

Indonesia Government. 2021. Government Regulation number 22 of 2021 Concerning Implementation of Environmental Protection, Organisationand Management. Government Regulations, Jakarta. [Indonesian]

Isdianto A, Ariefandi MF, Asadi MA, Yamindago A, Setyawan FO, Bintoro G, Setyanto A, Lelono TD, Tumulyadi A, Adhihapsari W, Setyoningrum D, Fathah AL, Putri BM, Supriyadi, Luthfi OM. 2024. Community structure and biomass of reef fish concerning coral cover in Sempu Strait, East Java, Indonesia. Biodiversitas 25 (8): 3376-3385. DOI: 10.13057/biodiv/d250808.

Iskandar R, Soemarno, Kusuma Z, Wiadnya DGR. 2020. Coral reef condition with Chaetodontidae fish as the indicators in the waters of the Samber Gelap Island of Kotabaru, South Kalimantan. Russ J Agric Socio-Econ Sci 107 (11): 81-89. DOI: 10.18551/rjoas.2020-11.10.

Kim H, Franco AC, Sumaila UR. 2023. A selected review of impacts of ocean deoxygenation on fish and fisheries. Fishes 8 (6): 316. DOI: 10.3390/fishes8060316.

Koester A, Gordó-Vilaseca C, Bunbury N, Ferse SCA, Ford A, Haupt P, A'Bear L, Bielsa M, Burt AJ, Letori J, Mederic E, Nancy E, Sanchez C, Waller M, Wild C. 2023. Impacts of coral bleaching on reef fish abundance, biomass and assemblage structure at remote Aldabra Atoll, Seychelles: Insights from two survey methods. Front Mar Sci 10: 1230717. DOI: 10.3389/fmars.2023.1230717.

Kondratev SI. 2015. Peculiarities of nutrients distribution in the coastal waters near the Danube Estuary in 1997-2013. Phys Oceanogr 5 (5): 32-48. DOI: 10.22449/1573-160x-2015-5-32-48.

Krebs CJ. 2014. Ecology: The Experimental Analysis of Distribution and Abundance. 6th Eds. Pearson Education Limited, USA.

Loiseau N, Gaertner J-C. 2015. Indices for assessing coral reef fish biodiversity: The need for a change in habits. Ecol Evol 5 (18): 4018-4027. DOI: 10.1002/ece3.1619.

Luthfi OM, Isdianto A, Sirait APR, Putranto TWC, Affandi M. 2020. Ecology of cubes artificial reef of Pantai Damas, East Java, Indonesia. Ecol Environ Conserv 26 (4): 1798-1805.

Madduppa HH, Ferse SCA, Aktani U, Palm HW. 2012. Seasonal trends and fish-habitat associations around Pari Island, Indonesia: Setting a baseline for environmental monitoring. Environ Biol Fish 95: 383-398. DOI: 10.1007/s10641-012-0012-7.

Marista E, Zibar Z, Raynaldo A, Shofiyah SS, Saputra R, Alimuddin A, Linda R. 2023. Diversity of coral and types of reef fish in West Belitung waters, Bangka Belitung Islands. Jurnal Laut Khatulistiwa 6 (1): 30-39. DOI: 10.26418/lkuntan.v6i1.60137. [Indonesian]

Martin AP, Richards KJ, Bracco A, Provenzale A. 2002. Patchy productivity in the open ocean. Glob Biogeochem Cycles 16 (2): 9-1-9-9. DOI: 10.1029/2001gb001449.

McCosker E, Stuart-Smith RD, Edgar GJ, Steinberg PD, Vergés A. 2022. Sea temperature and habitat effects on juvenile reef fishes along a tropicalizing coastline. Divers Distrib 28 (6): 1154-1170. DOI: 10.1111/ddi.13484.

Meyer-Gutbrod E, Kui L, Miller R, Nishimoto M, Snook L, Love M. 2021. Moving on up: Vertical distribution shifts in rocky reef fish species during climate-driven decline in dissolved oxygen from 1995 to 2009. Glob Change Biol 27 (23): 6280-6293. DOI: 10.1111/gcb.15821.

Meylani V, Hernawati D, Putra RR, Wibowo A. 2023. Elucidating environmental determinants of coral species richness at Pangandaran Beach: A dissolved oxygen-centric model. Intl J Des Nat Ecodynamics 18 (6): 1291-1297. DOI: 10.18280/ijdne.180602.

Moira VS, Luthfi OM, Isdianto A. 2020. Analysis of relationship between chemical oceanography conditions and coral reef ecosystems in Damas Waters, Trenggalek, East Java. J Mar Coast Sci 9 (3): 113-126. DOI: 10.20473/jmcs.v9i3.22294. [Indonesian]

Morais RA, Bellwood DR. 2018. Global drivers of reef fish growth. Fish Fish 19 (5): 874-889. DOI: 10.1111/faf.12297.

Morais RA, Bellwood DR. 2020. Principles for estimating fish productivity on coral reefs. Coral Reefs 39 (5): 1221-1231. DOI: 10.1007/s00338-020-01969-9.

Munday PL, Donelson JM, Domingos JA. 2017. Potential for adaptation to climate change in a coral reef fish. Glob Change Biol 23 (1): 307-317. DOI: 10.1111/gcb.13419.

Nadia LO, Ramil M, Nadia LMH, Purnama MF, Male I. 2021. The richness of reef fish community in an environmentally-friendly bioreeftech area of the Staring Bay, Indonesia. AACL Bioflux 14 (2): 931-941.

Najmi N, Darmarini AS, Razi NM, Suriani M, Kahar S. 2023. The current condition of coral reef and fish diversity in Gosong Island, Southwest Aceh. Jurnal Ilmu Perikanan dan Kelautan 15 (1): 57-70. DOI: 10.20473/jipk.v15i1.35917.

Padios HG, Baleta FN, Bolaños JM, Correspondence H. 2016. Influence of seasonal variation on the utilization and catch composition of fishing gears in Palanan, Isabela seashore, Philippines. Intl J Fish Aquat Stud 5 (1): 314-318.

Papadakis VM, Glaropoulos A, Alvanopoulou M, Kentouri M. 2016. A behavioural approach of dominance establishment in tank-held sea bream (*Sparus aurata* L.) under different feeding conditions. Aquac Res 47 (12): 4015-4023. DOI: 10.1111/are.12854.

Pastorok R, Bilyard G. 1985. Effects of sewage pollution on coral-reef communities. Mar Ecol Prog Ser 21 (1-2): 175-189. DOI: 10.3354/meps021175.

Perevolotsky T, Martin CH, Rivlin A, Holzman R. 2020. Work that body: Fin and body movements determine herbivore feeding performance within the natural reef environment. Proc R Soc B Biol Sci 287 (1938): 20201903. DOI: 10.1098/rspb.2020.1903.

Putra MGA, Zamani NP, Natih NMN, Yuliardi AY. 2023. Potential sources and distribution of marine debris in the coral reef ecosystem of Kelapa Island, Kelapa Dua Island, and Harapan Island, DKI Jakarta. J Mar Aquat Sci 8 (2): 244-253. DOI: 10.24843/jmas.2022.v08.i02.p09. [Indonesian]

Ramadlanie FY, Indrayanti E, Handoyo G. 2023. Determination of upwelling areas based on sea surface temperature and Chlorophyll-a indicators in Sunda Strait Waters 2010 - 2019. Indones J Oceanogr 4 (4): 62-73. [Indonesian]

Rizal A, Nugraha RBA, Farhan AR, Triwibowo H, Widjanarko E, Secasari Y, Mbay LN, Naibaho N, Borneo BB, Farahdita WL, Siagian H, Rahmania R, Gautama BG. 2022. Analysis of coral reef diversity and its correlation to fish abundance in Biawak Island cluster areas. IOP Conf Ser: Earth Environ Sci 1033: 012002. DOI: 10.1088/1755-1315/1033/1/012002.

Röhrs J, Sperrevik AK, Christensen KH, Broström G, Breivik Ø. 2015. Comparison of HF radar measurements with Eulerian and Lagrangian surface currents. Ocean Dyn 65: 679-690. DOI: 10.1007/s10236-015-0828-8.

Rummer JL, Munday PL. 2017. Climate change and the evolution of reef fishes: Past and future. Fish Fish 18: 22-39. DOI: 10.1111/faf.12164.

Sangkhaduang T, Sawain A, Kumgunsilp N. 2023. Exploring factors influencing tourists' environmentally responsible behavior for snorkeling tourism, Thailand. Intl J Sustain Dev Plan 18 (7): 2183-2190. DOI: 10.18280/ijsdp.180722.

Shraim R, Dieng MM, Vinu M, Vaughan G, McParland D, Idaghdour Y, Burt JA. 2017. Environmental extremes are associated with dietary patterns in arabian gulf reef fishes. Front Mar Sci 4: 285. DOI: 10.3389/fmars.2017.00285.

Sugianto DN, Rochaddi B, Wulandari SY, Subardjo P, Suryoputro AAD, Atmodjo W, Satriadi A, Suryono CA, Soenardjo N. 2017. Current characteristics in Demak waters based on acoustic measurement. Intl J Civ Eng Technol 8 (9): 749-760.

Suhanda D, Putra MGA. 2021. The influence of seasons on the distribution of temperature, salinity and density in the Halmahera Sea. Jurnal Riset Kelautan Tropis 3 (1): 1-11. DOI: 10.30649/jrkt.v3i1.34. [Indonesian]

Suriya C, Satian C, Visut B, Supadha K. 2023. Diversity of freshwater fish at Sago Palm Wetlands, Nakhon Si Thammarat Province, Thailand. Biodiversitas 23 (12): 6335-6344. DOI: 10.13057/biodiv/d231230.

Tony F, Soemarno S, Wiadnya DGR, Hakim L. 2020. Diversity of reef fish in Halang Melingkau Island, South Kalimantan, Indonesia. Biodiversitas 21 (10): 4804-4812. DOI: 10.13057/biodiv/d211046.

Tony F, Soemarno S, Wiadnya DGR, Hakim L. 2021. Habitat biodiversity as a determinant of fish community structure on coral reefs in Halang Melingkau Island, Kotabaru, South Kalimantan - Indonesia. Egypt J Aquat Biol Fish 25 (1): 351-370. DOI: 10.21608/ejabf.2021.149758.

Topor ZM, Rasher DB, Duffy JE, Brandl SJ. 2019. Marine protected areas enhance coral reef functioning by promoting fish biodiversity. Conserv Lett 12 (4): e12638. DOI: 10.1111/conl.12638.

Ulfah I, Yusuf S, Rappe RA, Bahar A, Haris A, Tresnati J, Tuwo A. 2020. Coral conditions and reef fish presence in the coral transplantation area on Kapoposang Island, Pangkep Regency, South Sulawesi. IOP Conf Ser: Earth Environ Sci 473: 012058. DOI: 10.1088/1755-1315/473/1/012058.