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Community structure and biomass of reef fish concerning coral cover in Sempu Strait, East Java, Indonesia

ANDIK ISDIANTO[1,♥], MUHAMMAD FIKRI ARIEFANDI[1], MUHAMMAD ARIF ASADI[2], ADE YAMINDAGO[1], FAHREZA OKTA SETYAWAN[3], GATUT BINTORO[4], ARIEF SETYANTO[5], TRI DJOKO LELONO[5], AGUS TUMULYADI[4], WIRASTIKA ADHIHAPSARI[4], DESY SETYONINGRUM[1], AULIA LANUDIA FATHAH[6], BERLANIA MAHARDIKA PUTRI[7], SUPRIYADI[8], OKTIYAS MUZAKY LUTHFI[9]

[1]Department of Marine Sciences, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia. Tel.: +62-341-553512, Fax.: +62-341-557837, ♥email: andik.isdianto@ub.ac.id
[2]Coastal Resilience and Climate Change Adaptation Research Group, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia
[3]Integrated Coastal Ecosystem Restoration and Sustainable Development, Research Group, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia
[4]Department of Fisheries, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia
[5]Im Fisher Research Group, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia
[6]Graduate Program of Environmental Management and Development, Graduate School, Universitas Brawijaya. Jl. MT Haryono 169, Malang 65145, East Java, Indonesia
[7]Graduate Program of Environmental Sciences, Universitas Gadjah Mada. Jl. Teknika Utara, Sleman 55284, Yogyakarta, Indonesia
[8]Doctoral Program in Ocean Resource and Environmental Changes, National Taiwan Ocean University. Keelung City 202, Taiwan
[9]Institute of Marine and Environmental Sciences, University of Szczecin. Mickiewicza 16a, Szczecin, 70-383, Poland

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Abstract. *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: 3376-3385.* Reef fishes were used as bioindicators of biodiversity in coral reef ecosystems. However, coral cover and reef fish abundance around Sempu Strait tended to decrease. The study aims to obtain reef fish's community structure and biomass and their correlation to coral cover. We observed significant variability in reef fish populations through bi-monthly monitoring using an underwater visual census and underwater photo transect conducted from December 2022 to April 2023. Based on these observations, the average range of coral fish abundance was 0.453 to 0.577 individuals per square meter, with the highest value at Rumah Apung station (0.577 ind/m^2). The community structure included 81 reef fish species, categorized into major (50 species), indicator (10 species), and target (21 species) groups, demonstrating a community with moderate diversity, stable evenness, and low dominance across the observed stations. Further, the research quantified fish biomass, recording an average of 0.0207 kg/m^2 or 207.571 kg/Ha, categorized as low, with the highest biomass measurements at Rumah Apung station (0.0054 kg/m^2). Strong correlations were identified between coral cover and both fish abundance (correlation coefficient = 0.741) and biomass (correlation coefficient = 0.666). These results emphasize the profound impact of coral health on the conditions and sustainability of reef fish populations. These findings underscore the critical dependency of reef fish on coral ecosystems and provide essential data for conservation efforts to maintain and restore these vital marine habitats.

Keywords: Coral fish abundance, coral-fish relationships, reef fish diversity, underwater photo transect, underwater visual census

INTRODUCTION

Coral reefs, important for global biodiversity and ecosystem services, are sophisticated and dynamic habitats characterized by complex interactions between flora and fauna (Mujahidah et al. 2023). In these ecosystems, reef fish play an important role, carrying out various ecological functions for maintaining and health of coral reefs (Karnan 2022; Gress et al. 2023). These functions include grazing algae, controlling populations of other marine organisms, contributing to bioerosion, and participating in sedimentation processes that shape the physical structure of reefs (Ulfah et al. 2023; Eddy et al. 2021). The health and vitality of coral reef ecosystems are thus closely linked to reef fishes' biomass and community structure. Any significant changes in these parameters can profoundly impact coral reefs' sustainability and resilience (Mujiyanto et al. 2023). Coral reefs' structural integrity and ecological functions are closely linked to the biodiversity and abundance of associated reef fish species. The diversity within these ecosystems supports numerous marine species, many of which rely exclusively on coral reefs for survival (Darling et al. 2017; Richardson et al. 2018; Dwita et al. 2022). Coralivores, such as those in the Chaetodontidae family, exhibit a high degree of sensitivity to the changes and destruction that coral reefs undergo. This sensitivity results from the fish's substantial dependence on corals as both food sources and habitats (Shidqi et al. 2018). Consequently, coral reef health directly influences these fish's population dynamics and biodiversity, making them excellent indicators of reef health.

In Indonesia, coral reefs exhibit a broad range of biomass values among reef fishes, from less than 100 kg/Ha to over 17,000 kg/Ha, reflecting the variability and vulnerability of these ecosystems to both natural and anthropogenic pressures (Campbell et al. 2020). Factors such as overfishing, habitat destruction, and environmental pollution have caused significant declines in reef fish populations, impacting community structure and coral reef resilience (Luthfi et al. 2016). Moreover, studies have shown that even minor reductions in fish biomass—such as a 5% decrease—can precipitate substantial changes in the community structure, indicating the sensitive balance within these ecosystems (Pereira et al. 2014). Anthropogenic activities significantly threaten coral reefs due to negative impacts such as chemical pollution, use of non-environmentally friendly fishing gear, irresponsible tourism practices, and waste input (Permana et al. 2020; Zuhri et al. 2023).

Indonesia plays an important diversity of coral reefs, including those located within the waters of the Sempu Strait. This specific region is impacted by human activity, including tourist, residential areas, and fishing ports (Isdianto et al. 2024). The abundance of reef fish showed fluctuations in the years 2015, 2016, 2018, 2021, and 2022, which can be connected to the condition of the coral cover (Bintoro et al. 2023). The occurrence of damage will impact the long-term sustainability of the coral ecosystem. It is important to carry out regular monitoring of reef fish to build a comprehensive database of the distribution, abundance, and diversity of reef fish (Luthfi et al. 2016); this correlates with the establishment of a comprehensive database of the distribution, abundance, and diversity of reef fish (Luthfi et al. 2016); it is correlated with coral cover and community structure.

This research examines how variations in coral cover affect community structure and coral reef fish biomass in the Sempu Strait. This research aims to describe coral conditions direct and indirect impacts on reef fish populations by utilizing a systematic underwater visual census and photographic transect method at bi-monthly intervals from December 2022 to April 2023. The results of this research will likely provide valuable insights into those issues. Complex ecological interdependencies in coral reef systems contribute to increasing conservation strategies to protect biodiversity but increasingly threatened ecosystems. Through these efforts, we aspire to increase understanding of coral reef ecology, highlighting the dynamic interactions between coral structures and the various marine species that depend on them, thereby informing the broader global ecological and conservation dialogue.

MATERIALS AND METHODS

The study was conducted bimonthly in the Sempu Strait, more precisely in Malang District, Indonesia, from December 2022 to April 2023. Five research sites (Figure 1, Table 1) were chosen because of their peculiarity as waters located close to the Sempu Island natural reserve area and the Pondokdadap fishing port: Jetty Port (JT), Rumah Apung (RA), Banyu Tawar (BT), Watu Meja (WM), and Waru-waru (WW).

Table 1. Description of locations

Station	Coordinate	Description
Jetty Port	8°26'1.57"S, 112°41'3.21"E	This location has a lot of fishing activities including fishing boat berthing facilities, ship transit, and also a loading and unloading area. A lot of organic and non-organic waste is found in this area
Rumah Apung	8°26'13.67"S, 112°40'47.32"E	Located at the western end of the Sempu Strait and directly adjacent to the Indian Ocean. Located near residential areas
Banyu Tawar	8°26'1.35"S, 112°41'19.65"E	This location has run off of small river
Watu Meja	8°25'45.13"S, 112°41'49.65"E	Located in the east and is directly facing the open sea, so it is also far from the influence of anthropogenic activity
Waru-waru	8°25'49.69"S, 112°41'33.16"E	The only location in the Sempu Strait that commonlyusedastourist attraction

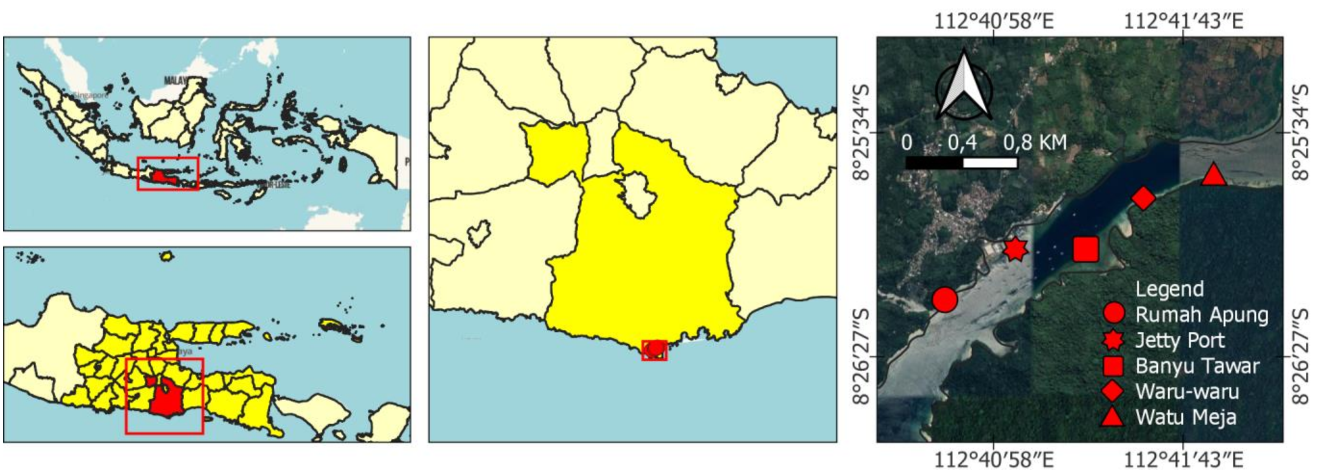


Figure 1. Research location map of Sempu Strait in Sempu Island, Malang, East Java, Indonesia

The turbidity of the JT Station waters is caused by the large number of ships in the area, which usually dump various waste materials, including oil, fuel, and ballast water. Various waste deposits were also observed in various locations, including around the port, and fragments of damaged ships were found in the JT. At this RA station, we observe the accumulation of rubbish on the coastline and a large amount of recycled ship material carried by the waves from JT. Apart from that, the area around the RA is also a fishing location for local residents. The condition of the waters at BT Station is characterized by several beaches in the area which are the anchorage for many ships on Sempu Island.

WW Station offers beautiful coastal morphology away from fishing activities, offering relatively unobstructed water conditions. However, despite its beach appeal, WW Beach faces the risk of being used as a tourist destination by both tourists and local communities. As a result, the existence of ecological systems in the aquatic environment is reduced. WM Station is located some distance from human activity. The station is on the outer edge of the strait, adjacent to Tamban Beach, a famous tourist destination where local fishing operations occur. It is hypothesized that the waters at this particular station also receive material input from Tamban Beach, significantly influencing conditions in the monitoring waters. Due to its location close to the strait, high-speed currents sometimes occur.

An underwater camera collects data on the abundance of coral reef fish along a 100x5 m line transect parallel to the coastline between 3 and 6 meters deep. The biomass of reef fish was also measured using the UVC technique by calculating the fish's overall length. Underwater Photo Transect (UPT) data collection on coral reef cover was carried out by imaging the 100x100 cm transect quadrant. Data on water parameters temperature, salinity, brightness, and currents were collected, and these four parameters are known to affect the survival of coral reefs and reef fish. The tools used to measure water parameters include AAQ Rinko 1183s-F to measure temperature and salinity, Secchi disk for measuring water clarity, and sediment trap for measuring sedimentation rate. Meanwhile, the current velocity data uses secondary data from the website https://podaac.JTl.nasa.gov/.

Data analysis

The percentage of coral cover in this study was calculated with the assistance of CPCe (Coral Point Count with Excel extensions), a program created especially to handle and efficiently analyze coral cover statistics based on specified areas (Tabugo et al. 2016). An equation based on Giyanto et al. (2014) determined the percentage of living coral cover.

$$Percentage\ cover = \frac{Total\ length\ category}{Total\ of\ transect} x100\%$$

The abundance of coral reefs was the number of coral reefs found at the observation station per station of the observation transect area. The equation for the abundance of reef fish according to Odum (1971):

$$N = \frac{ni}{A}$$

Where: N: abundance of reef fish (m^2), Ni: total number of reef fish, A: the area of the observation

The Diversity Index (H') was calculated using the Shannon-Wiener Index (H') (Krebs 2014) formula:

$$H' = -\sum\left(\frac{ni}{N}\right)\ln\left(\frac{ni}{N}\right)$$

Where: H': Shannon diversity index, Ni: number of individuals of a species, N: total number of individuals of all species

The Evenness Index reflects whether the distribution of biota is even or not. Ecosystem balance improves when the distribution of individuals between species becomes more uniform (Labrosse et al. 2002). The fish evenness index can be calculated using a formula according to Odum (1971):

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

Where: E: index of evenness, H': diversity index, H'max: LnS, where S: the number of species

Dominance is an index that compares the number of individuals in a species with the total number of species in the entire species. In general, if the diversity index shows low criteria, this indicates the dominance of one coralfish species over another species. Dominance Index (C) was calculated using the Simpson Index formula:

$$D = \sum\left(\frac{ni}{N}\right)^2$$

Where: D: Simpson dominance index, Ni: number of individuals of a species, N: total number of individuals of the entire species

Table 2 contains values regarding the classification of each criterion of the coral fish community structure, namely diversity index, index of evenness, and dominance index.

The long-weight equation is used to determine fish weight based on fish length in calculating fish biomass. Long-weight index derived from Fishbase for every species in the family. The following equations are used to determine the weight of fish:

$$W = aL^b$$

Where: W: weight (kg), L: total length per species (cm), a and b: species-specific indices

Table 2. Criteria for reef fish community structure

H'	Criteria	E	Criteria	C	Criteria
H'<1	Low	0<E<0.5	Pressed	0<D< 0.5	Low
1<H' <3	Moderate	0.5<E<0.75	Unstable	0.5<D<0.75	Moderate
H'>3	High	0.75<E<1	Stable	0.75< D<1	High

For fish biomass, each station is then arranged (Giyanto et al. 2014) using the formula:

$$Biomass = \frac{W}{A}$$

Where: W: biomass per sampling unit, A: the area of the sampler unit (m^2)

RESULTS AND DISCUSSION

Water quality

Water parameters include temperature, salinity, brightness, sedimentation, and current. Temperature changes, reduced salinity, brightness, current velocity, and sedimentation within specific ranges can damage coral reefs and impact the organisms inhabiting them, such as reef fish. The results of the average measurement of water quality parameters obtained from data collection in December 2022, February 2023, and April 2023 are presented in Table 3.

According to Government Regulation (PP) No.22/ 2021, water temperature and brightness parameters are within the optimal range, while salinity still does not meet the quality standards to support the life of coral reefs and reef fish. According to Rina et al. (2020), the salinity levels in the water are below the established threshold, yet they remain within the acceptable range of 25-40‰, which maintains coral life. Ramlah et al. (2015) stated current speed in the Sempu Strait Waters belongs to the average category (0.25-0.50 m/s). Currents are very important for marine biota because they can transport nutrients for coral fish larvae or juveniles (Rosdianto 2021). It can be noted that the sedimentation rate at the entire station is >50 mg/cm^2/day, which belongs to the high and dangerous categories (Pastorok and Bilyard 1985). Sedimentation has been identified as a major trigger for the existence and recovery of coral species and their habitats. Suspended sediments in coral reefs can damage coral and interfere with its eating, growing, and reproducing ability (Environmental Protection Agency 2017). Apart from that, high sedimentation also harms fish life. For example, suspended sediments have been shown to interfere with visual acuity and odor in some coral reef fish (O'Connor et al. 2016).

Coral cover

The station is covered in living corals of both Acropora and non-Acropora species. Figure 2 highlights the proportion of coral cover conditions at depths of 3-6 m based on research completed at 5 observation stations.

The average range of living coral coverage varies from 12.57 to 14.28% across all sites and varies from 10.28 to 18.36 per month classified as "damaged" category. This aligns with the latest study, which showed that the percentage of living coral coverage in Sempu Waters ranged from 3.3 to 18.7%, classified in the damaged category (Isdianto et al. 2023). This shows that there has been no significant change in the percentage of coral coverage from the previous year to the present. The poor level of coral coverage in the Sempu Strait was due to the surrounding environment, which stresses corals to the point that coral-eating diseases become increasingly common (Isdianto et al. 2024).

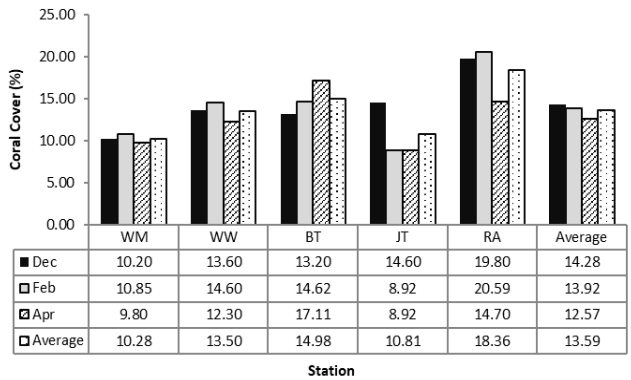


Figure 2. Coral cover in the Sempu Strait Waters, Malang, East Java, Indonesia

Table 3. Measurement results of water quality parameters in the Sempu Strait Waters, Malang, East Java, Indonesia

Stations	Parameters				
	Temperature (°C)	Salinity (‰)	Brightness (m)	Current (m/s)	Sedimentation (mg/cm^2/day)
Jeti	29.6	32.1	90	0.38	89.27
Rumah Apung	29.7	32.2	73.3	0.45	58.13
Banyu Tawar	29.7	32.1	66.7	0.47	61.05
Waru-waru	29.8	32.4	80	0.49	85.49
Watu Meja	29.4	32.4	100	0.50	74.73
Government Regulation (PP) No.22/ 2021	28-30	33-34	<5		
Ramlah et al. (2015)				Slow: 0-0.25 m/s Moderate: 0.25-0.50m/s Fast: 0.50-1 m/s Very fast: >100 m/s	
(Pastorok and Bilyard 1985)					1-10: slight-moderate 10-50: moderate-severe >50: severe-catastrophic

The high coral coverage at the RA station has been attributed to limited human intervention and few encounters with fishing vessels. The findings indicated that the abiotic substrate exhibits a greater influence than the biotic substrate. This significant prevalence indicates pressure on corals at all stations. This is due to a fishing port in the Sempu Strait, which experiences high levels of fishing activity every day. The large number of fishing vessels in the reservoir area poses a significant risk to coral reefs. These ships anchored in various locations and rested on Sempu Island without considering the existence of coral reef ecosystems at the bottom of the waters. Apart from that, the decline in live coral cover was caused by several factors, such as ship traffic, beach tourism, and student activities. In addition, prolonged natural phenomena such as global warming, climate change, and unpredictable weather patterns can potentially destroy coral reefs, leaving only fragmented reefs (Riskiani et al. 2019). Observed coral abundance is also controlled by the amount of macroalgae, which indirectly causes competition for coral life (Pereira et al. 2014).

Reef fish abundance

According to visual observations, 82 fish species have been identified, belonging to 44 genera and 24 families (Table 4). Data collection on the abundance of fish in the Sempu Strait and obtained average abundance in each station from December 2022 to April 2023. The average abundance of reef fish in the five stations at JT station (0.447 ind/m^2), RA station (0.577 ind/m^2), BT station (0.453 ind/m^2), WW station (0.546 ind/m^2), and WM station (0.461 ind/m^2). The research results show that the RA station had the highest average abundance over three months, while Station JT showed the lowest level of abundance. The high population of coral fish seen at the RA station is due to the greater extent of live coral cover compared to other stations. The reduction or continued reduction in coral reef habitat impacts coral fish's population number and diversity. The abundance of coral fish from December 2022 to April 2023 can be seen in Figure 3.

Local environmental conditions, regional and seasonal variations, and internal factors can cause fluctuations in fish abundance seen at each data collection station. Local factors include natural and artificial elements, such as habitat quality, productivity of planktonic or benthic organisms, direct or indirect impacts of fishing, and other stressors, such as pollution or sedimentation, either separately or in combination (DeMartini and Smith 2015; Taylor et al. 2015; Williams et al. 2015). Furthermore, human activities in the waters of the Sempu Strait were believed to have an important role in influencing the population size of coralfish communities at the designated observation locations. Human recreational activities significantly affect coastal ecosystems, especially fish and coral communities. This impact is clearly visible in changes in the trophic structure of fish communities on Pacific coral reefs, leading to a decrease in live coral cover and a shift in the dominance of herbivores in fish communities (Ruppert et al. 2017; Zhu et al. 2022).

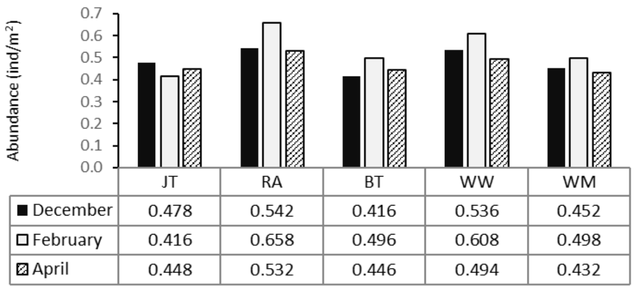


Figure 3. The abundance of coral reef fish in the Sempu Strait Waters, Malang, East Java, Indonesia

Table 4. Reef fish inventory in Sempu Strait Waters, Malang, East Java, Indonesia

Family	Genus	JP	RA	BT	WW	WM
Chaetodontidae	*Chaetodon*	+	+	+	+	+
Acanthuridae	*Acanthurus*	+	+	+	+	+
Scaridae	*Chlorurus*		+			
Siganidae	*Siganus*	+			+	
Caesionidae	*Caesio*	+	+	+		
Balistidae	*Sufflamen*	+	+	+	+	+
Holocentridae	*Myripristis*	+	+	+		
Haemulidae	*Plectorhinchus*	+	+		+	+
Ephipidane	*Platax*	+	+	+	+	+
Muraenidae	*Gymnothorax*	+		+	+	+
Pomacantridae	*Abudefduf*	+	+	+		
Labridae	*Anampses*	+	+		+	+
Apogonidae	*Pristiapogon*			+	+	+
Pomacanthidae	*Pomacanthud*	+	+			
Zanclidae	*Zanclus*	+	+	+	+	+
Tetraodontidae	*Canthigaster*	+	+	+	+	+
Diodontidae	*Diodon*		+			+
Aulostomidae	*Aulostomus*	+	+	+	+	+
Fistulariidae	*Fistularia*	+	+	+	+	
Centriscidae	*Aeoliscus*	+				
Anthiidae	*Pseudanthias*					+
Cirhitidae	*Paracirrhites*	+	+	+	+	+
Pinguipedidae	*Parapercis*	+	+	+	+	+
Scorpionidae	*Dendrochirus*	+		+	+	+

Furthermore, this RA station exhibits a relatively low level of human activity, such as shipping, port operations, and settlement, compared to other stations because entry to this area is only accessible by walking and using a small boat. One of the regional factors that can affect water conditions is the season in data collection. Seasons play a crucial role in influencing various aspects of marine ecosystems. Freshwater rivers experience increased discharge and drainage during the rainy season, leading to a higher concentration of organic material and dissolved nutrients in seawater. This influx of nutrients results in abundant reef fish (Zamani 2022). Furthermore, internal factors come from the research itself, apart from local and regional factors. Data collection for fish surveys is limited to daylight hours, so results may be biased compared to fish at night. In addition, the location for collecting data on coral reefs and coral fish surveyed between stations is too far (even less than 5 kilometers). The results do not provide a comprehensive assessment scale nor show greater similarity in substrate composition or reef fish abundance (Elston et al. 2020).

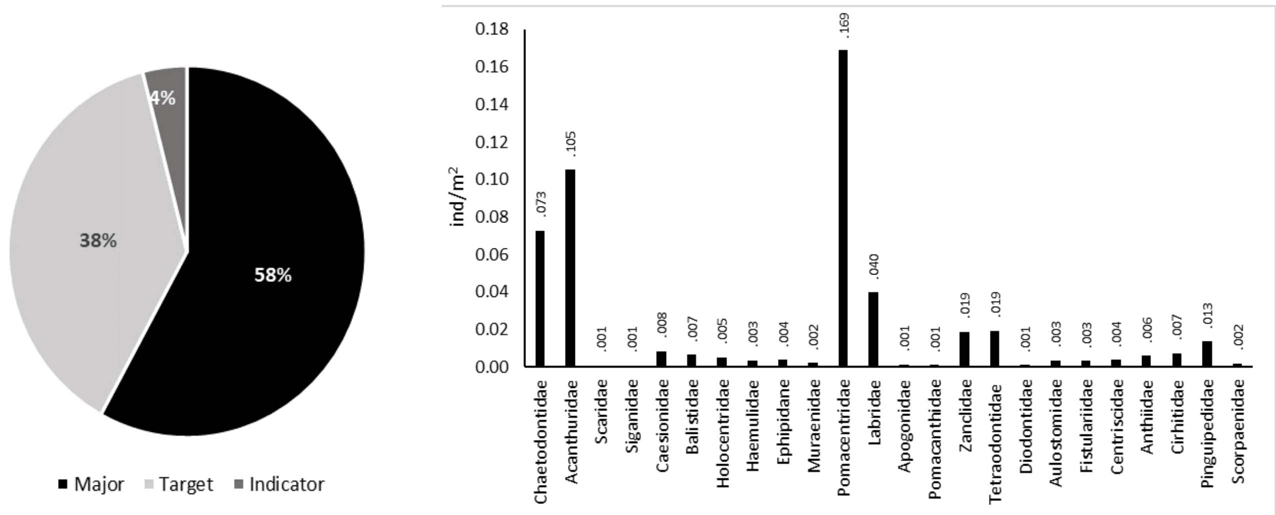
Reef fish group

The fish found throughout the station were grouped into three large groups: indicator, target, and major fish. Indicator fish are found in as many as 10 species of 2 genera belonging to the family of Chaetodontidae or butterflyfish. The target species of fish were found to include 21 species belonging to 11 genera and coming from 9 families, namely Acanthuridae, Scaridae, Siganidae, Caesionidae, Balistidae, Holocentridae, Haemulidae, Ephipidane, and Muraenidae. Meanwhile, major fish are found in as many as 50 species of 31 genera belonging to 14 families, consisting of Pomacentridae, Labridae, Apogonidae, Pomacanthidae, Zanclidae, Tetraodontidae, Diodontidae, Aulostomidae, Fistulariidae, Centriscidae, Anthiidae, Cirhitidae, Pinguipedidae, and Scorpaenidae. The abundance of coral reef fish based on their function and families can be seen in Figure 4 and Figure 5.

The study revealed the large fish category has the highest abundance in the waters of the Sempu Strait, namely 58% of the total abundance. The family Pomacentridae, or damselfish, contains the most extensive assemblage of important fish. The coral reef environment is mainly inhabited by large fish widely used as ornamental fish (Tony et al. 2020). The study also indicated that the Pomacentridae family has the greatest abundance among all the families studied. The Pomacentridae family belongs to planktivorous fish, with certain members also belonging to the omnivorous family. This family predominantly inhabits coral reefs and exhibits territorial behavior characterized by limited movement away from food sources and shelter. This specific family prefers coral reefs covered with branching corals (Ulfah et al. 2020).

The second most common group is the target fish category, comprising 27% of the total. It is mostly dominated by the Acanthuridae family, specifically the surgeonfish. Target fish refers to a category of fish that is consumed and holds significant economic worth. These fish are classified as herbivorous due to their reliance on macroalgae as a source of nutrition. Herbivorous reef fish are of significant importance in increasing the resilience of coral reefs due to their ability to restrict the presence and development of macroalgae (Sheppard et al. 2023).

The indicator fish category refers to the fish from the Chaetodontidae family, specifically the butterflyfish, with the lowest percentage value of 15%. A notable characteristic of the Chaetodontidae family is its diverse color patterns. Indicator fish refers to a certain species of fish that have a significant association with corals or a high degree of dependence on the presence of corals within a coral environment. The abundance of the Chaetodontidae family is directly impacted by the destruction of coral reefs (Riskiani et al. 2019).



A B

Figure 4. A. Abundance of reef fish based on function, B. Abundance of reef fish based on families

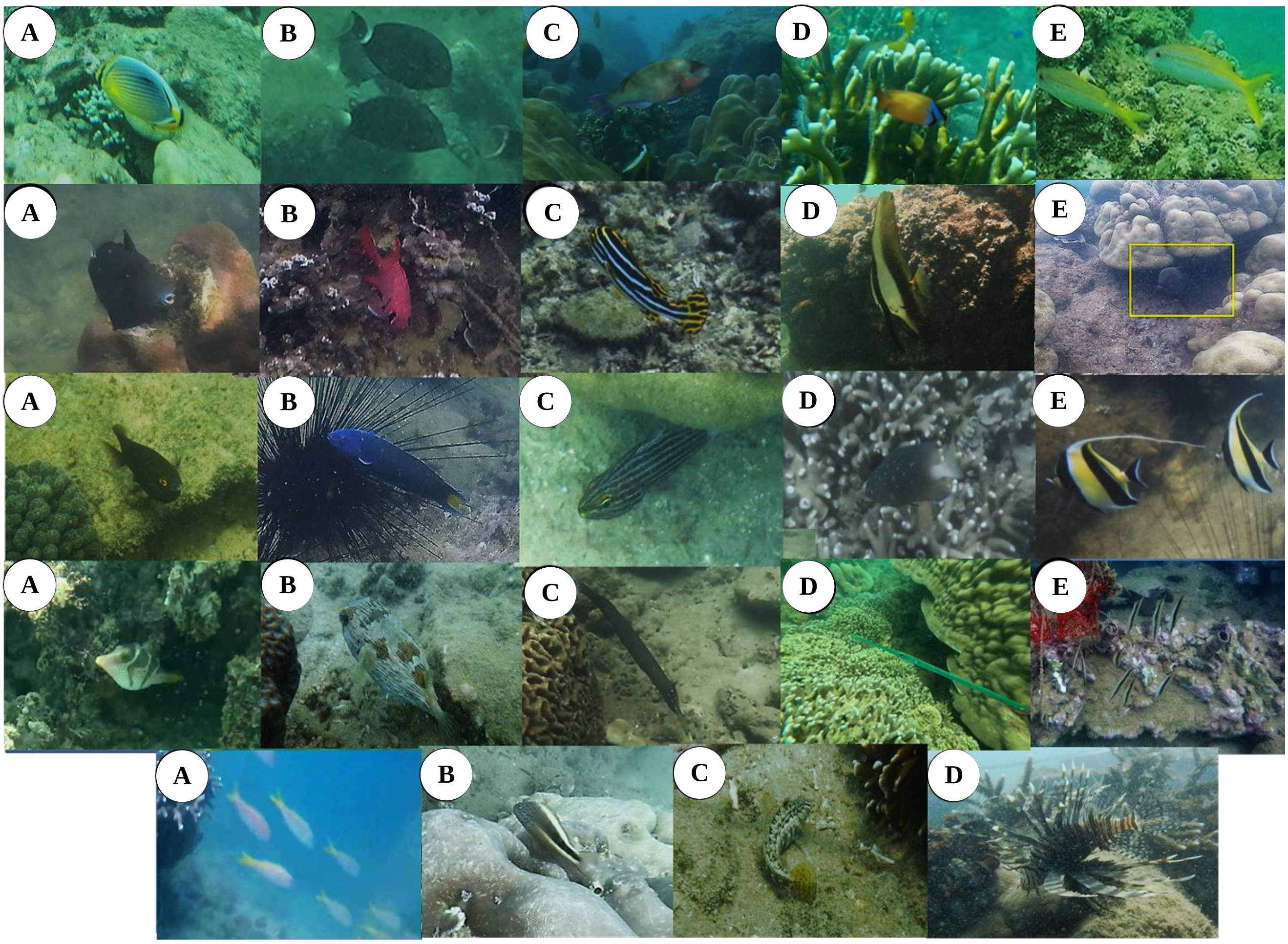


Figure 5. Families of reef fish in Sempu Strait, Malang, East Java, Indonesia. A. Chaetodonidae, B. Acanthuridae, C. Scaridae, D. Siganidae, E. Caesionidae, F. Balistidae, G. Holocenthridae, H. Haemulidae, I. Ephippidae, J. Muraenidae, K. Pomacentridae, L Labridae, M. Apogonidae, N. Pomacanthidae, O. Zanclidae, P. Tetraodontidae, Q. Diodontidae, R. Aulostomidae, S. Fistulariidae, T. Centriscidae, U. Anthiidae, V. Cirrhitidae, W. Pinguipedidae, X. Scorpaenidae

Table 5. Ecological index of reef fish

Station	Diversity	Criteria	Uniformity	Criteria	Dominance	Criteria
Jetty	2.249	Moderate	0.773	Stable	0.151	Low
Rumah Apung	1.923	Moderate	0.699	Stable	0.206	Low
Banyu Tawar	1.916	Moderate	0.727	Stable	0.203	Low
Waru-waru	1.744	Moderate	0.662	Stable	0.255	Low
Watu Meja	1.995	Moderate	0.725	Stable	0.194	Low

Reef fish community structure

The diversity of reef fish species in reefs greatly affects the balance of ecosystems in the waters. The differential values of each station can be seen in Table 5, The diversity index (H') value ranges from 1.744 to 2.249. This can be seen from the diversity index (H') criteria of Shannon Weiner (Krebs 2014). Table 5 indicates that reef fish diversity of the Sempu Strait is "moderate" and has moderate community stability. Fish community structure is known to be positively influenced by coral diversity and certain coral species (Darling et al. 2017). Similarly, Luza et al. (2022) stated that fish species have a stronger connection with coral than with turf algae, underscoring the crucial role of coral species in sustaining fish occurrence. Furthermore, Komyakova et al. (2018) examined the correlations between coral species, fish species richness, and fish abundance, revealing that coral species have a major impact on the diversity and structuring of reef fish ecosystems.

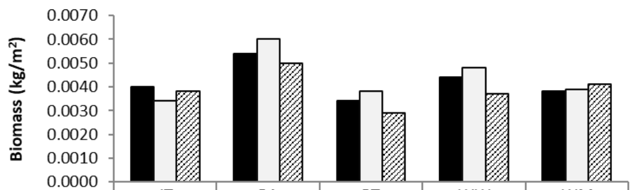
The stability of a community is indicated by the homogeneity index (E). According to Table 5, the range of the diversity index was from 0.662 to 0.773. The diversity value of the five stations, as determined by the criteria of 0.6 E≥1 (Odum 1971), may be inferred that the Sempu Strait waters show a "stable" diversity index. This suggests that the condition is not characterized by a decline or the presence of a dominant family or fish species. The Coral Reef Dominance Index (C) pertains to the notable prevalence or abundance of one or more fish species that exert control over the coral reef fish community within a specific area or region. The dominance index derived from the analysis of the five stations fits within the range of 0.151-0.255. According to Odum (1971), the dominance score of 0.5 on the five stations implies a "low" level of dominance. This observation shows that the distribution and role of fish species in the coral reef ecosystem are evenly distributed throughout the research location, with no particular species dominating in one area. The low value of the dominance index is visible at all stations. All research locations show H' and E index values, which indicate that environmental conditions support the survival of coral fish.

Reef fish biomass

Fish biomass is needed to see optimal levels of productivity in conservation areas. Based on the results of data analysis, the average value of reef fish biomass at each station was obtained from 3 months of data collection. Biomass at JT station (0.0037 kg/m^2), RA (0.0054 kg/m^2), BT (0.0034 kg/m^2), WW (0.0043 kg/m^2), and WM (0.0039 kg/m^2). It is known that the highest biomass values are at RA stations, and the lowest biomass was at BT stations. The result is the average total biomass of coral reef fish in the entire station is 0.0207 kg/m^2 or 207,571 kg/Ha. Based on Giyanto et al. (2017), the biomass is in the criteria <970 kg/Ha and belongs to the "low" category. The biomass reef fish of each station and each month can be seen in Figure 6.

Several factors affect the high biomass of coral reef fish at the RA station. One of the factors that greatly affect the high low biomass of coral reef fish is the health and sustainability of the existence of the reef that is found in the waters. The RA station exhibits the largest percentage of living coral coverage, as determined by its coral coverage percentage. Furthermore, it should be noted that the correlation between fish biomass and fish abundance is not necessarily linear. Due to the high quantity, there is a greater likelihood of observing fish with a smaller body form and weight than fish with a larger weight. It is stated in Ackerman et al. (2004) that little variations in the estimated size of large-scale fish can magnify the variations in the community's estimated weight and total biomass. Often, bigger carnivorous fish add more to the group's total biomass than do incredibly many little carnivorous species. Large fish also often hunt for fishermen but are generally more cautious and stay away from divers than smaller fish (Januchowski-Hartley et al. 2015; Goetze et al. 2017).

Another factor is the anthropogenic impact that occurs through habitat or environmental degradation that ultimately reduces the capacity of affected reefs to support the structures of the community life of marine species such as fish. Reef fish biomass is also very susceptible to biophysical factors, which include island type, marine productivity, and habitat complexity (Robinson et al. 2017). Other features include the significant fish population compared to other stations and several fish with a total length above 10cm. Within the RA station, it was observed that fish belonging to the Diodontidae family, exclusive to the RA and WM stations, had substantial weights per species. This has an impact on the estimation of fish weight at the station. Several studies have indicated that fish biomass is influenced not only by the environmental conditions of coral reefs but also by the pressure exerted on the fish through exploitation or capture. The primary factors contributing to the extinction of local biota and the decline of environmental services are excessive exploitation and habitat degradation.



	JT	RA	BT	WW	WM
December	0.0040	0.0054	0.0034	0.0044	0.0038
February	0.0034	0.0060	0.0038	0.0048	0.0039
April	0.0038	0.0050	0.0029	0.0037	0.0041

Figure 6. Reef fish biomass

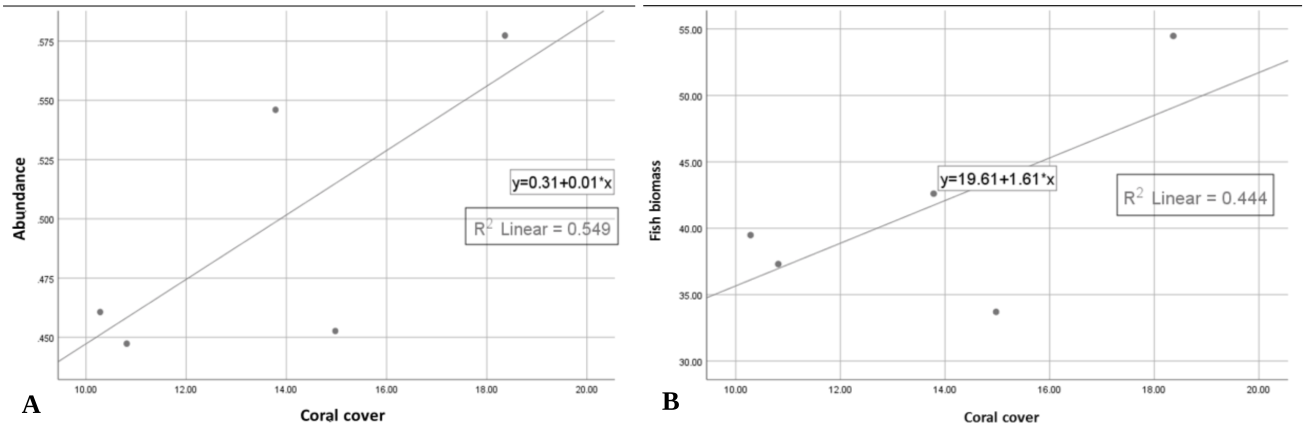


Figure 7. A. Regression test of coral fish abundance with coral cover; B. Regression test of coral fish biomass with coral cover

Correlation between live coral cover, reef fish abundance, and biomass

The percentage of live coral cover and reef fish abundance was positively and significantly correlated, according to the Pearson correlation test findings of 0.741 (Figure 7.A). This implies that the quantity of reef fish increases with the amount of living coral cover. Around 74.1% of the abundance of coral fish is influenced by the condition of live coral cover. Meanwhile, around 25.9% of the remaining coral fish abundance can be influenced by factors outside the variables tested, such as season, water parameters, time and hour of data collection, etc. The findings of this study align with the research conducted by Ulfah et al. (2020), which showed a correlation coefficient of 0.549.

The correlation analysis on the relationship between coral covering and reef fish biomass (Figure 7.B) showed a correlation coefficient of 0.666, indicating a positive and strong relationship. This implies that the higher the percentage of living coral coverage, the higher the reef fish biomass. A regression test with a determination value of 0.444 was obtained, which means that the coverage of living corals has an impact of 44.4% on the reef fish biomass, with the remaining 55.6% influenced by other factors or variables. Damaged coral reefs will reduce the quantity of reef fish (Kusuma et al. 2020). Most coral reef fish live near the reef substrate and have a strong connection to the habitat structure (biological and/or physical) offered by scleractinian corals. Up to 75% of reef fish depend on live coral for food and protection. Therefore, coral cover often has a large positive relationship with the abundance and diversity of coral reef fish (Rizal et al. 2022). Environmental factors that contributing to a loss in living coral coverage include strong biota competition from macroalgae, sponges, and soft corals, low coral recruitment, unstable water substrates, high sedimentation, and increasing global CO_2 concentrations (Gowan et al. 2014; Ashani et al. 2019).

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