

Analysis of reef fish community structure as a basis for identifying potential OECM in the Kilwaru-Kiltay Area, East Seram, Indonesia

Mujiyanto Mujiyanto^{1*}, Ofri Johan¹, Andrias S. Samusamu¹, Reny Puspasari¹, Tirtadanu Tirtadanu², Karsono Wagoyo², Masayu Rahmia Anwar Putri¹, Muhammad Taufik², Puput Fitri Rachmawati², Prihatiningsih Prihatiningsih², Yayuk Sugianti¹, Adipati Rahmat³, and Ahadar Tuhuteru³

¹Research Center for Conservation of Marine Resources and Inland Waters, National Research and Innovation Agency, Kawasan Sains dan Teknologi Dr. (H.C.) Ir. H. Soekarno Jalan Raya Jakarta-Bogor, Cibinong, Bogor 16911, West Java, Indonesia

²Research Center for Fishery, National Research and Innovation Agency, Kawasan Sains dan Teknologi Dr. (H.C.) Ir. H. Soekarno Jalan Raya Jakarta-Bogor, Cibinong, Bogor 16911, West Java, Indonesia

³Directorate General of Capture Fisheries, Ministry of Marine Affairs and Fisheries, Gedung Mina Bahari II Lantai 14, Jalan Medan Merdeka Timur No.16, Central Jakarta, Indonesia

Abstract. Reef fish communities are widely used as sensitive bioindicators of coral reef ecosystem condition and provide an ecological basis for area-based conservation planning, including Other Effective Area-based Conservation Measures, yet site-specific ecological evidence supporting OECM screening remains limited in many eastern Indonesian reef systems. This study assessed reef fish community structure at nine stations in the Kilwaru-Kiltay waters, East Seram, using a standardized Underwater Visual Census conducted in May-June 2023, with species-level identification based on direct underwater observations and standard identification guides. Community structure was evaluated using abundance metrics, ecological indices, and Principal Component Analysis at family and species levels. A total of 115 reef fish species were recorded, showing high species richness and pronounced spatial variation among stations. Pomacentridae consistently dominated most sites, while diversity, evenness, and dominance indices revealed clear site-specific differences in internal community organization rather than uniform ecological conditions. Multivariate ordination further highlighted distinct spatial differentiation in assemblage composition and functional group structure across stations. These results demonstrate that reef fish community structure provides a robust, site-specific ecological indicator for screening potential OECM areas and supports spatially informed conservation planning beyond formally protected areas in eastern Indonesia.

* Corresponding author: muji019@brin.go.id

Keyword: reef fish, underwater visual census, ecological indices, principal component analysis, OECM

1 Introduction

Reef fish are an important component of reef health in coral reef ecosystems. They serve as bioindicators of ecosystem health, control algal dynamics via herbivore guilds, and support coastal fisheries [1]. Reef-associated organisms are highly sensitive to changes in habitat structure and water quality, as these factors directly affect ecological functioning, species interactions, and community resilience. Indonesia lies at the core of the Coral Triangle region and supports approximately 30 per cent of the world's coral reef area while harbouring nearly 75 per cent of all known coral species, highlighting its global importance for coral reef biodiversity [2]. Therefore, reef fish dynamics in Indonesian waters are of significant biogeographic and conservation importance [3]. At the bioindicator scale, reef fish groups such as Chaetodontidae are widely applied in reef health assessments because they respond quickly to habitat degradation. The strong ecological dependence of this family on live coral cover makes their presence and abundance reliable indicators of coral reef condition [4]. There is pressure from climate change, and human activities (warming, eutrophication, and sedimentation) reduce ecosystem resilience. Sea surface temperature increases of $>2\text{ }^{\circ}\text{C}$ have been recorded as a cause of mass coral mortality, which in turn alters fish community structure [5]. In the context of reef ecosystem function, reef fish herbivore abundance is generally inversely related to algal dominance, maintenance of coral recruitment space, and stability of ecological processes [6]. Consistent assessment of reef fish community structure across sites and sampling periods is commonly achieved through both underwater visual census (UVC) and functional group categorization [7]. This combined approach offers a standardised framework that enhances comparability among locations and facilitates the identification of essential ecological indicators, providing a consistent basis for integrated reef health assessments and management decisions [8].

In recent years, research conducted in the East Seram waters, particularly the Kilwaru-Kiltay area, has indicated that ecosystem-based assessments show a "yellow zone" risk status for several important species. There is evidence that coral reef ecosystems experience significant anthropogenic pressure, where both the intensity of fishing and the use of destructive fishing gear are linked to coral reef degradation and subsequent impacts on habitat complexity and associated fish assemblages [9]. This necessitates the implementation of more adaptive fisheries management based on spatial management, and community involvement is required. In line with this concept, the ecosystem-based management framework, known as EAFM (Ecosystem Approach to Fisheries Management), values "fishing techniques" as a key element in balancing ecological-socioeconomic objectives. A study evaluating the status of ecosystem-based fisheries management using EAFM indicators reported that, despite overall moderate performance, gaps persist in domains such as resource capacity, fishing effort, legal vessel documentation, and crew certification, indicating the need for targeted improvements to achieve more effective implementation [10]. Comparative research based on protected area classification systems has shown that the distribution and abundance of coral fish can vary significantly among zones (core, protected, and used). This classification emphasizes the importance of accurate spatial design to maintain ecosystem services and resilience of fish stocks in coastal and marine areas [1]. Connectivity with seagrass beds and mangrove forests is also associated with improved ecological conditions and higher reef fish richness, which is an important lesson for designing OECM networks that rely on conservation values outside formally protected areas. Regarding restoration, biotransplantation methods on dead coral substrates have demonstrated technical feasibility

and improved community indicators and have the potential to be combined with community-based ecotourism to strengthen social capital and conservation finance [4, 8]. Overall, this evidence underscores the need for measurable analyses of the reef fish community structure as a scientific basis for identifying potential OECM sites in Kilwaru-Kiltay, East Seram.

This study aimed to analyze the reef fish community structure in the Kilwaru-Kiltay area (East Seram) as an evidence base for screening other potential effective area-based conservation measures (OECM). Specifically, this study focuses on characterizing taxonomic and functional diversity and trophic composition as core descriptors of reef fish assemblages, examining spatial patterns of community composition across reef zones based exclusively on reef fish community metrics, identifying candidate sites that consistently exhibit high ecological value, resilience-related attributes inferred from community structure (e.g., indicator taxa presence and balanced assemblage composition), and practical management feasibility. Multivariate ordination and classification were applied to explore patterns of community assemblages and spatial contrasts among reef zones, providing an integrated view of the reef fish structure within a spatial management context. The resulting ecological metrics were interpreted within an OECM screening framework to inform area-based conservation options, including adaptive zoning, effort regulation, and community-led restoration, thereby strengthening locally grounded governance while supporting biodiversity conservation and fisheries sustainability.

2 Method

2.1 Time and location

The reef fish observation stations were evenly distributed throughout the Seram Laut waters in the Kilwaru Kiltay district, encompassing nine locations along the reef divide and wind flow gradients (windward, leeward, and current channels) to reflect habitat diversity. The sampling locations were selected based on the *Sasi* area (traditional management of a conservation area). It is shaped by local oceanographic features, including oceanic water masses, semidiurnal tidal cycles [11], and the interconnected mosaic of mangrove-seagrass-coral ecosystems that drive community dynamics [12]. Data collection was conducted in May and June 2023, and the sampling stations and their respective locations are presented in **Fig. 1**. Beyond ensuring adequate ecological representation, the station layout was developed in line with Ecosystem-Based Fisheries Assessment principles to enhance spatial planning for habitat conservation and support the implementation of effective, community-based management strategies to sustain coral reef fisheries.

2.2 Data collection

Reef fish diversity and abundance data collection was conducted using the Underwater Visual Census (UVC) method, based on belt transects, developed from the belt transect approach described in the Survey Manual for Tropical Marine Resources, 2nd edition [13]. It is a standard and reproducible method that allows comparisons between studies [14]. At each station, a census visual was conducted along a 100-m transect line (tape measure) with a width of 5 m ($\pm$ 2.5 m left and right of the line), resulting in a total observation area of 500 m² per station. This protocol aligns with standard underwater visual census approaches applied in comparable studies. Conducting UVC surveys at depths of approximately 3-4 m in shallow reef zones optimises observer visibility and ensures adequate representation of the reef fish community. Similar methodological considerations have been widely adopted in regional reef fish assessments, reflecting practical experience in shallow coral reef

environments. Reef fishes were identified to the species level in situ whenever possible; individuals that could not be confidently identified underwater were documented using underwater photographs and subsequently identified using standard reef fish identification guides [15, 16], as well as online taxonomic references such as the World Register of Marine Species (WoRMS).

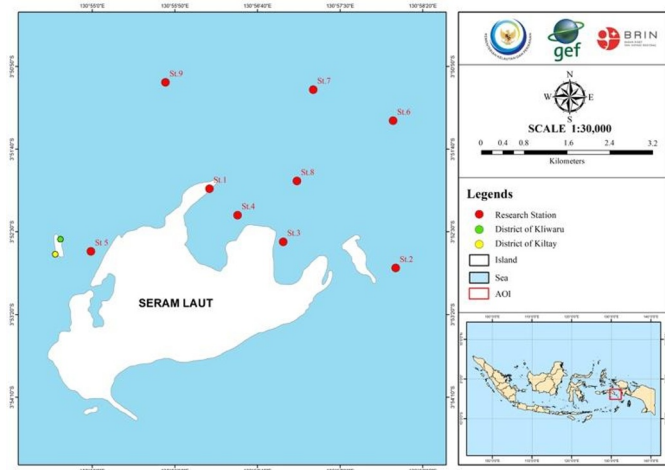


Fig. 1. Reef fish observation stations in Kilwaru-Kiltay waters, Seram Laut Island, East Seram, Indonesia.

2.3 Data analysis

2.3.1 Density

Reef fish density or abundance refers to the number of individuals per unit area of observation, and is a fundamental ecological indicator for evaluating the condition of coral reef ecosystems. Density is commonly calculated using the formula proposed by [17]: $D = \frac{\sum Ni}{A}$; where N_i denotes the number of individuals of species i and A represents the surveyed area. In this study, reef fish density was strictly applied as a quantitative ecological metric, without the use of categorical thresholds, given that density values are highly influenced by local environmental conditions and sampling design.

Numerous studies have consistently documented substantial spatial variability in reef fish density across locations, indicating that density patterns are more reflective of site-specific ecological contexts than are universal benchmarks. Research on coral reefs has shown that reef fish densities may remain relatively low even when species richness is moderate to high, suggesting spatial decoupling between abundance and diversity under specific local conditions [18]. Similarly, surveys conducted in the waters of West Belitang recorded 1,917 reef fish belonging to 66 species, with density values varying markedly among sites and closely associated with local habitat characteristics [19]. Comparable patterns of spatial heterogeneity in reef fish density driven by variations in habitat structure and disturbance regimes have also been reported in other tropical reef systems [20]. Collectively, these findings underscore the pronounced spatial heterogeneity of reef fish density across regions and caution against the application of fixed-density categories for ecological assessment. Instead, they highlighted the critical role of habitat conditions, reef structural complexity, and ecosystem-level interventions in shaping reef fish density patterns, thereby supporting a site-specific interpretation of density values within the Kilwaru-Kiltay area.

2.3.2 Diversity index

The diversity index of coral fishes was calculated using the Shannon-Wiener index [21] with the following formula: $H' = -\sum_{i=1}^S P_i \ln P_i$; where H' = Shannon-Wiener diversity index, P_i = percentage of individuals of the i th species (n_i/N), n_i = number of individuals of the i th species at each station, N = total number of individuals of all species, and S = number of species found [22]. The H' value is then categorized into three diversity levels: low ($H' \leq 1$), moderate ($1 < H' < 3$), and high ($H' \geq 3$). The Shannon-Wiener diversity index (H') is classified as low ($H' \leq 1$), moderate ($1 < H' < 3$), or high ($H' \geq 3$). This index is widely used in reef fish ecology to reflect community stability and serve as an indirect measure of ecological pressure on reef habitats. Most empirical studies report H' values within the moderate range, indicating balanced community structures under intermediate environmental stress.

2.3.3 Evenness index

The evenness index was calculated based on the Shannon-Wiener formula [23]: $E'_1 = \frac{H'}{H_{\max}}$; where $E'_1 = H'$ = Shannon-Wiener diversity index, $H_{\max} = \ln s$, and s = species number. This index describes how evenly distributed individuals of each species are within a community. An E'_1 value close to 1 indicates a stable community with a relatively even distribution of individuals, whereas a low value indicates dominance by a particular species. According to [24], evenness is categorized into five levels: uneven (0.00-0.25), less even (0.26-0.50), fairly even (0.51-0.75), almost even (0.76-0.95), and even (0.96-1.00). Previous ecological assessments have reported high evenness values exceeding 0.90, which indicate a stable community structure. Comparable patterns have been observed in other reef fish assemblages, where E' values range between 0.88 and 0.95, commonly reflecting a relatively uniform distribution of individuals among species within reef habitats.

2.3.4 Dominance index

The dominance index was used to describe the extent to which a species dominated a community within an ecosystem. The formula used was derived from $C = \sum \left[\frac{n_i}{N} \right]^{-2}$; where C is the dominance index, n_i is the number of individuals of the i th species, and N is the total number of individuals of all the species. Dominance index values ranged from 0 to 1. Dominance analysis is important for assessing the structure of reef fish communities because high dominance generally correlates with low diversity and ecosystem stability. Dominance indices are essential for evaluating reef fish community structure, as elevated dominance values are typically associated with reduced diversity and lower ecosystem stability. Empirical studies of coral reef fish assemblages have reported low to moderate dominance levels, suggesting that no single species controls the community and that the ecosystem maintains a relatively balanced and stable state.

2.3.5 Analysis of reef fish composition closeness

To analyze reef fish community closeness between stations, a multivariate approach using Principal Component Analysis (PCA) [25] was applied at two levels: family and species. The analysis emphasized PCA as an ordination method for summarizing patterns in the reef fish community composition among stations. The abundance data from each station were standardized and transformed to ensure the homogeneity of the scale and distribution. Family level PCA was used to investigate the ecological associations between functional groups such

as herbivores, planktivores, and predators. Simultaneously, species-level PCA provided a more detailed solution for the relationships between dominant species and potential specific ecological niches. The PCA biplot shows the relative positions of stations based on similarities in the reef fish assemblage structure, with stations closer together reflecting comparable community composition shaped by local site characteristics. This was similar to the study by [26], which emphasised the use of PCA and other multivariate analyses to reveal the correlation between benthic physical conditions and the structure of coral fish communities.

3 Results and discussion

3.1 Reef fish composition

The total number of reef fish identified at the nine observation stations was 7,372 individuals, representing 115 species. The reef fish species composition at the nine stations showed striking differences between the sites, both in terms of the number of individuals and taxonomic distribution. The reef fish community was consistently dominated by the Pomacentridae family. Representative genera included *Chromis*, *Dascyllus*, and *Chrysiptera* (**Table 1**). This family plays a key role in shaping community structure across sampling units, as noted in multiple ecological assessments. Species composition may vary among sites and depths, but Pomacentridae frequently remains the most prevalent group. This indicates its strong ecological dominance within reef fish assemblages. Similar results were obtained in the Sempu Strait, where variations in fish populations between stations indicated that Pomacentridae was the most common family [27].

At Station 2, the highest densities were *Chromis viridis* (424 individuals) and *Chrysiptera cyanea* (221 individuals) (**Table 1**), making this station the most abundant location at all stations. This indicates that habitat conditions continue to support the presence of planktivorous fish, which are closely associated with branching corals. This finding is consistent with research confirming that planktivorous damselfish (Pomacentridae) are a dominant component of tropical coral reefs, where complex coral habitat conditions strongly influence their abundance and play a crucial role in energy transfer from plankton to coral reef ecosystems [28]. Station 2 also demonstrated the dominance of small schools of fish, which play a crucial role in the coral food chain. Station 1, on the other hand, showed relatively low values, with a predominance of *Pomacentrus proteus* (230 individuals), but relatively slight variation in other species. This indicates that despite the high number of individuals, the species composition was uneven, resulting in a high likelihood of the dominance of particular species. Stations 6 and 9 also showed high diversity, with the presence of many economically important families such as Lutjanidae, Serranidae, and Scaridae as well as indicator fish from the Chaetodontidae family. *Lutjanus rufolineatus* (23 individuals at Station 6, increasing significantly to 137 individuals at Station 9), as a target species based on its function, indicates the potential for good coral reef fish stocks at this location. These results are consistent with those of demographic studies showing that *L. rufolineatus* is a relatively short-lived snapper species (≤ 12 years) with early sexual maturity. Populations generally recover faster than those of other species, although ecologically sound management is necessary to maintain sustainability [29]. In contrast, stations 4 and 5 were among the sites with the lowest abundances. Only a few species were found, which generally belong to the Pomacentridae group, with limited abundance. This may indicate habitat degradation or fishing pressure, which decreases the abundance and diversity of reef fish. Generally, *Chromis viridis* and *Chrysiptera cyanea* dominated at Station 2. In contrast, the lowest abundances were recorded at stations 4 and 5, with a very limited abundance (**Table**

1). This distribution indicates differences in habitat quality among the stations. It was influenced by substrate conditions, live coral cover, and varying anthropogenic pressures at each site.

Table 1. Composition of reef fish species recorded at nine observation stations in the Kilwaru-Kiltay.

Family/Species	Research Stations								
	1	2	3	4	5	6	7	8	9
ACANTHURIDAE									
<i>Acanthurus auranticavus</i>	-	15	-	-	-	25	2	-	-
<i>Acanthurus lineatus</i>	-	-	-	-	-	5	18	-	3
<i>Acanthurus pyroperus</i>	-	-	-	-	-	-	3	-	4
<i>Acanthurus leucopareius</i>	-	-	-	-	-	-	1	-	2
<i>Acanthurus triostegus</i>	-	13	-	-	-	2	-	-	-
<i>Ctenochaetus bonotatus</i>	-	-	-	2	-	-	10	-	-
<i>Ctenochaetus striatus</i>	-	186	-	-	-	269	83	2	118
<i>Paracanthurus hepatus</i>	-	-	-	-	-	6	-	-	1
<i>Zebрасoma scopas</i>	-	27	-	2	-	2	-	-	3
BALISTIDAE									
<i>Melichthys indicus</i>	-	-	-	2	-	1	-	-	-
<i>Melichthys niger</i>	-	-	-	-	-	10	9	-	4
<i>Odonus niger</i>	-	-	-	-	-	22	-	-	38
CAESIONIDAE									
<i>Caesio caeruleaurea</i>	-	-	13	12	-	-	-	-	73
<i>Pterocaesio randalli</i>	-	-	-	34	-	-	-	-	33
CHAETODONTIDAE									
<i>Chaetodon falcula</i>	3	-	1	-	-	-	-	-	-
<i>Chaetodon kleinii</i>	-	-	1	-	-	-	-	-	2
<i>Chaetodon lineolatus</i>	-	2	-	-	-	-	-	-	2
<i>Chaetodon melannotus</i>	6	-	21	1	-	6	-	7	-
<i>Chaetodon rafflesi</i>	-	3	1	-	1	-	3	1	-
<i>Chaetodon speculum</i>	-	-	-	10	-	-	2	-	-
<i>Chaetodon triangulum</i>	-	-	-	-	-	2	2	-	-
<i>Chaetodon trifascialis</i>	-	-	-	-	-	-	2	-	6
<i>Chaetodon ulietensis</i>	-	-	4	-	-	-	3	-	-
<i>Chaetodon vagabundus</i>	2	5	2	-	3	5	1	1	2
<i>Chaetodon lunulatus</i>	-	-	25	2	10	-	10	2	-
<i>Forcipiger longirostris</i>	-	-	-	-	-	-	4	-	22
<i>Heniochus acuminatus</i>	-	-	4	-	-	6	-	-	-
<i>Heniochus chrysostomus</i>	-	9	-	-	-	-	-	-	6
<i>Heniochus varius</i>	2	-	-	-	-	-	4	-	9
CHELONIIDAE									
<i>Eretmochelys imbricata</i>	-	-	3	-	-	1	-	-	-
CYPRAEIDAE									
<i>Cypraea tigris</i>	-	-	-	-	-	-	-	1	4
GOBIDAE									
<i>Istigobius rigilius</i>	-	-	3	1	-	-	-	-	-

Family/Species	Research Stations								
	1	2	3	4	5	6	7	8	9
GRYPHAEIDAE									
<i>Hyotissa hyotis</i>	-	3	-	-	7	-	-	3	-
HAEMULIDAE									
<i>Plectorhinchus polytaenia</i>	-	-	-	-	-	-	5	-	1
<i>Plectorhinchus vittatus</i>	-	-	-	-	-	-	5	-	2
<i>Plectorinchus albobittatus</i>	-	-	-	-	-	-	24	-	17
<i>Plectorinchus lineatus</i>	-	-	-	-	-	-	12	-	8
HOLOCENTRIDAE									
<i>Myripristis bumsdjan</i>	-	-	-	-	-	-	64	-	6
<i>Myripristis chryseres</i>	-	-	-	-	-	1	22	-	21
LABRIDAE									
<i>Cheilinus fasciatus</i>	-	-	20	-	-	-	-	-	7
<i>Cheilinus undulatus</i>	-	-	-	-	-	-	4	-	1
<i>Halichoeres hotulanus</i>	-	-	4	1	4	-	-	-	-
<i>Hemigymnus melapterus</i>	-	-	-	-	-	-	1	-	4
<i>Labroides bicolor</i>	-	-	-	-	-	3	-	4	-
<i>Labroides dimidiatus</i>	-	5	1	1	1	6	3	2	2
<i>Thalassoma hardwicke</i>	1	-	-	-	-	-	4	8	9
<i>Thalassoma janseni</i>	-	-	-	-	-	-	4	-	2
LETHRINIDAE									
<i>Monotaxis grandoculis</i>	2	-	-	2	-	-	-	-	3
LUTJANIDAE									
<i>Lutjanus decussatus</i>	-	4	-	-	-	8	5	-	35
<i>Lutjanus fulvus</i>	-	-	-	3	-	-	3	-	12
<i>Lutjanus rufolineatus</i>	-	-	-	-	-	23	-	-	137
MARGARITIDAE									
<i>Pinctada margaritifera</i>	-	-	-	-	-	4	-	-	12
MICRODESMIDAE									
<i>Gunnelichthys viridescens</i>	456	-	-	-	-	12	-	-	-
MULIDAE									
<i>Parupeneus barberinoides</i>	-	-	-	-	-	-	12	-	10
<i>Parupeneus barberinus</i>	-	-	-	2	-	11	2	-	5
<i>Parupeneus bifasciatus</i>	2	-	-	-	-	-	2	-	6
<i>Parupeneus cyclostomus</i>	-	-	-	-	-	-	6	-	8
<i>Parupeneus macronemus</i>	-	-	-	-	-	1	2	-	-
<i>Parupeneus trifasciatus</i>	-	-	-	-	-	-	1	-	3
NEMIPTERIDAE									
<i>Pentapodus trivittatus</i>	1	23	1	-	-	-	1	27	-
OPHIDIASTERIDAE									
<i>Linckia laevigata</i>	-	-	-	2	-	5	-	2	-
<i>Protoreaster nodosus</i>	-	-	2	-	2	2	-	-	-
OREASTERIDAE									
<i>Linckia laevigata</i>	-	7	-	-	-	-	4	-	5
<i>Protoreaster nodosus</i>	-	16	-	12	3	-	-	9	-
OSTRACIDAE									

Family/Species	Research Stations								
	1	2	3	4	5	6	7	8	9
<i>Ostracion cubicus</i>	-	-	-	-	-	-	-	3	1
<i>Ostracion meleagris</i>	-	-	-	-	-	-	-	7	1
PECTINIDAE									
<i>Pecten</i> sp.	-	-	-	-	-	-	-	1	4
PINGUIPEDIDAE									
<i>Parapercis millipunctata</i>	-	2	-	2	-	1	-	-	5
<i>Parapercis tetracantha</i>	-	-	2	-	1	-	-	-	-
POMACANTHIDAE									
<i>Pomacanthus navarchus</i>	-	-	2	-	-	-	-	-	2
<i>Pygoplites diacanthus</i>	1	-	1	-	-	1	-	-	-
POMACENTRIDAE									
<i>Abudefduf bengalensis</i>	40	-	-	-	-	-	-	-	38
<i>Abudefduf vaigiensis</i>	-	-	-	-	-	-	48	2	-
<i>Amblyglyphidodon curacao</i>	25	-	372	23	25	3	-	3	-
<i>Chromis atripectoralis</i>	3	-	35	72		205	5	84	-
<i>Chromis dimidiata</i>	-	-	-	-	-	-	-	2	7
<i>Chromis ternatensis</i>	16	-	83	43	28	9	-	25	-
<i>Chromis viridis</i>	-	424	45	-	-	-	-	-	14
<i>Chrysiptera cyanea</i>	-	221	47	156	10	163	15	33	-
<i>Chrysiptera hemicyanea</i>	-	-	-	-	-	-	-	22	2
<i>Chrysiptera rex</i>	-	-	-	4	19	-	-	-	-
<i>Chrysiptera rolandi</i>	11	-	35	13	34	2	-	-	-
<i>Chrysiptera springeri</i>	4	-	-	-	-	-	-	117	-
<i>Dascyllus aruanus</i>	-	111	12	152	99	-	4	363	-
<i>Dischistodus melanotus</i>	-	4	8	1	-	-	1	4	1
<i>Dischistodus perspicillatus</i>	-	13	9	5	-	-	-	12	-
<i>Hemiglyphidodon plagiometopon</i>	5	44	76	9	8	45	-	15	-
<i>Plectroglyphidodon dicki</i>	-	-	-	-	-	-	1	-	2
<i>Plectroglyphidodon lacrymatus</i>	-	20	4	-	-	16	4	-	-
<i>Pomacentrus alexanderae</i>	-	-	-	-	-	124	11	-	-
<i>Pomacentrus moluccensis</i>	-	73	19	-	-	258	8	-	-
<i>Pomacentrus philippinus</i>	-	-	-	-	-	-	-	5	5
<i>Pomacentrus proteus</i>	230	-	-	-	-	-	-	21	34
PRIACANTHIDAE									
<i>Priacanthus hamrur</i>	-	-	-	-	-	1	-	4	-
SCARIDAE									
<i>Chlorurus atrilunula</i>	-	-	-	-	-	-	8	4	-
<i>Scarus flavipectoralis</i>	-	22	2	-	-	-	2	-	-
<i>Scarus forsteni</i>	-	4	4	-	-	16	7	1	7
<i>Scarus niger</i>	-	-	4	-	-	-	-	-	1
<i>Scarus oviceps</i>	-	-	-	-	-	-	13	-	13
<i>Scarus psittacus</i>	5	7	-	-	-	4	18	-	12
<i>Scarus quoyi</i>	-	7	1	-	-	7	13	-	1
SCOLOPSIDAE									
<i>Scolopsis binileata</i>	-	-	-	1	3	-	-	-	3
<i>Scolopsis lineata</i>	-	-	-	1	3	-	-	-	-

Family/Species	Research Stations								
	1	2	3	4	5	6	7	8	9
<i>Scolopsis margaritifera</i>	1	-	-	1	2	-	1	-	3
SERANIDAE									
<i>Cephalopholis spiloparaea</i>	-	-	-	-	-	-	7	5	8
<i>Epinephelus quoyanus</i>	-	-	-	-	7	-	-	3	6
<i>Epinephelus mera</i>	-	1	-	-	5	-	-	-	-
<i>Plectropomus laevis</i>	-	-	9	-	-	4	-	-	-
<i>Scarus forsteni</i>	-	-	-	3	-	-	3	3	-
SIGANIDAE									
<i>Siganus puellus</i>	-	-	-	-	-	2	1	-	9
<i>Siganus virgatus</i>	-	-	-	-	-	-	3	-	5
<i>Siganus vulpinus</i>	5	-	7	-	-	17	8	-	-
TETRAODONTIDAE									
<i>Arothron nigropunctatus</i>	-	-	-	-	1	-	-	4	4
<i>Diodon hystrix</i>	-	1	-	3	-	-	-	-	4
ZANCLIDAE									
<i>Zanclus cornutus</i>	-	-	5	2	5	21	5	-	12

Note: The table presents the individual compositions of each reef fish species observed at each station based on Underwater Visual Census surveys conducted during the study period. These data illustrate spatial variation in species composition and provide the basis for assessing community structure, dominant taxa, and ecological patterns among stations.

The dominant species composition at nine observation stations in the Kilwaru-Kiltay waters showed striking differences between the sites. At most stations, the family Pomacentridae was predominant, including *Pomacentrus proteus* (230 ind.; Station 1), *Chromis viridis* (424 ind.; Station 2), *Amblyglyphidodon curacao* (372 ind.; Station 3), *Dascyllus aruanus* (152 ind.; Station 4 and 363 ind.; Station 8), and *Chromis atripectoralis* (205 ind.; Station 5) (**Table 2**). The dominance of this group indicates the important role of small planktivorous and omnivorous fishes, which are closely related to the structure of branching corals and availability of algae as a food source. A similar pattern of Pomacentridae dominance was also observed in research following artificial reefs in Saleh Bay, West Nusa Tenggara, demonstrating the reef's intense attraction to large groups such as damselfishes [30]. Ecological investigations of reef fish communities have consistently identified the Pomacentridae family as the most dominant group across the majority of sampling units. This family is frequently recorded in both shallow reef flats and deeper reef slopes, underscoring its ecological significance and its value as an indicator of reef ecosystem condition and overall habitat health. These patterns are in line with experimental findings showing that *Dascyllus aruanus* relies heavily on coral reefs, such as *Pocilloporidae* sp., so any decline in coral cover directly affects their populations [31]. In addition, a survey in Palawan documented no fewer than 137 damselfish species, reinforcing the ecological significance of this group as a key component of tropical reef communities [32].

In contrast, the occurrence of some non-Pomacentridae reef fish species at several stations indicated a more diverse community structure. *Ctenochaetus striatus*, an herbivorous fish in the Acanthuridae family, dominated stations 6 (269 individuals; high category) and 7 (83 individuals; medium category) (**Table 2**), indicating its important role in controlling algal growth on reef substrates. A similar finding was observed in Saleh Bay, where herbivorous species contributed to community enrichment and accelerated habitat recovery [30]. In contrast, Station 9 was uniquely dominated by *Lutjanus rufolineatus* (137 individuals; high

category), a carnivorous fish in the Lutjanidae family, indicating a relatively complete food web with the availability of small fish and invertebrates. The Lutjanidae family has been recognised as a key target group that contributes substantially to the trophic structure of reef fish communities. Differences in depth have been shown to influence the relative abundance of herbivorous and carnivorous fishes, patterns that are closely linked to the condition of live coral cover. Variations in dominance among sampling units indicate that reef ecosystems are not sustained solely by Pomacentridae as a principal group, but are also supported by herbivores and carnivores whose functional roles are essential for maintaining ecological balance within coral reef systems.

Table 2. Dominant reef fish species recorded at nine observation stations in the Kilwaru-Kiltay waters, East Seram.

Stations	Dominant Species (Individuals)	Density Category
1	<i>Pomacentrus proteus</i> (230)	Moderate
2	<i>Chromis viridis</i> (424)	High
3	<i>Amblyglyphidodon curacao</i> (372)	High
4	<i>Dascyllus aruanus</i> (152)	Moderate
5	<i>Chromis atripectoralis</i> (205)	Moderate
6	<i>Ctenochaetus striatus</i> (269)	High
7	<i>Ctenochaetus striatus</i> (83)	Moderate
8	<i>Dascyllus aruanus</i> (363)	High
9	<i>Lutjanus rufolineatus</i> (137)	High

Note: The table summarizes the dominant species at each station based on individual abundance and corresponding density categories derived from Underwater Visual Census data. These results highlight spatial differences in dominant taxa and provide insight into local variation in reef fish community structure among stations.

3.2 Reef fish density

The results of the reef fish density analysis at the nine observation stations showed striking spatial variation. Station 2 recorded the highest density of 2,546 individuals/m² from 1,273 individuals, followed by Station 6 with 2,648 individuals/m² from 1,324 individuals. The high-density values at these two sites indicated habitat conditions with relatively good coral structural complexity, which can support a large reef fish community. Research by [8] Paraja Bay also showed that the reef fish community structure was strongly influenced by the condition of the coral ecosystem, with the Pomacentridae and Labridae families dominating highly complex habitats. In contrast, one sampling unit showed the lowest fish density, at approximately 0.57 individuals per square meter, equivalent to 285 individuals, while several other units also displayed comparatively low values. Comparable patterns reported in previous studies suggest that reduced coral cover is strongly associated with low reef fish abundance, particularly in areas characterised by greater depth and structurally simple substrates. This difference confirms that habitat complexity and substrate conditions play a significant role in determining the variations in reef fish density at each site. [33] showed that reef fish species richness and assemblage composition are largely structured by benthic habitat type and within habitat structural complexity across coral reefs, macroalgae beds, and sand or rubble substrates, implying that variation in live coral structure, rubble fields, and algal habitats can shape the occurrence patterns of key reef fish groups including butterflyfishes (Chaetodontidae), groupers (Serranidae), and snappers (Lutjanidae).

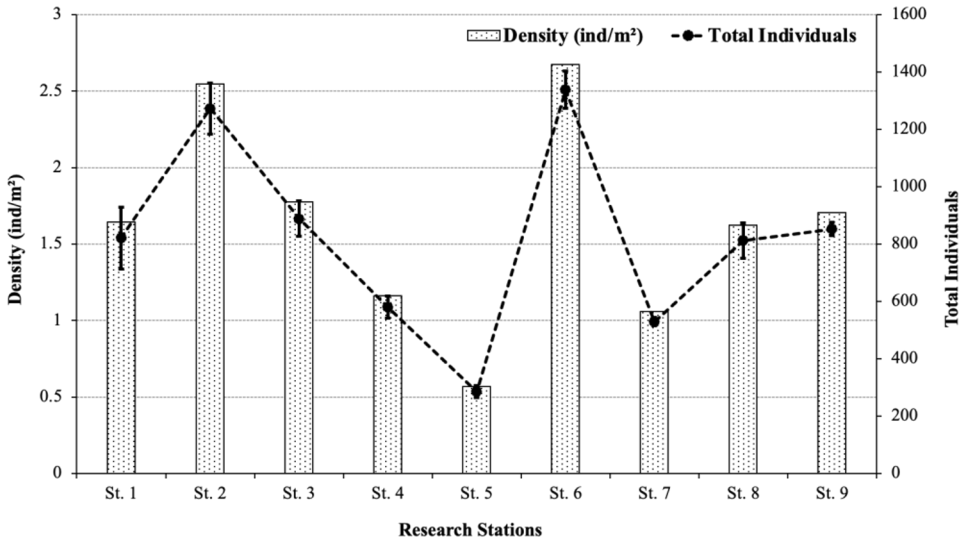


Fig. 2. Reef fish density values recorded at each observation station in the Kilwaru-Kiltay waters, East Seram (Note: The figure illustrates variation in reef fish density among stations based on Underwater Visual Census data, highlighting spatial differences in abundance patterns that reflect local habitat conditions and community structure).

The species composition at each station showed a strong dominance of the Pomacentridae family, with significant contributions from planktivores, such as *Chromis viridis*, *Chrysiptera cyanea*, *Amblyglyphidodon curacao*, *Dascyllus aruanus*, and *Pomacentrus proteus*. At station 2, the community was marked by a high number of *Chromis viridis* (424 individuals) and *Chrysiptera cyanea* (221 individuals), whereas station 3 was dominated by *Amblyglyphidodon curacao* (372 individuals). *Dascyllus aruanus* was particularly abundant at stations 4 (152 individuals) and 8 (363 individuals), whereas *Chromis atripectoralis* was most prominent at station 5 (205 individuals). Research by [34] Tunda Island also showed that Pomacentridae was a family that consistently dominated the reef fish community following coral transplantation, reflecting their role as a key group that is highly dependent on living coral structures. It was also confirmed that dominance of Pomacentridae reflects not only reef ecosystem health but also corresponds with improvements in coral habitat structure associated with restoration outcomes [34].

3.3 Ecological index of reef fishes

Diversity index (H') values indicated significant spatial variation in the reef fish community at each observation station. The lowest value was found at station 1 ($H' = 1.36$), indicating a low-diversity community structure with a strong dominance of a few species, particularly *Pomacentrus proteus*. This pattern generally reflects habitat conditions with low structural complexity, resulting in ecological niches disproportionately dominated by opportunistic species. In contrast, the highest values were found at stations 7 ($H' = 3.37$) and 9 ($H' = 3.35$), indicating a highly diverse reef fish community with a relatively balanced structure. At station 7, the assemblage of reef fish was primarily composed of *Ctenochaetus striatus* and *Abudefduf vaigiensis*. Meanwhile, station 9 was distinguished by the occurrence of *Lutjanus rufolineatus* alongside *Ctenochaetus striatus* and *Caesio caerulaurea*. The result by [35], using the Shannon-Wiener index (H') analysis, found one of the most widely applied measures for evaluating fish community structure, as it captures both species richness and the evenness of their distribution. Furthermore, [36] the Shannon and Simpson indices

complement each other in assessing diversity and dominance, indicating that communities with high H' values generally also have a more even distribution of individuals across species. Therefore, the results from stations 7 and 9 indicate ecological conditions that are more favorable for the survival of diverse species and allow for better niche partitioning, thus maintaining community stability and resilience.

Table 3. Ecological index values of reef fish communities recorded at nine observation stations in the Kilwaru-Kiltay waters, East Seram.

Station	H'	E	C
St. 1	1.36	0.45	0.39
St. 2	2.22	0.65	0.18
St. 3	2.34	0.64	0.20
St. 4	2.25	0.64	0.17
St. 5	2.36	0.74	0.16
St. 6	2.51	0.66	0.13
St. 7	3.37	0.83	0.06
St. 8	2.16	0.60	0.24
St. 9	3.35	0.79	0.07

The distribution of reef fish across species at each station also showed significant variation, as reflected in the evenness index (E) values. Stations with low evenness values, such as Station 1 ($E \approx 0.45$), exhibited clear dominance patterns and unbalanced community structures. Within the Kilwaru-Kiltay system, this low E value indicates a skewed distribution of individuals among species at that station, reflecting a reduced internal community balance rather than an absolute ecological condition. This observation is consistent with [37] who demonstrated that the combined use of diversity (H'), evenness (E), and dominance (C) indices provides a robust framework for evaluating the structural stability of reef fish communities, with evenness (E) acting as a critical indicator of balanced and stable assemblages. Conversely, stations with high E values (Station 7: $E \approx 0.83$; Station 9: $E \approx 0.79$) exhibited a more even distribution of individuals across the species. In the context of this study, these higher E values represent relatively balanced assemblages when compared across stations within the same study area rather than implying fixed thresholds of community stability. This interpretation is supported by observations from the Florida Keys National Marine Sanctuary [38], where changes in diversity and biomass do not always correspond to increases in evenness, as dominance by a few species may persist despite protection measures. Accordingly, the elevated evenness at Stations 7 and 9 was interpreted as a site-specific indication of improved niche partitioning and internal community organization. Furthermore, a study by [39] suggested that combining richness and evenness measurements provides a more accurate picture of reef fish community structure, as richness alone is insufficient without considering the distribution of individuals within species. Consistent with this principle, variations in evenness among stations in Kilwaru-Kiltay highlight differences in how individuals are distributed across species, reinforcing the value of evenness as a complementary quantitative descriptor of community structure.

Simpson dominance index (C) emphasizes the degree of concentration of individuals in one or a few specific species. The highest C value was recorded at Station 1 (~ 0.39). This indicated a strong dominance of species such as *Gunnelichthys viridescens* and *Pomacentrus proteus*. Within the study area, this high C value reflects a locally concentrated dominance pattern rather than a generalized condition applicable beyond the site. It was also aligned with [37], which used Simpson's C as the primary metric to assess species dominance in coral communities. Stations with low C values (Station 7: ~ 0.06 ; Station 9: ~ 0.07) indicated that

no single species dominated the population significantly, supporting a more heterogeneous and stable community structure. This pattern is consistent with findings from protected reef systems, including the Florida Keys National Marine Sanctuary [38], in which lower dominance values were associated with more balanced fish assemblages. A study by [39] also emphasized that combining diversity metrics such as Shannon and Simpson, which capture both richness and dominance simultaneously, provides a more complete picture of community structure than using a single metric. Taken together, the contrasting C values among stations reinforce a site-specific interpretation of dominance patterns and further support the use of multiple quantitative indices to characterize the reef fish community structure in the study area.

3.4 Closeness of reef fishes

Principal Component Analysis (PCA) of the reef fish family composition at nine observation stations revealed distinct distribution patterns and associations between functional groups (see **Fig. 3a**). Two principal axes, PC1 (32.21%) and PC2 (16.94%), cumulatively explained 49.15% of data variability. PC1 separated the planktivorous and small herbivorous fish groups (Pomacentridae, Caesionidae, and Ostraciidae), which were generally located in the lower right quadrant, from the predatory and carnivorous groups (Serranidae, Lutjanidae, Haemulidae, and Holocentridae), which were located in the upper right quadrant. In contrast, PC2 distinguished large herbivore families, such as Acanthuridae and Balistidae in the upper quadrant, from groups indicative of coral health, such as Chaetodontidae, Labridae, and Microdesmidae in the lower quadrant.

The spatial distribution of reef fish among the stations highlights the clear habitat heterogeneity characteristic of the habitats. At station 9, the community was mainly shaped by Lutjanidae and Pinguipedidae, reflecting the dominance of larger predatory species. In contrast, station 7 was associated with Serranidae, Scaridae, and Haemulidae, indicating a habitat with greater structural complexity. At the station, six were dominated by the family Acanthuridae, underscoring the ecological role of herbivores in sustaining the coral reef balance. Stations 1, 3, 5, and 8 were closely linked to the Chaetodontidae and Labridae families, which are often found in reefs with relatively healthy conditions. Station 2 showed strong associations with the families Balistidae, Labridae, and Cheloniidae, while station 4 occupied an intermediate position, suggesting a mixed community structure. Taken together, the PCA results illustrate that variations in reef fish family composition at the nine stations are shaped by habitat complexity, resource availability, and the ecological roles of different families. The relatedness of certain families, such as Pomacentridae, Caesionidae, Chaetodontidae, and Labridae, reflects similar ecological preferences and functional roles in coral reef ecosystems.

Principal Component Analysis (PCA) has proven highly effective in uncovering the functional correlations between trophic groups and the dynamics of reef fish communities. [40] recently applied PCA to examine similarities among reef fish communities at different reef sites and showed that two principal components were sufficient to explain structural variations linked to community composition and habitat characteristics. This aligns with our results, which show a clear separation between planktivore families, small herbivores (Pomacentridae, Caesionidae), and predators (Serranidae, Lutjanidae, Haemulidae) on the PC1 axis, and a differentiation between large herbivores and coral health indicators on PC2. [41] emphasized that a single taxonomic indicator such as the abundance of a single fish family does not adequately describe the complexity of a community. They recommended a function- and trait-based approach to capture more meaningful ecological variation through PCA. From the perspective of morphology and functional diversification, [42] PCA has been applied to the mechanical traits of the feeding apparatus (musculoskeletal assemblages) of

several families of reef fish. They found that PC1 describes a mechanical trade-off between jaw mobility and strength, reflecting different functional niches, such as planktivory versus hard-substrate feeders, similar to the ecological conclusions drawn from our PCA of community composition. Furthermore, [43] a meta-analysis of the effects of sewage on the structure of reef fish communities was conducted, applying PCA to refine taxa distribution patterns. They found that changes in PC1 and PC2 consistently reflected perturbations in community diversity and network structure at the polluted sites, illustrating the value of PCA as a diagnostic tool for ecological change.

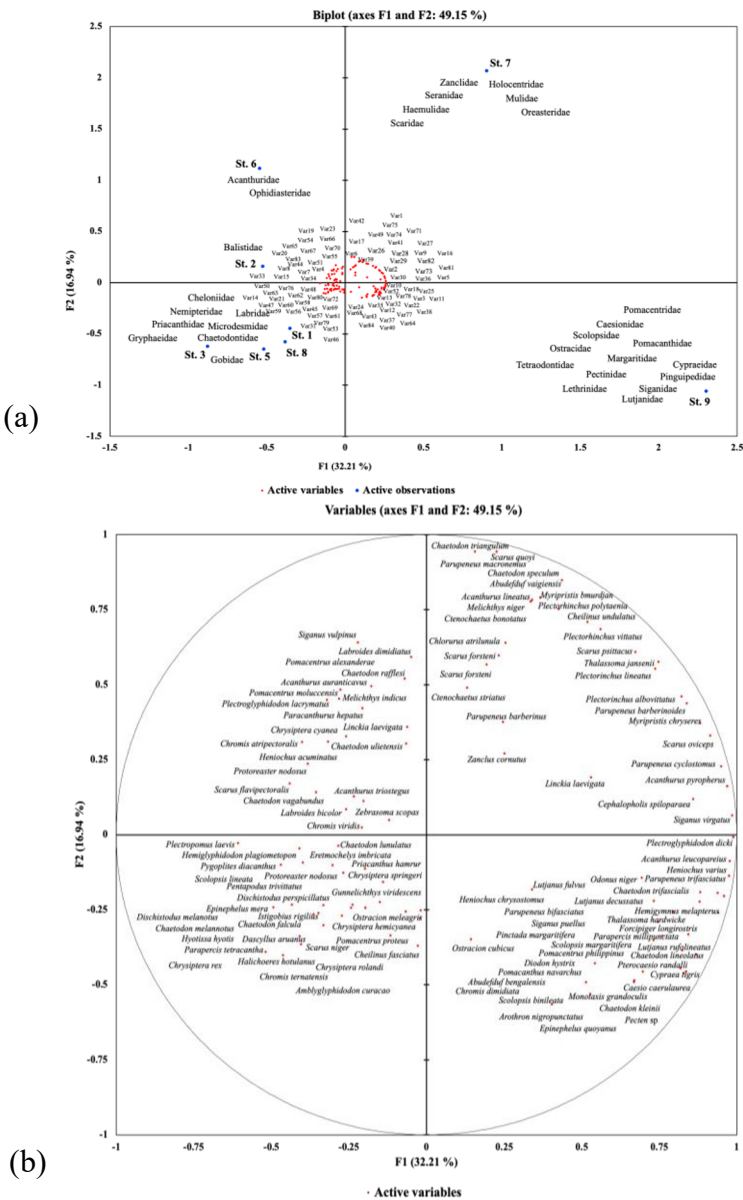


Fig. 3. Principal Component Analysis (PCA) biplot showing the relationships among reef fish families (a) and among reef fish species (b) at nine observation stations.

Finally, it is important to link these ecological interpretations to habitat structure. The early study by [41], though not as recent, remains a frequently cited primary reference. He applied PCA to the community structure of reef fish across different biogeographic regions, demonstrating that clustering patterns of families reflect different habitat conditions, such as reef diversity and complexity. This supports our finding that stations focused on predators (Stations 7 and 9) likely had complex structures capable of supporting carnivorous fishes. In contrast, stations near indicators of living corals (Chaetodontidae, Labridae) indicate relatively healthy habitats. Overall, the current evidence confirms that PCA is not only a dimensionality reduction tool but also an important means of linking the distribution patterns of reef fish communities to ecological functions and physical habitat conditions. Findings such as clusters between Pomacentridae, Caesionidae, large herbivores, and predators align with the functional principles and habitat structures described in the literature. These results are consistent with the methodological recommendations for using PCA along with a trait-function approach in monitoring coral ecosystems.

The PCA of the abundance data for each reef fish species revealed a striking distribution pattern along two principal axes, F1 (32.21%) and F2 (16.94%), which together accounted for 49.15% of the total variation (**Fig. 3b**). On the right side of the ordination plot (positive F1 values), species such as *Plectrorhynchus* spp., *Parupeneus barberinoides*, *Scarus oviceps*, and *Myripristis* spp. They create a cluster. This reflects the interspecific association commonly observed in planktivorous and benthopelagic fish communities. This group exhibited high cohesion, suggesting a shared ecological function in habitats with branching coral structures and productive water columns. On the left side of the graph (negative F1 values), species such as *Plectroglyphidodon lacrymatus*, *Acanthurus aurantiacus*, and *Labroides dimidiatus* were found closer together, indicating ecological niches occupied by surface herbivores and coral cleaners. On the vertical F2 axis, positive (upper) values include species such as *Scarus forsteni* and *Ctenochaetus striatus*, indicating specialized trophic strategies (e.g., scraping and detritivory), whereas negative (lower) F2 values represent species that are more generalist or occupy specialized niches. Overall, the biplot shows a clear community structure segmented by trophic function (herbivores, planktivores, and cleaning mutualists), and identifies groups of species that are consistently associated with each other across the stations.

The interpretation of the PCA results at the species level reflects the dynamics of the reef fish community, driven by trophic niches and habitat structure. The *Labroides dimidiatus* and *Acanthurus aurantiacus* (as herbivorous and carnivorous groups), in F1-negative species, support the theory that carnivorous and algal grazing strategies often co-occur in habitats with good coral cover. [44] showed that benthic conditions shape reef fish assemblages with herbivores and carnivores forming distinct spatial patterns. Similarly, PCA-based analyses highlight how habitat features, such as different depths and substrate complexities, influence species distribution [45]. [46] showed that PCA effectively links substrate features with community variation, emphasizing that reef fish assemblages are strongly shaped by ecological functions and local benthic characteristics. PCA facilitates the identification of associated trophic groups, planktivores, herbivores, and cleaning mutualists and emphasizes the importance of considering habitat context when monitoring and conserving coral reef ecosystems.

4 Conclusion

The study results showed apparent spatial variation in the structure of reef fish communities across nine observation stations in the Kilwaru-Kiltay waters of East Seram. A total of 115 species comprising 7,372 individuals were identified, with Pomacentridae being the

dominant group at most sites. These patterns provide a baseline description of the reef fish community structure that is relevant for evaluating the ecological conditions across stations. The observed distribution of trophic groups across stations indicates the presence of multiple functional components within the reef fish assemblage. The ecological index values varied among stations, highlighting differences in community structure and dominance patterns within the study area. Stations characterized by higher diversity, more even species distribution, and lower dominance represent locations with comparatively stronger community organization. A key contribution of this study lies in the use of multivariate analysis (PCA) at both the family and species levels to characterize spatial patterns in reef fish community composition. By integrating taxonomic composition, functional group structure, and ecological indices, this study provides a coherent evidence base for identifying candidate sites with ecological attributes relevant to Other Effective Area-based Conservation Measures (OECMs). The findings help address current knowledge gaps in Eastern Indonesia and support the application of the reef fish community structure as a practical ecological basis for OECM screening in the Kilwaru-Kiltay area.

The authors thank the Coastal Fisheries Initiative (CFI) Indonesia, the Global Environment Facility (GEF) 6 Program through the World Wildlife Fund (WWF), and the Ministry of Marine Affairs and Fisheries (MMAF) of the Republic of Indonesia for financial and institutional support. Their commitment to marine conservation enabled this study and supported its completion. The authors also thank the field teams, research personnel, and partner institutions for their dedication, technical support, and valuable contributions at every stage.

References

1. Y. Sugianti, M. Mujiyanto, Biodiversity of coral fish in Karimunjawa National Parks Waters, Jepara. *BAWAL Widya Ris. Perikan. Tangkap.* **5**, 23 (2013).
2. J. Veron, M. Stafford-Smith, L. DeVantier, E. Turak, Overview of distribution patterns of zooxanthellate Scleractinia. *Front. Mar. Sci.* **1**, 81 (2015). <https://doi.org/10.3389/fmars.2014.00081>
3. M.A. Samoilys, R.C. Roche, M. Gudka, C.J. Thouless, D. Obura, S. Rowlands, J. Mbugua, K. Osuka, Fish as indicators of coral reef ecosystem status. *Ecol. Indic* **179**, 114137 (2025). <https://doi.org/10.1016/j.ecolind.2025.114137>
4. B. Hamuna, J.D. Kalor, A.I. Rachmadani, Assessing the condition of coral reefs and the indicator fish (family: Chaetodontidae) in coastal waters of Jayapura City, Papua Province, Indonesia. *Europ. J. Ecol.* **5**, 2, 126-132 (2019). <https://doi.org/10.2478/eje-2019-0020>
5. L.J. Raymundo, D. Burdick, W.C. Hoot, R.M. Miller, V. Brown, T. Reynolds, J. Gault, J. Idechong, J. Fifer, A. Williams, Successive bleaching events cause mass coral mortality in Guam, Micronesia. *Coral Reefs* **38**, 677-700 (2019). <https://doi.org/10.1007/s00338-019-01836-2>
6. W. Forstmeier, E.J. Wagenmakers, T.H. Parker, Detecting and avoiding likely false-positive findings-a practical guide. *Biol. Rev.* **92**, 4, 1941-1968 (2016). <https://doi.org/10.1111/brv.12315>
7. B. Wen, C. Liu, J. Cai, J. Guo, G. Ren, Restoration of ecological connectivity in Zhaotong City under the interference of human activities. *Sustainability*, **17**, 1287 (2025). <https://doi.org/10.3390/su17031287>
8. F. Favoretto, C. Lopez-Sagastegui, E. Leon-Solorzano, O. Aburto-Oropeza, A scalable and normalized reef status index for assessing fish trophic structure reveals conservation gaps. *Ecol. Indic.* **166**, 112515 (2024). <https://doi.org/10.1016/j.ecolind.2024.112515>

9. L.O.M.Y. Haya, M. Fujii, Assessment of coral reef ecosystem status in the Pangkajene and Kepulauan Regency, Spermonde Archipelago. *Mar. Pol.* **118**, 104028 (2020). <https://doi.org/10.1016/j.marpol.2020.104028>
10. J. Abrahamsz, M.M. Makailipessy, I.M. Thenu, Ecosystem Approach to Fisheries Management Status at West Kei Kecil Small Island Park, South East Maluku Regency. *Mar. Fish.: J. Mar. Fish. Technol. Manag.* **14**, 1, 117-129 (2023). <https://doi.org/10.29244/jmf.v14i1.45735>
11. M.V. do Nascimento, V.L. da S. Alves, S.P.P. Barros, R.G.B.C. Genzani, C.G.S. Pinheiro, A.S. Moura, Geotechnical properties of carbonate sands on the Coast of Ceará: Implications for offshore wind foundations and green hydrogen initiatives. *Sustainability* **17**, 4726 (2025). <https://doi.org/10.3390/su17104726>
12. K. R.F. Bastos, D.L. Lippi, A.L.B. Gaspar, G.T. Yogui, T. Frédou, A.M. Garcia, B.P. Ferreira, Ontogeny drives allochthonous trophic support of snappers: Seascape connectivity along the mangrove-seagrass-coral reef continuum of a tropical marine protected area. *Estuar. Coast. Shelf Sci.* **264**, 107591 (2022). <https://doi.org/10.1016/j.ecss.2021.107591>
13. S. English, C. Wilkinson, V. Baker, Survei manual for tropical marine resource, 2nd Ed. (Australian Institute of Marine Science "AIMS", Townsville, 1997).
14. Z.R. Caldwell, B.J. Zgliczynski, G.J. Williams, S.A. Sandin, Reef fish survey techniques: Assessing the potential for standardizing methodologies. *PLoS One* **11**, e0153066 (2016). <https://doi.org/10.1371/journal.pone.0153066>
15. R.H. Kuiter, T. Tonozuka, Indonesian reef fishes (Zoonetics, Melbourne, 2001)
16. G.R. Allen, R. Steene, P. Humann, N. DeLoach, Reef fish identification: Tropical Pacific (New World Publications, Florida, 2003).
17. E.P. Odum, *Fundamental Ecology*, 3rd ed. (WB Saunders Co., Philadelphia, 1971)
18. R. Karkarey, R. Arthur, K.L. Nash, M.S. Pratchett, M. Sankaran, N.A. Graham, Spatial decoupling of α and β diversity suggest different management needs for coral reef fish along an extensive mid-oceanic ridge. *Glob. Ecol. Conserv.* **36**, e02110 (2022). <https://doi.org/10.1016/j.gecco.2022.e02110>
19. E. Elma, M. Gullström, S.A.S. Yahya, J.B. Jouffray, H.K. East, M. Nyström, Post-bleaching alterations in coral reef communities. *Mar. Pollut. Bull.* **186**, 114479 (2023). <https://doi.org/10.1016/j.marpolbul.2022.114479>
20. M. Randrianarivo, L.M. Gasimandova, J. Tsilavonarivo, A. Razakandrainy, J. Philippe, F. Guilhaumon, R.L. Botosoamananto, L. Penin, G. Todinanahary, M. Adjeroud, Assessing recovery potential of coral reefs in Madagascar and the effects of marine protected areas. *Reg. Stud. Mar. Sci.* **77**, 103710 (2024). <https://doi.org/10.1016/j.rsma.2024.103710>
21. A.E. Magurran, Measuring biological diversity. *Curr. Biol.* **31**, 19 (2021). <https://doi.org/10.1016/j.cub.2021.07.049>
22. R. Fox, E.B. Dennis, C.A. Harrower, D. Blumgart, J.R. Bell, P. Cook, A.M. Davis, L.J. Evans-Hill, F. Haynes, D. Hill, N.J. Isaac, The state of Britain's larger moths (Butterfly Conservation, Wareham, 2021).
23. C.J. Krebs, *Ecological Methodology*, 2nd Ed., (Benjamin Cummings, Menlo Park, 1999).
24. E.C. Pielou, *Mathematical Ecology*, 2nd Ed., (John Wiley & Sons, New York, 1977).
25. M. Bonada, I. Buesa, M.A. Moran, V.O. Sadras, Interactive effects of warming and water deficit on Shiraz vine transpiration in the Barossa Valley, Australia. *PLoS One* **52**, 135 (2018). <https://doi.org/10.20870/oeno-one.2018.52.2.2141>
26. J. Hadj-Hammou, T.R. McClanahan, N.A.J. Graham, Decadal shifts in traits of reef fish communities in marine reserves. *Sci Rep.* **11**, 23470 (2021). <https://doi.org/10.1038/s41598-021-03038-9>

27. A. Isdianto, K. Gibran, A. Yamindago, S.H.J. Sari, A.T. Yanuar, D. Setyoningrum, A. Setyanto, L.N. Hidayah, K. Marsela, M.F. Haykal, A.L. Fathah, B.M. Putri, Supriyadi, O.M. Luthfi, D.C. Pratiwi, Environmental determinants of reef fish community structure in Sempu Strait, East Java, Indonesia. *Biodiversitas* **25**, 12 (2024). <https://doi.org/10.13057/biodiv/d251214>
28. M.J. Emslie, M. Logan, A.J. Cheal, The distribution of planktivorous damselfishes (Pomacentridae) on the Great Barrier Reef and the relative influences of habitat and predation. *Diversity* **11**, 33 (2019). <https://doi.org/10.3390/d11030033>
29. B.M. Taylor, Z.S. Oyafuso, C.B. Pardee, D. Ochavillo, S.J. Newman, Comparative demography of commercially-harvested snappers and an emperor from American Samoa, *PeerJ*. **6**, e5069 (2018). <https://doi.org/10.7717/peerj.5069>
30. M. Mujiyanto, S.T. Hartati, Composition and abundance of fish stock of bio fouling and growth in artificial reefs of the Teluk Saleh, West Nusa Tenggara. *J. Lit. Perikan. Ind.* **17**, 1 (2011). <https://doi.org/10.15578/jppi.17.1.2011.51-59>
31. M.S. Pratchett, V. Messmer, S.K. Wilson, Size-specific recolonization success by coral-dwelling damselfishes moderates resilience to habitat loss. *Sci. Rep.* **10**, 17016 (2020). <https://doi.org/10.1038/s41598-020-73979-0>
32. R.L. Villanueva, N.J.M.F. Mecha, E.G. Villanueva, M.A.D. Maga-ao, R.G. Dolorosa, A checklist of damselfishes (Pomacentridae) from Palawan, Philippines. *Palawan Sci.* **15**, 1 (2023). <https://doi.org/10.69721/TPS.J.2023.15.1.02>
33. A.E. Hall, M.J. Kingsford, Habitat type and complexity drive fish assemblages in a tropical seascape. *J. Fish Biol.* **99**, 4, 1364-1379 (2021). <https://doi.org/10.1111/jfb.14843>
34. W.S. Fisher, Relating fish populations to coral colony size and complexity. *Ecol. Indic.* **148**, 110117 (2023). <https://doi.org/10.1016/j.ecolind.2023.110117>
35. G. Fang, Y. Zhang, H. Yu, C. Chen, J. Liang, Y. Tang, Taxonomic and functional diversities reveal different fish assemblage dynamics of stow net fishery in Haizhou Bay. *Heliyon*. **10**, e39428 (2024). <https://doi.org/10.1016/j.heliyon.2024.e39428>
36. A.K. Thukral, R. Bhardwaj, V. Kumar, A. Sharma, New indices regarding the dominance and diversity of communities, derived from sample variance and standard deviation. *Heliyon*. **5**, e02606 (2019). <https://doi.org/10.1016/j.heliyon.2019.e02606>
37. A. Hafizah, S. Adibrata, M.R. Muftiadi, R.A.T. Balisco, The reef fish community structure in Penyusuk Waters, Bangka Regency, Indonesia (Case Study of Artificial Reef in PT. Artha Cipta Langgeng). *Coast. Mar. J.* **1**, 2, 91-101. (2023). <https://doi.org/10.61548/cmj.v1i2.19>
38. M. Hepner, K. Shulzitski, B. Best, S. Gittings, C. Stallings and F. Muller-Karger, Patterns and drivers of reef fish biodiversity in the Florida Keys National Marine Sanctuary from 1999-2016. *ESS Open Archive*. (2018). <https://doi.org/10.1002/essoar.89ba035e95c58580.cbc8d824784048b7.1>
39. R. Riera, B.D. Fath, A.M. Herrera, R.A. Rodríguez, A strategic roadmap for interdisciplinary modeling in ecology: The result of reading 'Defining an ecological equation of state: Response to Riera et al. 2023' (Newman et al., 2023). *Ecol. Indic.* **490**, 110658 (2023). <https://doi.org/10.1016/j.ecolmodel.2024.110658>
40. E. Maire, J.P.W. Robinson, M. McLean, S. Arif, J. Zamborain-Mason, J.E. Cinner, S.C.A. Ferse, N.A.J. Graham, A.S. Hoey, M.A. MacNeil, D. Mouillot, C.C. Hicks, Managing nutrition-biodiversity trade-offs on coral reefs. *Curr. Biol.* **34**, (2024)
41. D.R. Bellwood, P.C. Wainwright, History and biogeography of fishes on coral reefs (Elsevier Science, San Diego, 2002). <https://doi.org/10.1016/B978-012615185-5/50003-7>
42. M.D. Burns, D.R. Satterfield, N. Peoples, H. Chan, A.J. Barley, M.L. Yuan, A.S. Roberts-Hughes, K.T. Russell, M. Hess, S.L. Williamson, K.A. Corn, M.

- Mihalitsis, D.K. Wainwright, P.C. Wainwright, Complexity and weak integration promote the diversity of reef fish oral jaws. *Commun. Biol.* **7**, 1433 (2024).
<https://doi.org/10.1038/s42003-024-07148-8>
43. R.A. Plazas-Gómez, S. Bejarano, C. Magneville, M. Fujitani, Beyond taxonomy: A functional approach reveals patterns of reef fish response to wastewater pollution. *Mar. Pollut. Bull.* **216**, 118024 (2025).
<https://doi.org/10.1016/j.marpolbul.2025.118024>
44. N. Mansoben, R. Bawole, J. Marwa, C.A. Bawole, E.V. Sirami, M. Mudjirahayu, The influence of coral reef benthic conditions on associated fish assemblages around Puruf Island Water, Cenderawasih Bay, Papua, Indonesia. *Asian J. Env. Ecol.* **23**, 11 (2024). <https://doi.org/10.9734/ajee/2024/v23i111618>
45. K. Noonan, T. Fair, K. Mathee, K. Sox, K. Smith, M. Childress, Reef fish associations with natural and artificial structures in the Florida Keys. *Oceans.* **2**, 3 (2021). <https://doi.org/10.3390/oceans2030036>
46. R.A. Wright, S. Hills, C.E. Stuart, K. Malhi, P. Palola, C.E. Benkwitt, H.E. Epstein, T. Beguet, H.V. Ford, M. Ward, L.M. Wedding, Biophysical drivers of coral reef community structure across a tropical benthic seascape. *Coral Reefs.* **44**, (2025).
<https://doi.org/10.1007/s00338-025-02684-z>