

Biodiversity and abundance of fish in estuarine waters of Sesayap and Sembakung, North Kalimantan, Indonesia

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Abstract. Laga A, Haryono MG, Achyani R, Bija S, Salim G, Mujiyanto, Romdoni TA, Hartinah S. 2025. Biodiversity and abundance of fish in estuarine waters of Sesayap and Sembakung, North Kalimantan, Indonesia. *Biodiversitas* 26: 5574-5594. The estuary of Sesayap and Sembakung Waters in North Kalimantan, Indonesia are areas which are semi-enclosed where river currents meet with tidal's. The extreme fluctuations are covered by the availability of food because they get nutrient supplies from the sea and land, so this area get variety of fish in abundance. This study aims to determine the biodiversity and abundance of fish in the estuarine waters of Sesayap and Sembakung. The research uses a quantitative descriptive method and it was conducted for 4 months from August 2021 to November 2021. The fish caught were obtained from fishermen using various fishing gear, including *sero* nets, gillnets, mini trawls, and *tugu* nets. The fish were sorted by species, weighed collectively, and the total length and weight of each individual were measured. Species identification was performed using three intact specimens, following guidelines from the fish identification book. The results of the study of fish species identification using different fishing gears, obtained as many as 28 species found in the *tugu* fishing gear dominated by white shrimp species with a percentage of 76.78%; as many as 15 species in the gill net dominated by the *selangat* (*Anodontostoma chacunda*) fish species at 47.85%; as many as 21 species in the tiger trawl dominated by the *nomei* (*Harpodon nehereus*) fish species at 56.93%, and as many as 30 species in the *sero* fishing gear dominated by the *Penaeus* sp. species at 69.13%. The highest abundance was white shrimp at 19.19% found in the *tugu* fishing gear, respectively. This explains that each fishing tool has characteristics that result in different variations in the catch. The ecological implications of these areas as important nursery grounds, migration routes, and feeding grounds require fishing regulations and the selective use of fishing gear to sustainably increase fisheries productivity.

Keywords: Abundance, biodiversity, estuarine, fishing gear, species richness

INTRODUCTION

Estuaries are semi-enclosed aquatic environments formed naturally at the confluence of freshwater from rivers and saline water from the sea (Potter et al. 2010; van Niekerk et al. 2020; Atekwana et al. 2022), especially in terms of salinity (25-35 ppt), temperature, turbidity, dissolved oxygen (5.95-6.94 mg/L), and pH (6-7) (Sugianti et al. 2021). These areas create unique salinity gradients and are considered among the most dynamic and productive aquatic ecosystems globally (Cloern et al. 2017; Salim et al. 2021; Siteo et al. 2024). The interaction between tidal flows, sediment deposition, and the mixing of water masses with varying physicochemical properties makes estuarine ecosystems complex habitats with high biodiversity and productivity (Cereja et al. 2022; Chen et al. 2024; D'Sa et al. 2025; Kampf 2025; Pan et al. 2025). These fluctuations impose considerable ecological stress on aquatic organisms. Only species with high physiological adaptability, such as euryhaline organisms, are capable of surviving under such conditions (Seale and Breves 2022; Zhou et al. 2023; Chen et al. 2025). On the other hand,

these extreme conditions also create strong selective pressures that may promote the emergence of high species biodiversity, including endemic species (Nodo et al. 2023a; Bandara 2024; Lai et al. 2024). Moreover, Pranata et al. (2024) found that the dynamic water quality of estuarine and river mouth areas in Tarakan, North Kalimantan, Indonesia, significantly influenced fish community structures, indicating adaptive responses to environmental pressures, including salinity and dissolved organic matter. These findings underscore that estuaries are not only ecologically important but also serve as critical buffer systems in maintaining coastal biodiversity.

Estuarine ecosystems serve vital ecological and economic functions (Seary et al. 2021; Tjahjo et al. 2023b; Hasan et al. 2023; Wirabuana et al. 2025), important fish species that naturally enter aquaculture ponds (Salim et al. 2024). They act as nursery grounds, feeding areas, and spawning sites (Tjahjo et al. 2023a, b; Hasan et al. 2023; Wirabuana et al. 2025) for various fish and invertebrate species (Miró et al. 2020; Guerreiro et al. 2021; Pessanha et al. 2021; Nodo et al. 2023b; Whitfield et al. 2023). As an integral part of the trophic network, estuaries support

coastal and marine fishery productivity (Blaber 2009). Nutrient inputs from both terrestrial and marine sources enrich estuarine ecosystems, boost primary productivity (Islamy and Hasan 2020; Mujiyanto et al. 2021; Isoni et al. 2023) and support the abundance of economically important fish populations (Douglas et al. 2022; Kim et al. 2025; Song et al. 2025).

The dynamic nature of estuarine environments demands high adaptability from resident biota. Certain fish have the ability to adjust their osmoregulatory mechanisms in response to rapid salinity changes due to tidal influences (Mozanzadeh et al. 2021; Abisha et al. 2024). These adaptations explain why such species are commonly found in estuarine habitats. Conversely, not all species can tolerate extreme environmental changes. Species survival is contingent on the environment remaining within their ecological tolerance limits. Therefore, human activities such as land reclamation, pollution, and infrastructure development can lead to habitat degradation and threaten the sustainability of estuarine biotic communities (Niu et al. 2021; Vogel et al. 2025). Such disturbances not only impact biodiversity but also undermine the ecological functions of estuaries in supporting fishery productivity and the livelihoods of coastal communities, either directly or indirectly.

Fishing activities in the estuary area can also cause a significant decline in biodiversity and abundance of fish populations over time, so fisheries studies are needed to obtain sustainable management strategies. The inventory of species and population structures supports conservation policy development (Sugianti et al. 2021) and serves as an ecological disturbance indicator driven by human activities and climate change. The Sesayap and Sembakung Estuaries, as transitional zones between rivers and the sea,

possess considerable yet underexplored scientific potential. Additionally, Tjahjo et al. (2023b) revealed that fish abundance in coastal zones is closely associated with environmental parameters, marking these regions as vital spawning and migration corridors. Such data are essential for developing adaptive, science-based sustainable management strategies that safeguard fishery resources while ensuring the long-term welfare of coastal communities. Therefore, the aim of this research is to discuss fish biodiversity and abundance in the estuarine waters of Sesayap and Sembakung, North Kalimantan, as crucial as a foundation for ecosystem-based fisheries management.

MATERIALS AND METHODS

Study area sampling

Fieldwork was conducted in the estuarine zones of the Sesayap and Sembakung Rivers, North Kalimantan, from August to November 2021, using traditional fishing gear known as guilding barrier (*sero*), gill nets, mini trawls, and stownets (trap net/*tugu* nets) (Figure 1). According to Marasabessy (2017), the fishing season is divided into three phases: peak season (June-August), normal season (September-November), and lean season (December-February). This research was conducted during the normal season in the fishing ground area. The method for determining the research location uses a purposive sampling method, where the determination of the research location is the fishing ground area used by fishermen to obtain their catch in the waters of the Sesayap and Sembakung Estuaries, North Kalimantan, Indonesia.

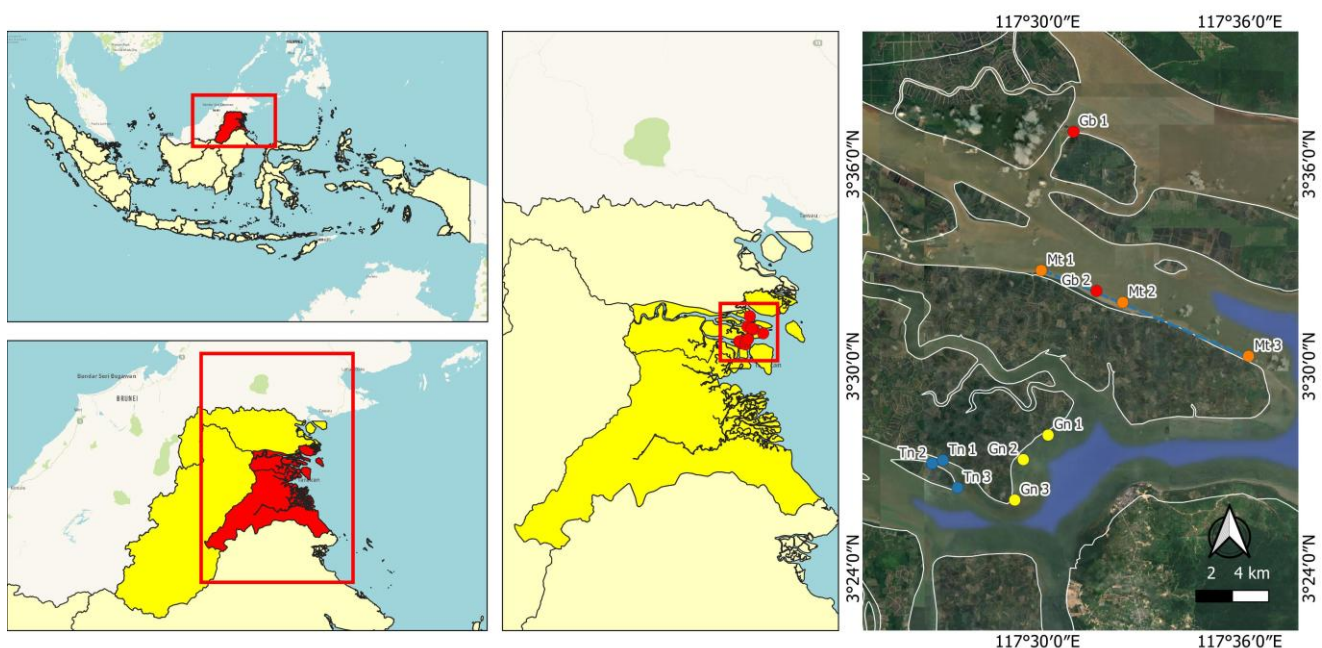


Figure 1. Sampling location of fish biodiversity and abundance in the Sesayap and Sembakung Waters, North Kalimantan, Indonesia. Gn: Gill-Net gear, Tn: Stownets/Trap Net gear, Mt: Hela's trawl gear, Gb: Guilding barrier gear

A purposive sampling method was applied to ensure that each site corresponded to the dominant fishing practice and habitat characteristics in the estuary. The Sesayap estuary is characterised by shallow muddy substrates and strong tidal currents, while the Sembakung estuary exhibits a higher salinity gradient, dense mangrove vegetation, and moderate hydrodynamic influence. The sampling sites were georeferenced using a handheld GPS receiver under the WGS 1984 UTM Zone 50N coordinate system. Each sampling station represents a different estuarine condition, ranging from mangrove-fringed inner estuary to open estuary zones and coastal trawl grounds near the river mouth. The coordinates and general descriptions of all sampling sites are summarised in Table 1.

Sampling procedure

This systematic approach to sampling and specimen handling followed recognized standards for biological sampling protocols, thereby reinforcing the validity of morphometric and ecological analyses (Roonjha et al. 2019; Hasan et al. 2024). The *tugu* (stownet) fishing gear (Figure 2.A) is operated by pressing the rings on the right and left sides of the net mouth, lowering it all the way to the bottom, opening the net mouth completely. The immersion process is then carried out for 3-4 hours, after which the hauling process is carried out. The catch is retrieved by closing the net mouth by lifting the bottom net upwards so that it joins the top net. The catch is then retrieved by untying the rope at the back end of the net, lifting the middle sections of the net until the catch is collected. The *tugu* (stownet) fishing gear operates during full moon tides. Temperature measurements range from 29-30°C; salinity measurements range from 18-20 ppt; clarity

measurements range from 27-45 cm; and pH measurements range from 7.16-8.23.

The *sero* fishing gear (Figure 2.B) operates based on the spring tide and neap tide cycles. During spring tides, it operates daily, and during high tides, it operates every 2-3 days. The immersion method involves submerging the *sero* net during high tide. The hauling method involves manually lifting the *sero* net and collecting the catch using a scoop net. The length of the *sero* net varies at three different stations. The length of the *sero* net varies between the first and second stations. The length of the *sero* net is 105 meters; the length of the second *sero* net is 22.5 meters; and the length of the third *sero* net is 30 meters. The wingspan of the first *sero* net is 19 meters, while the second and third *sero* nets are the same length, 12 meters. The *sero* net has a net length of 3.21 meters, a width of 2.14 meters, and a mesh size of 2.5 cm. Based on measurements, the water temperature ranges from 29-30°C; the pH ranges from 6.96-7.11; measurement of salinity variables ranges from 25-26 ppt; measurement of current velocity variables is 0.13-0.25 m/s with a brightness level ranging from 25-30.75 cm.

The mini trawl fishing gear (Figure 2.C) was operated during full moon tides and neap tides. Sample data was collected through direct observation of the landings of the mini trawlers' catch. The mini trawl was operated during low tide. The mini trawl had a mesh size of 2.5 cm, while the fish trawl had a mesh size of 3.75 cm. The mini trawl net length was 25.5 m and 27 m wide. The temperature was measured at 29°C; the salinity was measured at 18 ppt. The brightness was measured at 44-45 cm; the pH was measured at 8.12-8.20; and the current velocity was measured at 0.13-0.25 m/s.

Table 1. Coordinates and general descriptions of fish sampling sites in the Sesayap and Sembakung Estuaries, North Kalimantan, Indonesia

Site	Fishing gear	Latitude (N)	Longitude (E)	General description
Tn 1	Stownet/Trap net	3° 27' 12.802"	117° 27' 11.754"	Narrow estuarine channel with moderate current and muddy bottom; commonly used for trap nets near mangrove edges.
Tn 2	Stownet/Trap net	3° 27' 7.042"	117° 26' 52.523"	Area close to fishing village influenced by freshwater inflow; dominated by brackish-water fish species.
Tn 3	Stownet/Trap net	3° 26' 23.870"	117° 27' 37.699"	Transitional zone at mangrove-mudflat interface; typical location for stationary trap net operations.
Gn 1	Gill net	3° 27' 57.542"	117° 30' 19.084"	Open estuary mouth with stronger tidal flow; dominated by pelagic and demersal fish assemblages.
Gn 2	Gill net	3° 27' 13.921"	117° 29' 34.962"	Mid-estuarine channel with sandy-mud substrate and high turbidity; gill net fishing area.
Gn 3	Gill net	3° 26' 1.918"	117° 29' 19.684"	Nearshore estuarine zone close to the river mouth; exposed to tidal mixing and moderate salinity.
Mt 1	Mini trawl	3° 32' 50.816"	117° 30' 6.890"	Coastal trawl ground with deeper muddy bottom; utilized for small-scale trawling activities.
Mt 2	Mini trawl	3° 31' 53.936"	117° 32' 32.075"	Outer estuary margin with moderate current and mixed sediment substrate.
Mt 3	Mini trawl	3° 30' 18.112"	117° 36' 16.135"	Estuarine-marine transition zone exposed to stronger tidal currents; outer trawl fishing ground.
Gb 1	Guiding barrier	3° 36' 57.618"	117° 31' 4.386"	Northern section near Pulau Tambongan; shallow water influenced by tidal mangrove channels.
Gb 2	Guiding barrier	3° 32' 14.197"	117° 31' 45.242"	Central estuarine channel with semi-enclosed bay characteristics and calm current; suitable for guiding barrier gear.

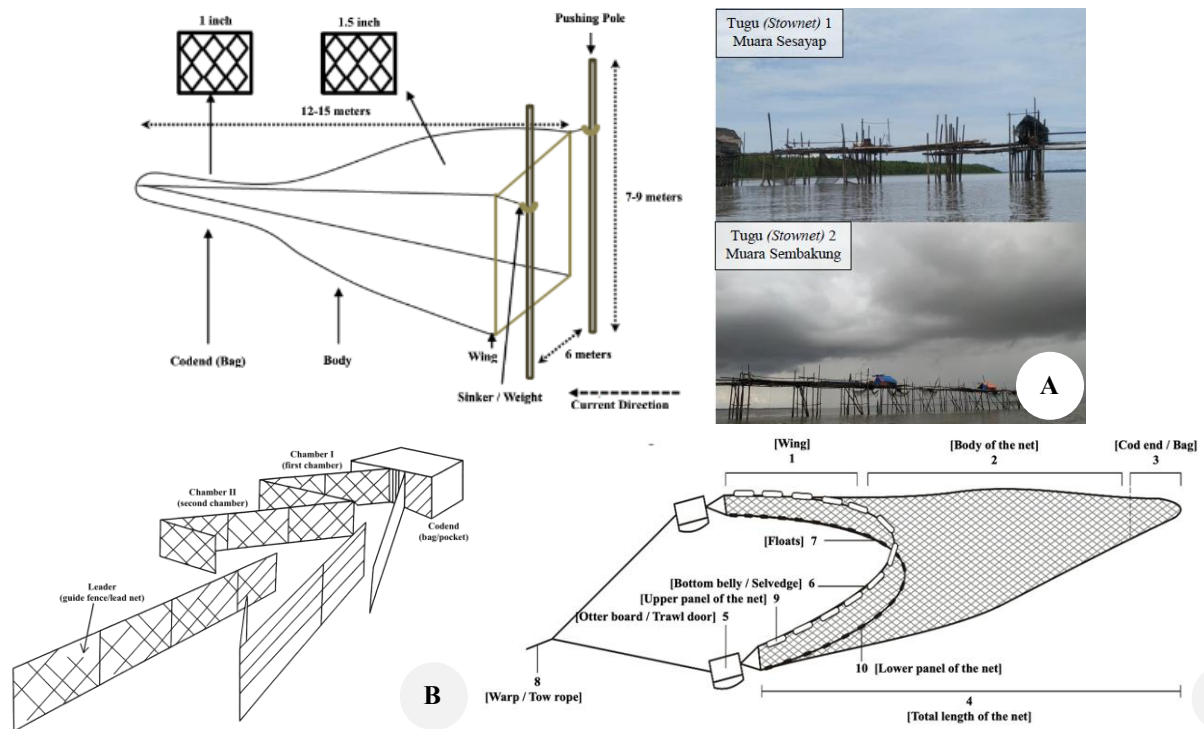


Figure 2. The pictures of: A. *Tugu*, B. *Sero*, C. Mini trawl fishing gears (Fitriya et al. 2021; Ruspika 2022)

Gill net fishing is operated during the full moon tide. Fishing takes place in the afternoon and evening during peak spring tide. Gill net fishermen use a 1 GT wooden boat equipped with a Yamaha engine with a power of 10-12 HP. The boat diameter ($l \times w \times h$) measures $(11 \times 1.5 \times 1) \text{ m}^3$. Gill nets are a fishing gear whose fishing operation takes place in the afternoon or evening, lasting one day (one day fishing) with one or two settings. The fish catch is stored in a fiber cool box with a capacity of 200 kg per box and is filled with one or two blocks of ice. Gill net has a rectangular shape with the same mesh size and has a buoyancy greater than its sinking power which consists of several components, namely the net body, floats, weights, float and weight ropes, upper and lower ris ropes, and auxiliary tools in the form of marker lights used at night so that the net is not hit by ships passing through the waters. The Gill net used by fishermen is made of clear monofilament number 28 with a mesh size of 2 inches, a net length of 10 m and a width of 3 m with a total of 33 net sets. The net is assembled into one unit of fishing gear with each existing component using a polyethylene float rope with a diameter of 5 mm which is inserted into the upper mesh without being tied and is a place to tie the float. The bottom of the net also uses a polyethylene weight rope with a diameter of 3 mm which is inserted into the mesh and is a place to tie the weight. The buoyancy rope and weight line at the end of the net body were extended by approximately 35-45 cm to allow for connecting one set to another. Temperature measurements ranged from 29-30°C. Salinity measurements ranged from 25-26 ppt. pH measurements ranged from 6.96-7.11. Current velocity measurements ranged from 0.23-0.25 m/s.

Fish samples collection and identification

The research samples used came from fishermen's fishing gear with four different types of fishing gear: guiding barriers (*sero*) (Wirnawati 2013; Salim et al. 2019; Asmin et al. 2023), gill nets (Sulistyowati and Wulandari 2022; Indarjo et al. 2023a, b; Muhammad et al. 2025), mini trawls (Utama and Wudianto 2009; Salim et al. 2023a, b; Lestari et al. 2025), and stownets (trap nets/*tugu* nets) (Makri et al. 2021). Each fishing unit was operated by four local fishermen to ensure uniformity of fishing effort across all sampling units. However, for stownets, sampling was conducted at three different stations. All fishing gear (guiding barriers/*sero*, gill nets, mini trawls, and stownets (trap nets/*tugu* nets) used were replicated four times.

Research data collection methods

The fish sampling method for obtaining biodiversity research data used purposive sampling, where samples from fishermen's catches were sorted by species and then the number of catches of the same species was recorded. After capture, fish specimens were sorted by species, collectively weighed, and then individually measured for total length (Indarjo et al. 2020, 2021) and body weight (Salim et al. 2020a, b, 2024). For each species, the three most intact specimens were selected for identification and further analysis at the Fisheries Biology Laboratory, Faculty of Fisheries and Marine Sciences, University of Borneo Tarakan.

The fish sampling method for species identification used random purposive sampling from fishermen's catches, where three fish of different sizes were sampled for each species: small, medium, and large. The samples obtained

were identified into taxonomic groups: family, genus, and species. Taxonomic group determination was based on the guidelines from the identification book from Saanin (1969), Kottelat et al. (1993), and White et al. (2013). In determining the local name of the fish, this was done by interviewing fishermen (Katarina et al. 2019).

Data analysis and modeling framework

All biometric and ecological data collected during the study were tabulated and analysed using one-way ANOVA with Tukey's HSD as the post-hoc multiple-comparison procedure at a 95% confidence level ($p < 0.05$). This approach is widely employed to test differences in catch composition and abundance among treatments, habitat types, and fishing gears in estuarine ecology and fisheries studies (Johnson et al. 2002; Barletta et al. 2003; Stunz et al. 2010). The one-way ANOVA was fit under the formula:

$$Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$$

Where:

Y_{ij} : Observed value of fish abundance or biodiversity from the j^{th} replicate of the i^{th} fishing gear

μ : Overall mean

τ_i : Effect of the i^{th} fishing gear

ε_{ij} : Random error term, assumed to be normally distributed with mean 0 and variance σ^2 ; following standard treatments for single-factor designs in ecological data analysis (Quinn and Keough 2002). The F-ratio was computed as follows (Vinagre and Costa 2014).

$$F = \frac{MS_{\text{between}}}{MS_{\text{within}}}$$

Where:

MS_{between} : Mean square between fishing gears

MS_{within} : Mean square within groups

If $F_{\text{count}} > F_{\text{table}}$, then H_0 is rejected and H_1 is accepted, indicating significant differences in fish catches among fishing gears. Conversely, if $F_{\text{count}} < F_{\text{table}}$, then H_0 is accepted. The significance level was determined using $\alpha = 0.05$. To evaluate whether fishing-gear type influences biodiversity or abundance, we tested the null hypothesis (H_0 : no effect of gear) against the alternative (H_1 : gear has a significant effect) using one-way ANOVA. We adopted a two-sided decision rule at $\alpha = 0.05$: if the test returned $p \geq 0.05$ (equivalently, $F_{\text{count}} \leq F_{\text{table}}$), we failed to reject H_0 ; if $p < 0.05$ ($F_{\text{count}} > F_{\text{table}}$), we rejected H_0 in favor of H_1 . When H_0 was rejected, we conducted Tukey's HSD at $\alpha = 0.05$ to identify which pairs of gears differed.

Additionally, local ecological knowledge, including vernacular names and ethno-ichthyological insights, was documented through structured interviews with local fishers and community members in the sampling areas, a method recognized for its value in fisheries research and species validation (Silvano and Begossi 2002). The relative abundance of each species was calculated using the formula proposed by DeVantier and Turak (2017), enabling quantitative comparisons among fish species and gear types. Relative Abundance (RA) is the proportional representation of a particular species in a community. The relative abundance (π_i) of each species is found in the

following formula (Krebs 2014; Achacoso et al. 2016; Basavaraj et al. 2025):

$$\text{Relative Abundance (RA)} = \frac{n_i}{N} \times 100\%$$

Where:

n_i : Number of individuals of the same species from the catch

N : Total number of individuals for all species from the catch

This metric was employed to quantify the dominance and distribution within the overall catch composition, thereby facilitating a more comprehensive understanding of its ecological role in the estuarine ecosystem.

RESULTS AND DISCUSSION

Biodiversity in the Sesayap and Sembakung Estuaries

The estuarine zones of the Sesayap and Sembakung Rivers are located along the northern coast of Kalimantan, precisely at the convergence between the Sesayap River and the adjacent marine waters. This region exhibits distinctive ecological characteristics, marked by extensive mangrove forests, dynamic tidal fluctuations, and dual functions as both a marine transportation corridor and a key fishing ground for coastal communities. Field surveys revealed that these estuarine waters possess abundant fishery resources, actively exploited by local fishers using various traditional fishing gears, such as guilding barrier (*sero*), gill nets, mini trawls, and stownets (trap net/*tugu* nets).

This biodiversity highlights the strategic ecological function of the Sesayap and Sembakung Estuaries as critical nursery grounds and migratory routes for economically and ecologically important fish species. Detailed data on the species composition and catch biodiversity are presented in Table 2.

Based on catches from four different fishermen guilding barriers (*sero*), gill nets, mini trawls, and stownets in Table 2, presented as percentages (Figure 4), five taxonomic classifications of biodiversity were obtained: Crustacea, Demersal (Pisces), Small-pelagic (Pisces), Mollusca, and Amphibious fish (Figure 3). Based on catches using fishing gear in the Sesayap and Sembakung Estuaries, stownets (*tugu* nets) dominated the catch, accounting for 26,779 individuals out of a total of 44,173 individuals (Table 2), with a crustacean taxonomic classification of 57.6% (Figure 4), with White shrimp (*Metapenaeus* spp.) dominating at 20,560 individuals (Table 2). followed by the results of fish catches using mini trawls fishing gear obtained as many as 13,734 ind (Table 2) with the taxonomic classification of class pisces category small pelagic which dominates at 17.95% (Figure 4) where the *nomei* fish species (*Harpodon nehereus*) which is mostly obtained as many as 7,819 ind (Table 2); guilding barrier fishing gear (*sero*) obtained fish catches as many as 2,099 ind (Table 2) with the taxonomic classification of class crustacea as many as 3.31% (Figure 4) where the *Penaeus* sp. species as many as 1,451 ind (Table 2); gillnet fishing gear is the fishing gear with the least catch obtained with a

catch of 1,561 ind (Table 2) with the taxonomic classification of class pisces category small-pelagic as many as 2.08% (Figure 4) with the *selangat* fish species

(*Anodontostoma chacunda*) obtained as many as 747 ind (Table 2).

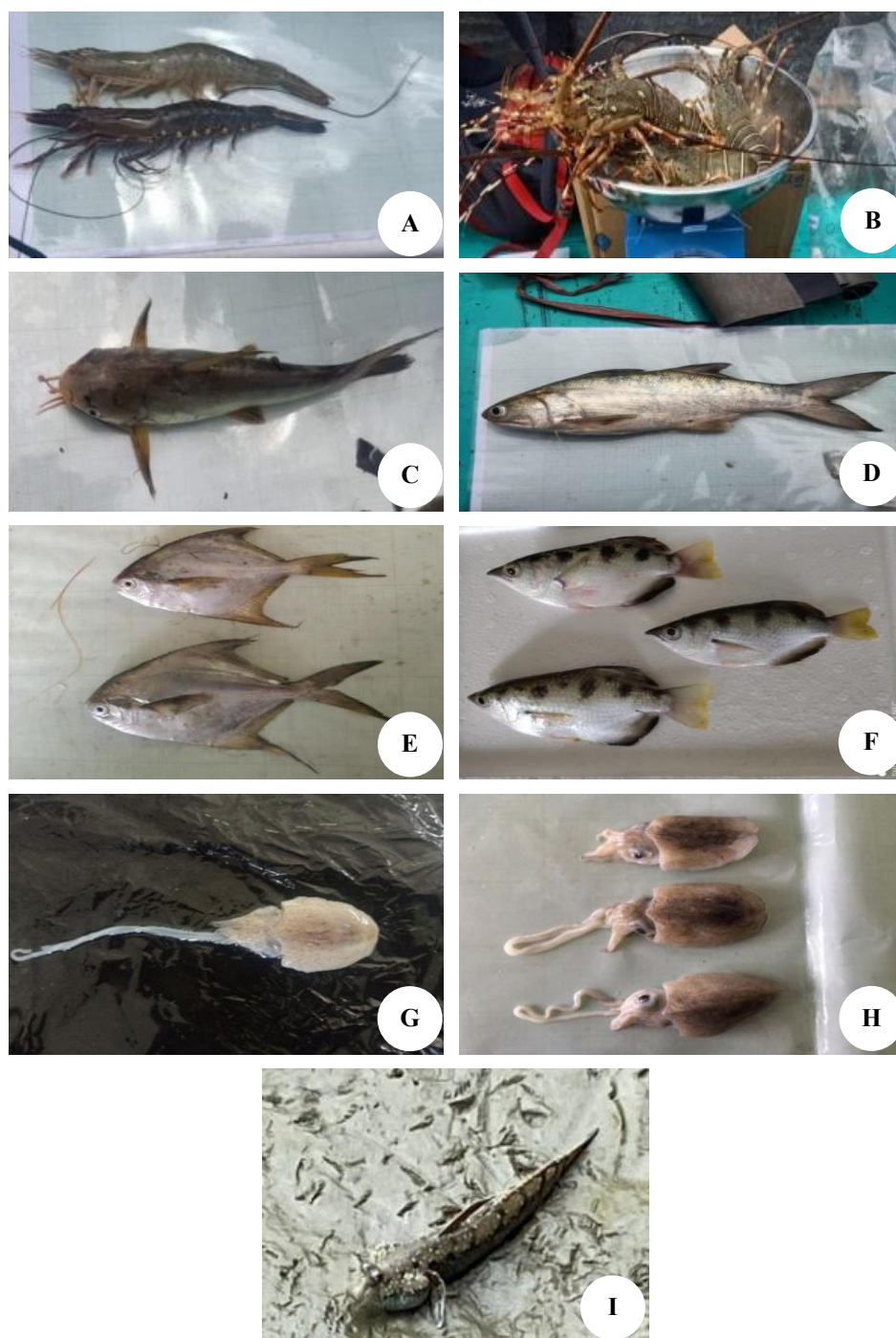


Figure 3. Representative species from five major taxonomic groups. Crustacea (A. *Penaeus* sp., B. *Panulirus* sp.); Demersal fishes (C. *Arius thalassinus*, D. *Eleutheronema tetradactylum*); Small pelagic fishes (E. *Pampus* sp., F. *Toxotidae* sp.); Mollusca (G. *Sepia* sp., H. *Loligo* sp.); and Amphibious estuarine species (I. *Boleophthalmus boddarti*) were recorded in the Sesayap and Sembakung Estuaries, North Kalimantan, Indonesia

Table 2. The biodiversity of catches by using guilding barrier (*sero*), Gill nets, mini trawls and Stownets/trap net in Sesayap and Sembakung Rivers, North Kalimantan, Indonesia

Family	Genera	Species	Local name	Common name	Abundance (Individuals)				Total (Individuals)
					Stownet (trap net/tugu net)	Gillnet	Mini trawl	Sero (guilding barrier)	
Crustacea									
Gecarcinucidae	<i>Parathelphusa</i>	<i>Parathelphusa</i> sp.	<i>Kepiting Batu</i>	Freshwater crab	25	-	-	5	30
Palaemonidae	<i>Macrobrachium</i>	<i>Macrobrachium rosenbergii</i> (De Man, 1879)	<i>Udang Galah</i>	Giant freshwater prawn	59	-	21	-	80
Palinuridae	<i>Panulirus</i>	<i>Panulirus</i> sp.	<i>Lobster</i>	Spiny lobster	-	-	-	3	3
Penaeidae	<i>Metapenaeus</i>	<i>Metapenaeus</i> sp1.	<i>Udang Putih</i>	White shrimp	20,560	-	-	-	20,560
Penaeidae	<i>Metapenaeus</i>	<i>Metapenaeus</i> sp2.	<i>Udang Bintik</i>	Speckled shrimp	2,887	-	2,161	-	5,048
Penaeidae	<i>Metapenaeus</i>	<i>Metapenaeus monoceros</i> (Fabricius, 1798)	<i>Udang Coklat</i>	Brown shrimp	8	-	-	-	8
Penaeidae	<i>Metapenaeus</i>	<i>Metapenaeus dalli</i> (Racek, 1957)	<i>Udang Dogol</i>	Dalli shrimp	-	4	-	-	4
Penaeidae	<i>Metapenaeus</i>	<i>Metapenaeus</i> sp3.	<i>Udang Kombet</i>	Comb shrimp	-	-	654	-	654
Penaeidae	<i>Penaeus</i>	<i>Penaeus semiculcatus</i> (De Haan, 1844)	<i>Udang Loreng</i>	Green tiger prawn	1,830	-	2,162	-	3,992
Penaeidae	<i>Penaeus</i>	<i>Penaeus monodon</i> (Fabricius, 1798)	<i>Udang Windu</i>	Giant tiger prawn	7	-	149	-	156
Penaeidae	<i>Penaeus</i>	<i>Penaeus</i> sp.	<i>Udang Windu</i>	Tiger prawn	-	-	-	1,451	1,451
Portunidae	<i>Scylla</i>	<i>Scylla serrata</i> (Forskål, 1775)	<i>Kepiting Bakau</i>	Mud crab	6	-	99	3	108
Squillidae	<i>Harpiosquilla</i>	<i>Harpiosquilla</i> sp.	<i>Udang Mantis</i>	Mantis shrimp	45	-	10	-	55
Demersal (Pisces)									
Ariidae	<i>Arius</i>	<i>Arius thalassinus</i> (Rüppell, 1837)	<i>Manyung/Otek</i>	Giant sea catfish	10	2	-	17	29
Carangidae	<i>Parastromateus</i>	<i>Parastromateus niger</i> (Bloch, 1795)	<i>Bawal Hitam</i>	Black pomfret	-	-	-	2	2
Chanidae	<i>Chanos</i>	<i>Chanos chanos</i> (Fabricius, 1775)	<i>Bandeng</i>	Milkfish	-	-	-	16	16
Cynoglossidae	<i>Cynoglossus</i>	<i>Cynoglossus lingua</i> (Hamilton, 1822)	<i>Lidah Pasir</i>	Long tongue sole	30	-	3	-	33
Dasyatidae	<i>Dasyatis</i>	<i>Dasyatis</i> sp.	<i>Macanan</i>	Stingray	-	-	-	1	1
Haemulidae	<i>Pomadasys</i>	<i>Pomadasys</i> sp.	<i>Gerot-gerot</i>	Grunt fish	-	-	-	57	57
Hemiscylliidae	<i>Hemiscyllium</i>	<i>Hemiscyllium</i> sp.	<i>Tokek Hiu</i>	Epulette shark	-	-	-	1	1
Latidae	<i>Lates</i>	<i>Lates</i> sp.	<i>Kakap Putih</i>	Barramundi	-	-	-	24	24
Leiognathidae	<i>Leiognathus</i>	<i>Leiognathus</i> sp	<i>Peperek</i>	Ponyfish	-	17	-	36	53
Lobotidae	<i>Labotes</i>	<i>Labotes surinamensis</i> (Bloch, 1790)	<i>Mujair</i>	Wrasse	-	-	-	1	1
Lutjanidae	<i>Lutjanus</i>	<i>Lutjanus rivulatus</i> (Cuvier, 1828)	<i>Arut</i>	Blubberlip snapper	-	-	-	8	8
Lutjanidae	<i>Lutjanus</i>	<i>Lutjanus</i> sp.	<i>Kakap Merah</i>	Red snapper	-	-	-	33	33
Megalopidae	<i>Megalops</i>	<i>Megalops</i> sp.	<i>Bulan-bulan</i>	Indo-Pacific tarpon	-	-	-	21	21
Mugilidae	<i>Valamugil</i>	<i>Valamugil</i> sp.	<i>Balanak</i>	Mullet	-	-	-	43	43
Muraenesocidae	<i>Congresox</i>	<i>Congresox talabon</i> (Cuvier, 1829)	<i>Remang</i>	Yellow pike conger	8	-	-	-	8
Muraenidae	<i>Gymnothorax</i>	<i>Gymnothorax</i> sp.	<i>Murai</i>	Moray eel	1	-	-	-	1
Paralichthyidae	<i>Paralichthys</i>	<i>Paralichthys</i> sp.	<i>Sebelah</i>	Flounder	-	-	-	2	2
Plotosidae	<i>Plotosus</i>	<i>Plotosus</i> sp.	<i>Sembelang</i>	Eel catfish	-	-	-	12	12

Polynemidae	<i>Eleutheronema</i>	<i>Eleutheronema</i> sp.	<i>Senangin</i>	Threadfin	1	572	9	25	607
Salmonidae	<i>Coregonus</i>	<i>Coregonus</i> sp.	<i>Putih</i>	Whitefish	-	-	-	158	158
Scatophagidae	<i>Scatophagus</i>	<i>Scatophagus argus</i> (Linnaeus, 1766)	<i>Ketang-ketang</i>	Spotted scat	24	-	-	-	24
Scatophagidae	<i>Scatophagus</i>	<i>Scatophagus</i> sp.	<i>Kipar</i>	Scat fish	-	-	-	88	88
Sciaenidae	<i>Argyrosomus</i>	<i>Argyrosomus amoyensis</i> (Bleeker, 1863)	<i>Gulama</i>	Amoy croaker	95	6	49	64	214
Serranidae	<i>Epinephelus</i>	<i>Epinephelus</i> sp.	<i>Kerapu</i>	Grouper	-	-	-	1	1
Siganidae	<i>Siganus</i>	<i>Siganus</i> sp.	<i>Baronang</i>	Rabbitfish	-	-	-	2	2
Stromateidae	<i>Pampus</i>	<i>Pampus</i> sp.	<i>Bawal</i>	Pomfret	157	5	27	-	189
Synbranchidae	<i>Monopterus</i>	<i>Monopterus</i> sp.	<i>Murai</i>	Swamp eel	-	-	-	1	1
Synodontidae	<i>Harpodon</i>	<i>Harpodon nehereus</i> (Hamilton, 1822)	<i>Nomei</i>	Bombay duck	630	30	7,819	-	8,479
Tetraodontidae	<i>Lagocephalus</i>	<i>Lagocephalus</i> sp.	<i>Buntal</i>	Pufferfish	22	-	21	-	43
Terapontidae	<i>Terapon</i>	<i>Terapon</i> sp.	<i>Kerong-kerong</i>	Grunter	4	5	-	-	9
Small-pelagic (Pisces)									
Carangidae	<i>Selaroides</i>	<i>Caranx tille</i> (Cuvier, 1833)	<i>Kwee</i>	Tille trevally	-	1	-	-	1
Carangidae	<i>Selaroides</i>	<i>Selaroides leptolepis</i> (Cuvier, 1833)	<i>Selar Kuning</i>	Yellowstripe scad	-	48	-	-	48
Caesionidae	<i>Caesio</i>	<i>Caesio teres</i> (Cuvier, 1829)	<i>Ekor Kuning</i>	Golden trevally	-	-	3	-	3
Chirocentridae	<i>Chirocentrus</i>	<i>Chirocentrus dorab</i> (Forsskål, 1775)	<i>Parang-parang</i>	Dorab wolf-herring	-	2	-	-	2
Clupeidae	<i>Anodontostoma</i>	<i>Anodontostoma chacunda</i> (Hamilton, 1822)	<i>Selangat</i>	Chacunda gizzard shad	107	747	-	-	854
Clupeidae	<i>Sardinella</i>	<i>Sardinella fimbriata</i> (Valenciennes, 1847)	<i>Tembang</i>	Fringescale sardine	1	-	-	-	1
Drepaneidae	<i>Drepane</i>	<i>Drepane punctata</i> (Linnaeus, 1758)	<i>Tapi-tapi</i>	Spotted sicklefish	-	-	2	6	8
Engraulidae	<i>Coilia</i>	<i>Coilia dussumieri</i> (Valenciennes, 1848)	<i>Bulu Ayam</i>	Dussumier's hairtail	68	-	154	-	222
Engraulidae	<i>Ilisha</i>	<i>Ilisha elongata</i> (Bennett, 1830)	<i>Puput</i>	Elongate ilisha	66	91	109	6	272
Leiognathidae	<i>Gazza</i>	<i>Gazza minuta</i> (Bloch, 1795)	<i>Bete-bete</i>	Anchovy herring	21	-	7	-	28
Scombridae	<i>Scomberomorus</i>	<i>Scomberomorus comersoni</i> (Lacépède, 1800)	<i>Tenggiri</i>	Narrow-barred Spanish mackerel	-	30	-	-	30
Sphyracidae	<i>Sphyracna</i>	<i>Sphyracna jello</i> (Cuvier, 1829)	<i>Alu-alu</i>	Pickhandle barracuda	-	-	-	6	6
Toxotidae	<i>Toxotes</i>	<i>Toxotes chatareus</i> (Hamilton, 1822)	<i>Sumpit</i>	Archerfish	-	-	-	6	6
Trichiuridae	<i>Trichiurus</i>	<i>Trichiurus savala</i> (Cuvier, 1829)	<i>Layur</i>	Ribbonfish	23	-	49	-	72
Mollusca									
Arcidae	<i>Anadara</i>	<i>Anadara granosa</i> (Linnaeus, 1758)	<i>Tudai</i>	Blood cockle	-	-	1	-	1
Loliginidae	<i>Loligo</i>	<i>Loligo</i> sp.	<i>Cumi-cumi</i>	Common squid	-	-	193	-	193
Sepiidae	<i>Sepia</i>	<i>Sepia</i> sp.	<i>Sotong</i>	Cuttlefish	64	1	32	-	97
Amphibious fish									
Oxudercidae	<i>Boleophthalmus</i>	<i>Boleophthalmus</i> sp.	<i>Tembakul</i>	Mudskipper	20	-	-	-	20
Total					26,779	1,561	13,734	2,099	44,173

Based on the classification of biodiversity categories from the overall catch of fishermen (Figure 5), 5 types of taxonomic class classifications were obtained, where the Crustacea class dominated biodiversity by 72.78%, the Pisces class with the Demersal category by 23%, the Pisces class with the Small Pelagic category by 3.52%, the Mollusca class by 0.66% and the amphibious fish class by 0.05% (Figure 5).

The results of the analysis used one way ANOVA (Kurniawan et al. 2015; Kaim et al. 2024) with a post-hoc multiple comparisons approach. Equal variances were assumed in the Tukey's HSD test at a 95% confidence level (significant at 5%). Table 3 shows the F_{count} for the Guilding barrier (*sero*) fishing gear of 567.754; the Gill net fishing gear of 944.701; the Mini trawl fishing gear of 145527.001; and the Stownet fishing gear (*tugu* net/trapnet) of 155775.962; with the F_{table} for all four fishing gears being 3.92 (n=61). This indicates that $F_{count} > F_{table}$. The decision-making results indicate that H_1 is accepted and H_0 is rejected. To strengthen the F_{count} test results, a further test using the Significant (α) test was used. Based on Table 2, a significant (α) value was obtained for all four fishing gears of 0.00. The decision-making results indicate that H_1 is accepted and H_0 is rejected. In the first test using F_{count} and the second test using significant (α), H_1 is accepted and H_0

is rejected. This explains that the analysis using one way ANOVA with the Tukey test found that the use of fishing gear used in the catch had an influence on biodiversity in the Sesayap and Sembakung estuary waters.

In the Sesayap and Sembakung Estuaries, the documented biodiversity and abundance of fish and shrimp underscore the essential ecological functions of these waters as nursery habitats, feeding zones, and migratory pathways for a range of commercially and ecologically valuable species.

A total of 61 fish and shrimp species were documented in the estuarine waters of the Sesayap and Sembakung Rivers. Among the various fishing gears utilized, *sero* (guilding barrier) recorded the highest species richness, capturing 30 species. The operational mechanism of *sero*, which intercepts fish during tidal migration, enhances its capacity to sample a broad spectrum of taxa. In contrast, gillnets yielded the lowest species richness, with only 15 species identified. This lower biodiversity is likely due to the narrow operational window of gillnets, typically restricted to full moon periods, thereby limiting the chances of encountering a wide range of taxa. Moreover, gillnets are inherently selective by design, targeting specific species (primarily shrimp) and size ranges.

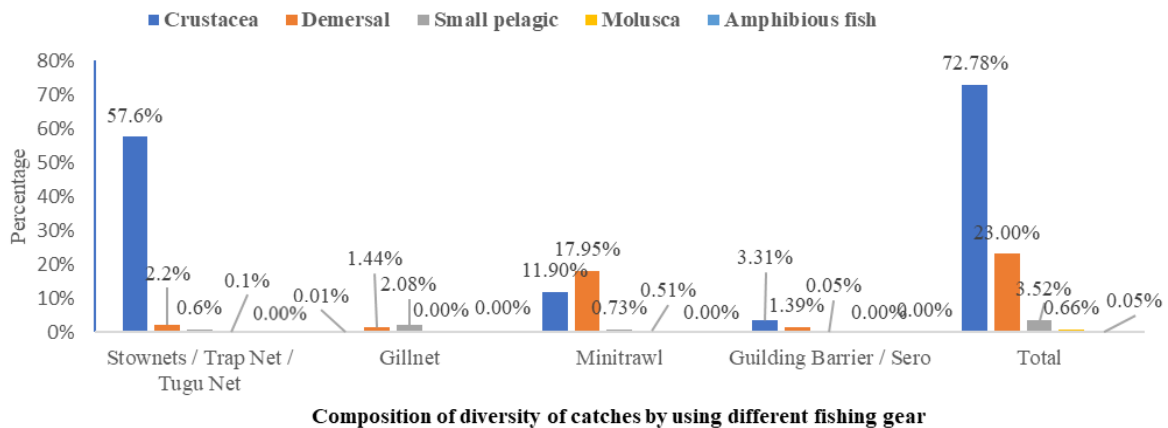


Figure 4. Percentage composition of biodiversity of catches by using different fishing gear

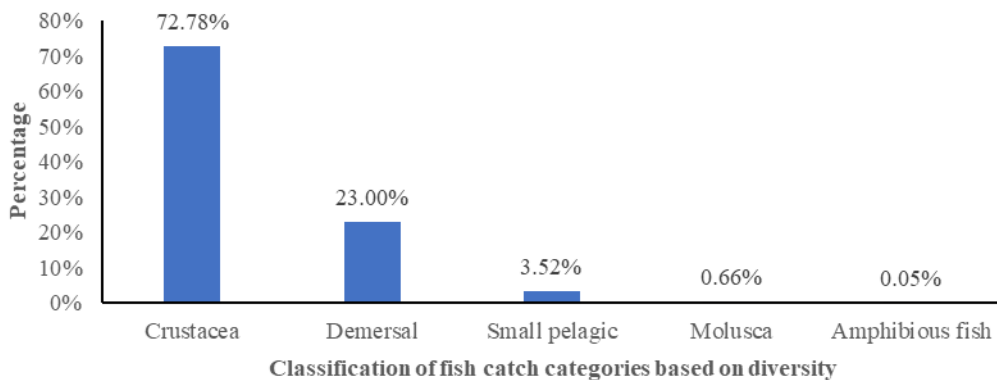


Figure 5. The overall percentage of fishermen's catch using the taxonomic class classification based on biodiversity

Trawl operations, meanwhile, recorded 21 species. Although this is slightly lower than the richness observed with *tugu* or *sero*, it likely reflects the broader spatial range of trawling, which often extends from estuarine zones into coastal and offshore areas. *Tugu* nets, a traditional passive fishing gear, accounted for 28 aquatic species, primarily comprising demersal fish and shrimp. Deployed predominantly in the northeastern estuarine zones of Tarakan City, *tugu* targets biologically productive areas that serve as migration corridors for estuarine-dependent species.

Species abundance and gear-based variation

Fishing in the Sesayap and Sembakung Estuaries was conducted using four different fishing gears. Data on fish abundance obtained from local fishermen's catches was processed using the relative abundance formula. Complete data on species composition and abundance are presented in Table 4.

Based on catches from four different fishermen guilding barriers (*sero*), gill nets, mini trawls, and stownets in Table 4, presented as percentages (Figure 6), five taxonomic classifications of fish abundance were obtained: Crustacea,

Demersal (Pisces), Small-pelagic (Pisces), Mollusca, and Amphibious fish (Figure 7).

Based on the catch results using different fishing gear, the type of stownet fish (*tugu* net), the abundance of fish that dominates the type of white shrimp (*Metapenaeus* sp.) is 76.78 (Table 4) with a crustacean taxonomic classification of 94.87% (Figure 6). Followed by the results of fish catches using the guilding barrier (*sero*) fishing gear, the abundance of fish from the *Penaeus* sp. type is 69.13 (Table 4) with a taxonomic classification of the small-pelagic crustacean class that dominates as much as 69.59% (Figure 6). The results of fish catches using mini trawl fishing gear obtained abundance of fish dominated by *nomei* fish (*H. nehereus*) of 56.93 (Table 4) with a taxonomic classification of the Pisces class in the demersal category of 57.68% (Figure 6). The results of fish catches using gillnet fishing gear obtained the least abundance of fish among other fishing gear, where the fish species obtained were dominated by the *selangat* fish (*A. chacunda*) type of 47.85 (Table 4) with the taxonomic classification of the Pisces class in the demersal category dominating at 58.81% (Figure 6).

Table 3. Comparison of fishing gear on the biodiversity of fish catches using One Way ANOVA analysis with Equal variances was assumed in the Tukey test

	Total	ANOVA				
		Sum of squares	df	Mean square	F	Sig.
Guilding barrier (<i>sero</i>)	Between Groups	2078230.532	40	51955.763	567.754	.000
	Within Groups	1830.222	20	91.511		
	Total	2080060.754	61			
Gill net	Between Groups	857578.865	40	21439.472	944.701	.000
	Within Groups	453.889	20	22.694		
	Total	858032.754	61			
Mini trawls	Between Groups	67928770.283	40	1698219.257	145527.001	.000
	Within Groups	233.389	20	11.669		
	Total	67929003.672	61			
Stownet (<i>tugu</i> net/trapnet)	Between Groups	423104821.94	40	10577620.549	155775.962	.000
	Within Groups	1358.056	20	67.903		
	Total	423106180.00	61			

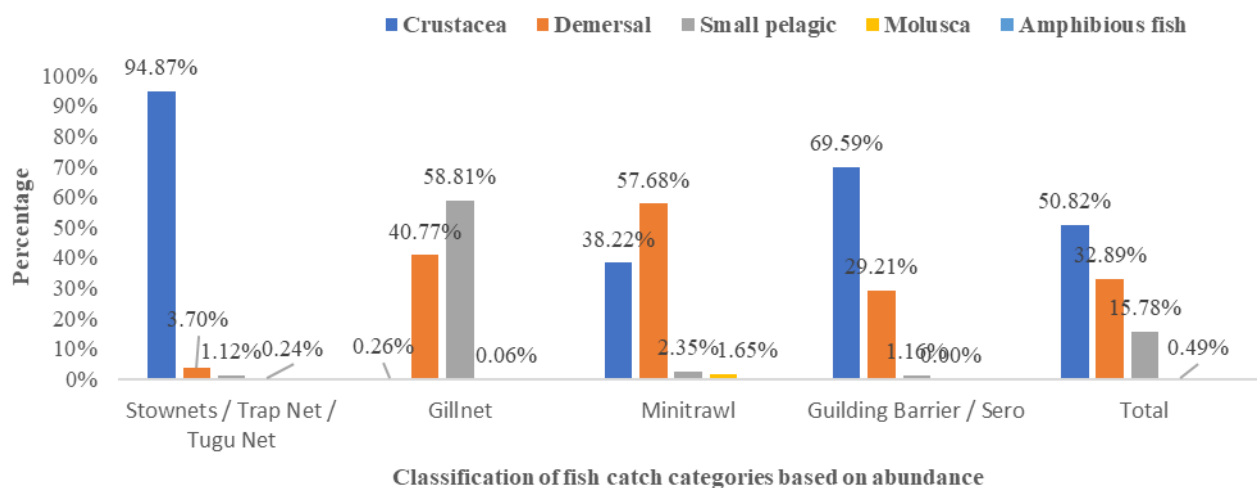


Figure 6. Percentage composition of abundance of catches by using different fishing gear

Table 4. The abundance of catches by using guildding barrier (*sero*), gill nets, mini trawls and stownets/trap net in Sesayap and Sembakung Rivers, North Kalimantan, Indonesia

Family	Genera	Species	Local name	Common name	Abundance (%)				Total	Total of abundance (%)
					Tugu net	Gillnet	Mini trawl	Sero		
Crustacea										50.77
Gecarcinucidae	<i>Parathelphusa</i>	<i>Parathelphusa</i> sp.	<i>Kepiting Batu</i>	Freshwater crab	0.09	-	-	0.24	0.33	0.08
Palaemonidae	<i>Macrobrachium</i>	<i>Macrobrachium rosenbergii</i> (De Man, 1879)	<i>Udang Galah</i>	Giant freshwater prawn	0.22	-	0.15	0	0.37	0.09
Palinuridae	<i>Panulirus</i>	<i>Panulirus</i> sp.	<i>Lobster</i>	Spiny lobster	-	-	-	0.14	0.14	0.04
Penaeidae	<i>Metapenaeus</i>	<i>Metapenaeus</i> sp1.	<i>Udang Putih</i>	White shrimp	76.78	-	-	-	76.78	19.19
Penaeidae	<i>Metapenaeus</i>	<i>Metapenaeus</i> sp2.	<i>Udang Bintik</i>	Speckled shrimp	10.78	-	15.73	-	26.52	6.63
Penaeidae	<i>Metapenaeus</i>	<i>Metapenaeus monoceros</i> (Fabricius, 1798)	<i>Udang Coklat</i>	Brown shrimp	0.03	-	-	-	0.03	0.01
Penaeidae	<i>Metapenaeus</i>	<i>Metapenaeus dalli</i> (Racek, 1957)	<i>Udang Dogol</i>	Dalli shrimp	-	0.26	-	-	0.26	0.06
Penaeidae	<i>Metapenaeus</i>	<i>Metapenaeus</i> sp3.	<i>Udang Kombet</i>	Comb shrimp	-	-	4.76	-	4.76	1.19
Penaeidae	<i>Penaeus</i>	<i>Penaeus semiculcatus</i> (De Haan, 1844)	<i>Udang Loreng</i>	Green tiger prawn	6.83	-	15.74	-	22.58	5.64
Penaeidae	<i>Penaeus</i>	<i>Penaeus monodon</i> (Fabricius, 1798)	<i>Udang Windu</i>	Giant tiger prawn	0.03	-	1.08	-	1.11	0.28
Penaeidae	<i>Penaeus</i>	<i>Penaeus</i> sp.	<i>Udang Windu</i>	Tiger prawn	-	-	0	69.13	69.13	17.28
Portunidae	<i>Scylla</i>	<i>Scylla serrata</i> (Forskål, 1775)	<i>Kepiting Bakau</i>	Mud crab	0.02	-	0.72	0.14	0.89	0.22
Squillidae	<i>Harpiosquilla</i>	<i>Harpiosquilla</i> sp.	<i>Udang Mantis</i>	Mantis shrimp	0.17	-	0.07	-	0.24	0.06
Demersal (Pisces)										32.84
Ariidae	<i>Arius</i>	<i>Arius thalassinus</i> (Rüppell, 1837)	<i>Manyung/Otek</i>	Giant sea catfish	0.04	0.13	-	0.81	0.98	0.24
Chanidae	<i>Chanos</i>	<i>Chanos chanos</i> (Fabricius, 1775)	<i>Bandeng</i>	Milkfish	-	-	-	0.76	0.76	0.19
Cynoglossidae	<i>Cynoglossus</i>	<i>Cynoglossus lingua</i> (Hamilton, 1822)	<i>Lidah Pasir</i>	Long tongue sole	0.11	-	0.02	-	0.13	0.03
Dasyatidae	<i>Dasyatis</i>	<i>Dasyatis</i> sp.	<i>Macanan</i>	Stingray	-	-	-	0.05	0.05	0.01
Haemulidae	<i>Pomadasys</i>	<i>Pomadasys</i> sp.	<i>Gerot-gerot</i>	Grunt fish	-	-	-	2.72	2.72	0.68
Hemiscylliidae	<i>Hemiscyllium</i>	<i>Hemiscyllium</i> sp.	<i>Tokek Hiu</i>	Epaulette shark	-	-	-	0.05	0.05	0.01
Latidae	<i>Lates</i>	<i>Lates</i> sp.	<i>Kakap Putih</i>	Barramundi	-	-	-	1.14	1.14	0.29
Leiognathidae	<i>Leiognathus</i>	<i>Leiognathus</i> sp.	<i>Peperok</i>	Ponyfish	-	1.09	-	1.72	2.8	0.7
Lobotidae	<i>Labotes</i>	<i>Labotes surinamensis</i> (Bloch, 1790)	<i>Mujair</i>	Wrasse	-	-	-	0.05	0.05	0.01
Lutjanidae	<i>Lutjanus</i>	<i>Lutjanus rivulatus</i> (Cuvier, 1828)	<i>Arut</i>	Blubberlip snapper	-	-	-	0.38	0.38	0.1
Lutjanidae	<i>Lutjanus</i>	<i>Lutjanus</i> sp.	<i>Kakap Merah</i>	Red snapper	-	-	-	1.57	1.57	0.39
Megalopidae	<i>Megalops</i>	<i>Megalops</i> sp.	<i>Bulan-bulan</i>	Indo-Pacific tarpon	-	-	-	1	1	0.25
Mugilidae	<i>Valamugil</i>	<i>Valamugil</i> sp.	<i>Balanak</i>	Mullet	-	-	-	2.05	2.05	0.51
Muraenesocidae	<i>Congresox</i>	<i>Congresox talabon</i> (Cuvier, 1829)	<i>Remang</i>	Yellow pike conger	0.03	-	-	-	0.03	0.01

Muraenidae	<i>Gymnothorax</i>	<i>Gymnothorax</i> sp.	<i>Murai</i>	Moray eel	0.05	-	-	-	0.05	0.01
Paralichthyidae	<i>Paralichthys</i>	<i>Paralichthys</i> sp.	<i>Sebelah</i>	Flounder	-	-	-	0.1	0.1	0.02
Plotosidae	<i>Plotosus</i>	<i>Plotosus</i> sp.	<i>Sembelang</i>	Eel catfish	-	-	-	0.57	0.57	0.14
Polynemidae	<i>Eleutheronema</i>	<i>Eleutheronema</i> sp.	<i>Senangin</i>	Threadfin	-	36.64	0.07	1.19	37.9	9.48
Salmonidae	<i>Coregonus</i>	<i>Coregonus</i> sp.	<i>Putih</i>	Whitefish	-	-	-	7.53	7.53	1.88
Scatophagidae	<i>Scatophagus</i>	<i>Scatophagus argus</i> (Linnaeus, 1766)	<i>Ketang-ketang</i>	Spotted scat	0.09	-	-	-	0.09	0.02
Scatophagidae	<i>Scatophagus</i>	<i>Scatophagus</i> sp.	<i>Kipar</i>	Scat fish	-	-	-	4.19	4.19	1.05
Sciaenidae	<i>Argyrosomus</i>	<i>Argyrosomus amoyensis</i> (Bleeker, 1863)	<i>Gulama</i>	Amoy croaker	0.35	0.38	0.36	3.05	4.14	1.04
Serranidae	<i>Epinephelus</i>	<i>Epinephelus</i> sp.	<i>Kerapu</i>	Grouper	-	-	-	0.05	0.05	0.01
Siganidae	<i>Siganus</i>	<i>Siganus</i> sp.	<i>Baronang</i>	Rabbitfish	-	0	-	0.1	0.1	0.02
Stromateidae	<i>Pampus</i>	<i>Pampus</i> sp.	<i>Bawal</i>	Pomfret	0.59	0.32	0.2	-	1.1	0.28
Stromateidae	<i>Parastromateus</i>	<i>Parastromateus niger</i> (Bloch, 1795)	<i>Bawal Hitam</i>	Black pomfret	-	-	-	0.1	0.1	0.02
Synbranchidae	<i>Monopterus</i>	<i>Monopterus</i> sp.	<i>Murai</i>	Swamp eel	-	-	-	0.05	0.05	0.01
Synodontidae	<i>Harpodon</i>	<i>Harpodon nehereus</i> (Hamilton, 1822)	<i>Nomei</i>	Bombay duck	2.35	1.92	56.93	-	61.21	15.3
Tetraodontidae	<i>Lagocephalus</i>	<i>Lagocephalus</i> sp.	<i>Buntal</i>	Pufferfish	0.08	0	0.15	-	0.24	0.06
Terapontidae	<i>Terapon</i>	<i>Terapon</i> sp.	<i>Kerong-kerong</i>	Grunter	0.01	0.32	-	-	0.34	0.08
Small-pelagic (Pisces)										15.87
Carangidae	<i>Caranx</i>	<i>Caranx tille</i> (Cuvier, 1833)	<i>Kwee</i>	Tille trevally	-	0.06	-	-	0.06	0.02
Carangidae	<i>Selaroides</i>	<i>Selaroides leptolepis</i> (Cuvier, 1833)	<i>Selar kuning</i>	Yellowstripe scad	-	3.07	-	-	3.07	0.77
Caesionidae	<i>Caesio</i>	<i>Caesio teres</i> (Cuvier, 1829)	<i>Ekor kuning</i>	Golden trevally	-	-	0.02	-	0.02	0.01
Chirocentridae	<i>Chirocentrus</i>	<i>Chirocentrus dorab</i> (Forsskål, 1775)	<i>Parang-parang</i>	Dorab wolf-herring	-	0.13	-	-	0.13	0.03
Clupeidae	<i>Anodontostoma</i>	<i>Anodontostoma chacunda</i> (Hamilton, 1822)	<i>Selangat</i>	Chacunda gizzard shad	0.4	47.85	-	-	48.25	12.06
Clupeidae	<i>Sardinella</i>	<i>Sardinella fimbriata</i> (Valenciennes, 1847)	<i>Tembang</i>	Fringescale sardine	0.05	-	-	-	0.05	0.01
Drepaneidae	<i>Drepane</i>	<i>Drepane punctata</i> (Linnaeus, 1758)	<i>Tapi-tapi</i>	Spotted sicklefish	-	-	0.01	0.29	0.3	0.08
Engraulidae	<i>Coilia</i>	<i>Coilia dussumieri</i> Valenciennes, 1848)	<i>Bulu Ayam</i>	Dussumier's hairtail	0.25	-	1.12	-	1.38	0.34
Engraulidae	<i>Ilisha</i>	<i>Ilisha elongata</i> Bennett, 1830	<i>Puput</i>	Elongate ilisha	0.25	5.83	0.79	0.29	7.16	1.79
Leiognathidae	<i>Gazza</i>	<i>Gazza minuta</i> (Bloch, 1795)	<i>Bete-bete</i>	Anchovy herring	0.08	-	0.05	-	0.13	0.03
Scombridae	<i>Scomberomorus</i>	<i>Scomberomorus comersoni</i> (Lacepède, 1800)	<i>Tenggiri</i>	Narrow-barred Spanish mackerel	-	1.92	-	-	1.92	0.48
Sphyraenidae	<i>Sphyraena</i>	<i>Sphyraena jello</i> (Cuvier, 1829)	<i>Alu-alu</i>	Pickhandle barracuda	-	-	-	0.29	0.29	0.07
Toxotidae	<i>Toxotes</i>	<i>Toxotes chatareus</i> (Hamilton, 1822)	<i>Sumpit</i>	Archerfish	-	-	-	0.29	0.29	0.07
Trichiuridae	<i>Trichiurus</i>	<i>Trichiurus savala</i> (Cuvier, 1829)	<i>Layur</i>	Ribbonfish	0.09	-	0.36	-	0.044	0.11

Molusca										0.48
Arcidae	<i>Anadara</i>	<i>Anadara granosa</i> (Linnaeus, 1758)	<i>Tudai</i>	Blood cockle	-	-	0.01	-	0.01	0
Loliginidae	<i>Loligo</i>	<i>Loligo</i> sp.	<i>Cumi-cumi</i>	Common squid	-	-	1.41	-	1.41	0.35
Sepiidae	<i>Sepia</i>	<i>Sepia</i> sp.	<i>Sotong</i>	Cuttlefish	0.24	0.06	0.23	-	0.54	0.13
Amphibious fish										0.02
Oxudercidae	<i>Boleophthalmus</i>	<i>Boleophthalmus</i> sp.	<i>Tembakul</i>	Mudskipper	0.07	-	-	-	0.07	0.02
Total					100	100	100	100	400	100

Based on the classification of fish abundance categories from the total catch of fishermen (Figure 7), 5 types of taxonomic Class classifications were obtained, where the Crustacea class dominated fish abundance by 50.82%, the Pisces class from the Demersal category by 32.89%, the Pisces class from the Small-pelagic category by 15.78%, the Mollusca class by 0.49% and the Amphibious fish class by 0.02% (Figure 7).

The results of the analysis used one way ANOVA (Kurniawan et al. 2015; Kaim et al. 2024) with a post-hoc multiple comparisons approach. Equal variances were assumed in the Tukey test at a 95% confidence level (significant at 5%). Table 5 shows the F_{count} for the guilding barrier (*sero*) fishing gear of 16187.937; the gill net fishing gear of 11399.231; the mini trawls fishing gear of 5208.654; and the stownet fishing gear (*tugu net/trapnet*) of 17581.796; with the F_{table} for all four fishing gears being 3.92 ($n=61$). This indicates that $F_{\text{count}} > F_{\text{table}}$. The decision-making results indicate that H_1 is accepted and H_0 is rejected. To strengthen the F_{count} test results, a further test using the significant (α) test was used. Based on Table 4, a significant (α) value was obtained for all four fishing gears of 0.00. The decision-making results indicate that H_1 is

accepted and H_0 is rejected. In the first test using F_{count} and the second test using significant (α), H_1 is accepted and H_0 is rejected. This explains that the analysis using one way ANOVA with the Tukey test found that the use of fishing gear used in the catch had an influence on fish abundance in the Sesayap and Sembakung estuarine waters.

A total of 61 species of fish and shrimp were identified in the estuarine waters of the Sesayap and Sembakung Rivers, with white shrimp (*Metapenaeus* spp.) exhibiting the highest relative abundance at 19.19%. Among all gear types employed, tugu nets demonstrated the widest variation in species abundance, ranging from 0.004% to 76.78%. The highest abundance recorded for *Metapenaeus* spp. occurred during sampling trips 1, 3, and 4, which coincided with neap tide phases. Other species frequently captured across gear types included *Penaeus* spp., *H. nehereus (nomei)*, and *A. chacunda (selangat)*, all of which were consistently recorded throughout sampling periods, irrespective of tidal phase. This consistency suggests broad habitat tolerance and stable residency patterns in estuarine environments, particularly in substrates dominated by sand or mud.

Table 5. Comparison of fishing gear on the abundance of fish catches using one way ANOVA analysis with equal variances was assumed in the Tukey test

		ANOVA				
		Sum of Squares	df	Mean Square	F	Sig.
Guilding barrier	Between Groups	2079986.365	38	54736.483	16187.937	.000
	Within Groups	74.389	22	3.381		
	Total	2080060.754	61			
Gillnet	Between Groups	3520.497	38	92.645	11399.231	.000
	Within Groups	.179	22	.008		
	Total	3520.676	61			
Mini trawls	Between Groups	3600.556	38	94.751	5208.654	.000
	Within Groups	.400	22	.018		
	Total	3600.956	61			
Stownet	Between Groups	5900.273	38	155.270	17581.796	.000
	Within Groups	.194	22	.009		
	Total	5900.467	61			

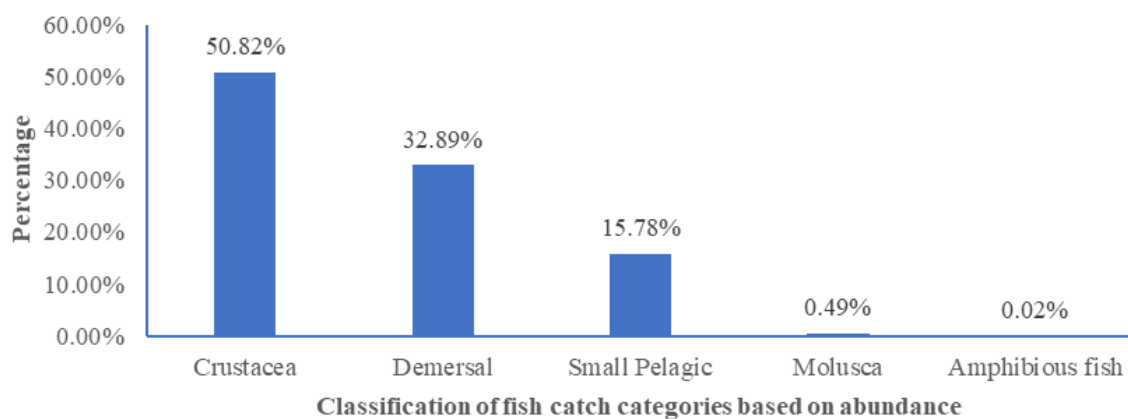


Figure 7. The percentage of the total catch of fishermen using taxonomic class classification based on abundance

In gillnet catches, *A. chacunda* exhibited the highest relative abundance at 47.85%, while *Metapenaeus dalli* represented the lowest at 0.26%. Trawl operations recorded *H. nehereus* as the most dominant species (56.93%), followed by *Metapenaeus* spp. (15.74%) and *Penaeus semisulcatus* (15.73%). In contrast, the lowest abundance was observed for *Anadara granosa* (blood cockle), at only 0.01%. The low catch rate of *A. granosa* is likely due to its infaunal behavior, burrowing into sediments, which reduces its exposure to active gear such as trawls. In *sero* gear (lift nets), *Penaeus* spp. accounted for the highest relative abundance (69.13%), while the lowest values were recorded for *Epinephelus* spp. (groupers) and *Labotes surinamensis* (tilapia), both at 0.048%. The high abundance of *Penaeus* spp. is attributable to their limited mobility during low tides, which increases their vulnerability to stationary gear such as *sero*, typically operated in shallow intertidal zones.

Discussion

Biodiversity of fish in the Sesayap and Sembakung Estuaries

Fishing activities in the area are intensive due to the region's strategic position as a major transit route connecting Tana Tidung Regency (KTT) and Tarakan Island. These findings are consistent with Radifah (2020), who highlighted the strategic role of the Sesayap River as both a fishery ground and an inter-district transportation route in North Kalimantan. Patangngari and Musbir (2024) explained that optimal catches were carried out in river waters, where the oceanographic factors that had an influence on catches were current factors which had a strong correlation with the number of catches. This observation is further supported by a recent study in Manado Bay, which demonstrated that estuarine areas characterized by tidal dynamics and dense mangrove cover support the presence of over 40 fish species from 30 families, most of which are captured using traditional gear (Bataragoa et al. 2024). Additionally, significant correlations between environmental fluctuations (e.g., salinity, dissolved oxygen, and depth) and fish density in estuarine ecosystems have been reported in several tropical river mouths in Indonesia, reinforcing the argument that fishery productivity in such areas is closely linked to dynamic hydrological conditions (Rais et al. 2017; Arevalo et al. 2023).

The heterogeneity of estuarine aquatic ecosystems greatly influences biodiversity levels, species abundance, and the spatial distribution of aquatic organisms, including fish (Woodland et al. 2019; Majhi et al. 2024). Based on field research employing traditional fishing methods such as gillnets, fish traps (*bubu*), and *sero* lift nets, a total of 61 fish species were identified from estuarine landings, representing 24 distinct families (Hutchison et al. 2014). Diversitas (2001) explains that research into the inventory of species, their characteristics, uses, and biology plays a vital role in maintaining and protecting biological resources for their sustainability. According to Odulate et al. (2020) and Rafiu et al. (2024), variations in biodiversity catches in waters are caused by sampling at difference time periods,

the use of difference fishing gear and different fish sampling designs. Hutchison et al. (2014) reported that out of 3,544 individual fish sampled, there was a clear dominance of species from the families Ariidae, Leiognathidae, and Sciaenidae—emphasizing the ecological importance of estuaries as nursery grounds and migration corridors. Similar findings were observed in the Musi River estuary and surrounding swamps, where local fishers used a range of traditional fishing devices including *seluang* nets, fixed gillnets, *bubu* traps, and bottom longlines (*rawai pendam*), all contributing significantly to estuarine catch compositions (Sudarmo et al. 2024). Furthermore, a study on the use of *sero* gear in tropical estuaries revealed that rabbitfish (*Siganus javus*) caught by traditional *sero* had an average standard length of 20.34 cm, with most individuals classified as juveniles, indicating the efficiency of this gear type in capturing early life stages of species utilizing estuaries and seagrass beds as nursery habitats (Ihsan et al. 2024).

This level of species richness surpasses that reported by Saleky et al. (2021), who identified only 12 species in Ndalir waters, Merauke, Papua, and is moderately lower than the 87 species reported by Nurfiarini et al. (2015) from the Cilacap coast in Central Java. The fish assemblage in the present study area was dominated by demersal species, a pattern likely driven by the turbidity of estuarine waters, where water transparency ranged between 27 and 45 cm optimal range for demersal organisms. Taxonomically, species were classified into major groups such as crustaceans, finfish, mollusks, and reptiles, and functionally into pelagic and demersal categories according to their ecological niches.

Based on the results of research using the guiding barrier (*sero*) fishing gear, the crustacean class was found to be dominated by the catch of *Penaeus* sp., with as many as 1,451 individuals. It is in accordance with the opinion of Patangngari et al. (2025), who explained that they found the use of *sero* fishing gear with an average large catch in the Crustacea class with the species *Litopenaeus vannamei*. These results indicate that increasing the net size can capture biologically viable fish and support resources in the estuary area. Patangngari et al. (2025) also noted that tidal current parameters greatly influence fish catches. The use of large mesh sizes can have a positive impact on the sustainability of aquatic organisms because if the mesh size is 5 mm or 15 mm, many catches are not suitable for capture because they have not reached the appropriate size. Furthermore, the dominance of *Penaeus* sp. in *sero* catches in this study is consistent with the findings of Rawin and Ardiansyah (2024), who reported that *Metapenaeus affinis* and *Penaeus monodon* were the most abundant crustaceans captured using *sero* in Luwu Timur Waters, Indonesia. Similarly, Setyadi et al. (2021) observed high crustacean abundance in mangrove ecosystems of Papua, Indonesia, while Muhtadi et al. (2022) demonstrated that penaeid shrimps persist throughout tidal cycles in tropical tidal lakes, confirming the influence of tidal dynamics on crustacean catch composition.

In addition, Mawardi et al. (2024) found that salinity variations significantly affected crustacean biodiversity and abundance in coastal estuaries of Aceh, Indonesia. These comparisons indicate that differences in catch composition among regions are likely influenced by local hydrodynamic and environmental conditions, as well as by mesh size and gear configuration. Patangngari and Musbir (2024) added that tidal current parameters greatly influence fish catches. The use of large mesh sizes can have a positive impact on the sustainability of aquatic organisms because if the mesh size is 5 mm and 15 mm, many catches are not suitable for capture because they have a size that is still undergoing reproduction (Salim et al. 2023a). However, the 5 mm mesh size has a high level of biodiversity. However, mesh sizes of more than 15 mm have a positive impact on the survival of fish in estuarine waters (Patangngari and Musbir 2024). According to Salim et al. (2019), guilding barrier (*sero*) fishing gear is categorized as environmentally friendly fishing gear. It has a high level of selectivity, produces little by-catch, is harmless to fishermen and consumers, is non-destructive to habitats and fishermen, produces fresh, high-quality fish, and is socially acceptable. Salim et al. (2019) added that guilding barrier (*sero*) fishing gear is a sustainable fishing gear that is recommended for use by fishermen because it relies on natural assistance such as tidal currents. According to Sabrah (2007), the catch using bottom trawl fishing gear is dominated by the biodiversity from the demersal species caught. This selective tendency is consistent with findings from Wirnawati (2013), who observed a dominance of *nomei* fish in gill nets catches despite shrimp being the primary target. According to Indarjo et al. (2023a, b), fishermen using bottom gillnet fishing gear make lobster and demersal fish one of the main targets in fishing. According to Salim et al. (2023a, b), the catch using mini trawls fishing gear is dominated by *nomei* fish (*H. nehereus*).

Typically operated during low tide, *tugu* nets are especially efficient in harvesting penaeid shrimp species (e.g., *Penaeus indicus*, *P. merguensis*), which exhibit increased foraging activity in shallow, muddy substrates during ebb tides (Munga et al. 2013). The strategic timing and spatial deployment of *tugu* gear allow it to capitalize on diel movement patterns of shrimp and bottom-dwelling fish, offering high efficiency with minimal ecological disturbance when compared to more invasive gear types (Pacho et al. 2021). The widespread local knowledge surrounding *tugu* fishing further reflects its cultural entrenchment and adaptive utility in small-scale estuarine fisheries management (Mendoza et al. 2023).

These deeper waters tend to be occupied by mature individuals, especially adult shrimp and fish, as noted by Prasetyo et al. (2014), who documented distributions spanning from shallow estuaries to depths of 5-60 m. The soft, muddy substrate typical of estuarine systems further supports shrimp populations by providing organic matter containing in the sediment (Tavares et al. 2025). In summary, the composition and abundance of estuarine species are strongly shaped by fishing gear type, operational timing, and prevailing environmental

conditions (Getz and Eckert 2022; Nguyen et al. 2025). Each gear type demonstrates unique selectivity patterns, which in turn influence catch composition and reflect underlying ecological processes within the estuary (Vieira et al. 2020; Romdoni et al. 2024). Estuaries such as these provide crucial transitional habitats supporting early life stages of penaeid shrimp, sciaenids, and other euryhaline species that are particularly sensitive to habitat alterations (Whitfield 2020). The observed spatial variability in species composition across different sampling stations highlights the role of microhabitat heterogeneity, tidal regimes, and seasonal freshwater inflow. These findings emphasize the necessity for habitat-specific management strategies and gear-selective regulations to ensure long-term fishery productivity and the preservation of estuarine biodiversity (Xu et al. 2022).

Species abundance and gear-based variation

Reported by Nurfiarini et al. (2015) in Cilacap waters, Central Java, but remains lower than the 30.83% abundance of *Mugil cephalus* reported by Saleky et al. (2021) in Ndalar waters, Papua. Such inter-site variation in species dominance is likely influenced by a range of local environmental factors, including turbidity, substrate composition, salinity gradients, food availability, and estuarine hydrodynamics (Aryani et al. 2020; Bhavan et al. 2025). According to Patangngari and Musbir (2024), besides tidal current parameters, depth is also a significant factor in analyzing fish populations. This is consistent with the opinion of Bergström et al. (2019), who explained that river water depth in estuaries plays a crucial role in species distribution, biomass, and the overall presence of fish stocks in nature.

During such periods, *Metapenaeus* species display heightened foraging activity and horizontal movement across shallow mudflats, increasing their susceptibility to passive gear (van der Velde et al. 2021). Their gregarious schooling behavior further enhances catchability in stationary gear systems (Abubakar et al. 2019). Known for their euryhaline tolerance and preference for fine muddy or sandy-mud substrates, *Metapenaeus* spp. often aggregate in nutrient-enriched estuarine zones (Nandy et al. 2022). Their seasonal peaks are also closely associated with reproductive cycles and post-larval drift during neap tides, facilitating high juvenile recruitment into estuarine nursery habitats (Simanjuntak et al. 2021).

This stark contrast illustrates the inherent selectivity of gillnets, which are designed based on specific mesh sizes that target mid-sized pelagic and demersal species with matching morphometrics (Sarr et al. 2023). The narrow taxonomic spectrum of gillnet catches may also reflect behavioral traits of non-target species that either avoid the gear or exhibit minimal activity during the gear's operational periods. In the present study, gillnets were primarily deployed during full moon phases, a time when increased ambient light and altered behavioral responses can reduce gear encounter rates, especially for nocturnally active or tide-sensitive species (Engman et al. 2017; Milardi et al. 2018). Species such as *M. dalli*, which exhibit peak movement during neap tides or darker lunar phases,

are thus less likely to be intercepted. These findings emphasize the critical role of lunar and tidal interactions in interpreting catch variability in passive fishing methods (Yanagihara et al. 2022; Rawat et al. 2025).

Conversely, groupers and tilapia are generally reef-associated or freshwater-tolerant species, respectively, and are less abundant in muddy estuarine systems (Nanami 2024). Overall, the variability in species composition and abundance across different fishing gears reflects the complex interactions between gear selectivity, operational timing, and ecological behavior of target species (Humphries et al. 2019; Mocuba et al. 2024). The long-term and increasing impact of human activities on coastal ecosystems (Airoldi and Beck 2007) due to fishing, according to Eriksson et al. (2009), suggests that various impacts on ecosystems are unlikely to be caused by high pressure on fish. Small mesh sizes can disrupt fish population stability. However, Salim et al. (2019) explain that environmentally friendly fishing gear is fishing gear that does not damage the ecological habitat of fish or the population of certain species. According to Bergström et al. (2019), Humphries et al. (2019), and Mocuba et al. (2024), they explain that over time, a more rigorous evaluation of no-take zones needs to be implemented, with the determination of management directions supported by the potential benefits obtained. However, no-take zones provide a rare opportunity to isolate the impacts of fishing from other pressures affecting the marine environment (Bergström et al. 2019; Humphries et al. 2019; Mocuba et al. 2024). These findings highlight the importance of employing multiple fishing methods in biodiversity assessments to capture the full ecological breadth of estuarine communities. In the context of the Sesayap and Sembakung Estuaries, such integrative approaches are essential for informing sustainable management strategies that support both fishery productivity and ecosystem integrity.

In summary, biodiversity and abundance in the Sesayap-Sembakung estuaries showed apparent spatial and gear-specific variation. The study documented 24 families; white shrimp (*Metapenaeus* spp.) dominated overall abundance (19.19%), and *H. nehereus* and *A. chacunda* were consistently present across gear types and sampling periods. Differences in species composition were strongly associated with gear selectivity. The prominence of demersal taxa reflects estuarine conditions, shallow depth, high turbidity, and muddy substrates, which favour benthic and euryhaline groups such as penaeids and sciaenids. These patterns highlight the ecological importance of the Sesayap and Sembakung Estuaries as nursery grounds, migration corridors, and feeding areas for commercially and ecologically important species. Accordingly, management should prioritise habitat-specific conservation zoning, gear-selective regulations, and systematic monitoring to evaluate zone suitability and support adaptive local fisheries policies, thereby sustaining long-term productivity and conserving estuarine biodiversity. Further research is also needed on fishing gear selectivity models directly modeling selectivity curves.

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