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RESEARCH ARTICLE

Purse Seine Fisheries: Analysis of Small Pelagic Fishes Captured in Southeast Sulu Sea from 2018 to 2023

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ABSTRACT

This study examined the catch composition and population status of dominant small pelagic species exploited by purse seine fisheries in the Southeast Sulu Sea from 2018 to 2023. The research aimed to develop a data-driven fisheries profile of the region by generating comprehensive information on species composition, exploitation patterns, and population dynamics associated with purse seine landings. Data were collected from twelve major landing sites and analyzed using established growth models and length-based stock assessment approaches. Results indicated that *Sardinella lemuru* dominated the total catch, contributing 1,118,742.9 mt (85.2%), followed by *Decapterus macrosoma* with 76,273.2 mt (5.8%), *Selar crumenophthalmus* with 37,176.8 mt (2.8%), *Amblygaster sirm* with 21,451.7 mt (1.6%), and *Decapterus macarellus* with 3,671.1 mt (0.3%). Stock assessment analyses revealed persistent fishing pressure and elevated exploitation levels in *S. lemuru* ($L\infty$ = 20.6 cm, k = 1.11 yr^{-1}, Ø′ = 2.673, M = 2.12 yr^{-1}, F = 2.78–4.38 yr^{-1}, Z = 4.92–6.50 yr^{-1}, E = 0.57–0.63), *D. macrosoma* ($L\infty$ = 26.77 cm, k = 1.03 yr^{-1}, Ø′ = 2.868, M = 1.88 yr^{-1}, F = 1.98–3.45 yr^{-1}, Z = 3.86–5.33 yr^{-1}, E = 0.51–0.65), and *S. crumenophthalmus* ($L\infty$ = 28.86 cm, k = 1.02 yr^{-1}, Ø′ = 2.929, M = 1.83 yr^{-1}, F = 1.83–3.87 yr^{-1}, Z = 3.66–5.70 yr^{-1}, E = 0.50–0.68), with exploitation ratios consistently exceeding the biological reference point for sustainable exploitation (E > 0.50). In addition, growth overfishing was evident, as the estimated lengths at first capture (L_{50}) for most species were generally below established length-at-maturity benchmarks, indicating substantial harvesting of immature individuals. In contrast, *D. macarellus* exhibited comparatively healthier stock conditions ($L\infty$ = 33.9 cm, k = 0.97 yr^{-1}, Ø′ = 3.047, M = 1.69 yr^{-1}, F = 0.91–1.69 yr^{-1}, Z = 2.60–3.38 yr^{-1}, E = 0.35–0.50), characterized by lower fishing mortality and exploitation rates. The study highlights the need for strengthened fishery management through improved gear selectivity, stricter enforcement of seasonal bans, and shifting fishing pressure toward less exploited stocks to prevent potential stock collapse and ensure long-term sustainability.

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1. INTRODUCTION

As of 2022, Region IX (Zamboanga Peninsula) was the most productive region in the Philippines in terms of fish landed through capture fisheries, contributing about 349,593.95 metric tons (17.58% of nationwide production) in that year alone, valued at about 25 billion in revenue (BFAR 2023). The majority of this production is from sardine commodities, wherein 53.12% of Region IX production was sardines. Data from the local National Stock Assessment Program (NSAP-IX) points out that this high volume of production came from Southeast Sulu Sea, which takes up about 81.9% of all production in the area from the years 2018–2023, followed by the Moro Gulf at 9.7%, East Sulu Sea at 7.1%, and Sibuguey Bay, Basilan Strait, and other areas approximately 1% of the remaining percentage (NSAP 2025).

Southeast Sulu Sea, situated in Fisheries Management 4, is a sea area located between the islands of the Zamboanga Peninsula, the Sulu Islands, and some parts of Borneo. It is characterized by high primary productivity near shallow coastal areas but is technically a "desert" farther offshore (Jones 2002). This high nearshore productivity makes it ideal for fish production, which helps explain the volume of fish landed from the Southeast Sulu Sea.

Fish production from the Southeast Sulu Sea is similar to the national counterpart, dominated by small pelagic fishes, averaging about 800,000 metric tons from 2018 to 2022 (BFAR 2023). Small pelagic fishes are a type of fish characterized by fast growth rates and short life spans; this includes sardines (genus *Sardinella*), round scads (genus *Decapterus*), bigeye scads (genus *Selar*), anchovies (genus *Stolephorous*), and mackerels (genus *Rastrelliger*). These types of fishes are cheap sources of protein for low-income households in the Philippines, making them a staple for 70% of the population and a key indicator of the country's food security (Zaragosa et al. 2004). In the Southeast Sulu Sea, a large portion of small pelagic fish is caught by commercial fishing vessels and landed in Zamboanga City (the location of most landing sites from the Sulu Sea; see Figure 1). Small pelagic fishes make up about 98% of local production in 2018–2023 (NSAP 2025)

Catches landed in Zamboanga City are caught using several fishing methods, including hook and line, bag nets, ring nets, drift gill nets, and the most dominant purse seine, which accounted for 97.32% in 2013 and 96.7% in 2018–2023 (NSAP 2025). Purse seining is a method in which a large net is deployed to encircle schools of fish in the water column using a floating lead line, usually deployed by a skiff, where the lead line of the net is then pulled to close the bottom of the net, preventing the fish from escaping, forming a "purse," hence the name "purse seine." This method of fishing targets schooling fish species, such as small pelagic fish. The dominance of this fishing gear and the sheer volume of fish landed using this method make it the optimal gear for studying small pelagic fishes caught in the Southeast Sulu Sea.

This paper aims to provide an analysis of the major small pelagic fishes caught by purse seine in the Southeast Sulu Sea and their population status by (1) determining the catch composition of the landed catches from Southeast Sulu Sea and (2) determining the E ratio, Mortality Estimates (e.g. F, M and Z), L_{25}, L_{50}, and L_{75} to assess the status of each species population.

This study focuses on the analysis of species composition from purse-seine landings at NSAP-monitored sites. In terms of the assessment of their population status, the main model that will be used for analysis is the FAO ICLARM STOCK ASSESSMENT TOOL, also known as FISAT II. The data that will be utilized are recorded catch landings from the Southeast Sulu Sea alone. Since this study focuses more on purse seine landings, catches from various gears are not aggregated and compared.

2. METHODOLOGY

2.1 Study Site

The study was conducted at 12 identified landing sites for purse-seine fishing vessels operating in the Southeast Sulu Sea (Figure 1)

2.2 Data Collection

Data collection was conducted in accordance with the standard protocols of the National Stock Assessment Program (Santos et al. 2017). Two trained enumerators were assigned per site, with each pair responsible for monitoring two designated landing sites.

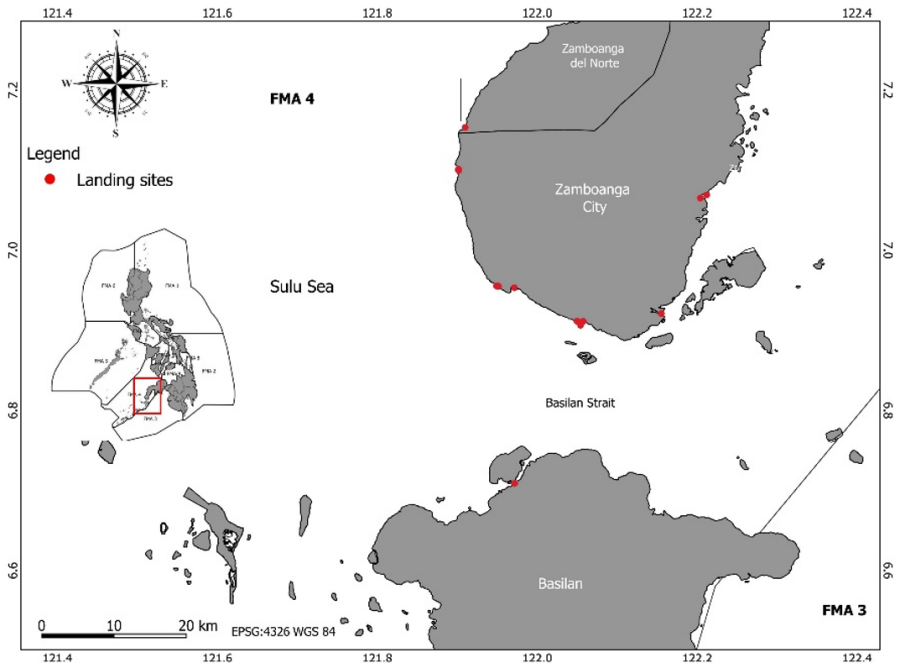

Figure 1. Commercial purse seine landing sites that operate from the Southeast Sulu Sea.

The information collected included fishing grounds, name of catcher vessels, fishing effort (days/hours), species composition, and total catch. Also collected were length-frequency data from representatives of the fish samples to support stock assessment. The collected data were then systematically recorded in the NSAP Forms 1, 2, and 2B. These data were then encoded in the NSAP database.

A total of 10–11 monitoring days per month were conducted at each landing site, depending on the month. This sampling method was designed to ensure adequate representation, data quality, and consistency in data collection.

2.3 Volume of Fish Caught

The total volume of fish caught was recorded and compared between different years. Trends in the volume of fishes caught are presented graphically across the sampling years (2018–2023).

2.4 Dominant Species

The dominant species were determined by identifying the top 5 species by volume caught, expressed as percentage or relative abundance. These dominant species were then analyzed for growth and population parameters.

2.5. Growth and population parameters

The population parameters were computed using the FAO-ICLARM Stock Assessment Tools II (FISAT II). Certain parameters were computed using the following: ELEFAN (Electronic Length Frequency Analysis) for the computation of the parameters for VBGF (Von Bertalanffy Growth Function), namely L_∞ or asymptotic length, and growth constant (k), which was determined using the k-scan routine of the analysis. The "best fit" values were determined, and appropriate values for available data for L_∞ and k were chosen based on the FishBase database. Values for Z (Total Mortality), M (Natural Mortality), and F (Fishing Mortality), together with the probability of catch in $L_{25,}$ L_{50} and L_{75}, and performance indicator E (Exploitation Rate), were also determined.

3. RESULTS AND DISCUSSIONS

Table 1 shows the catch distribution by fishing ground in the Zamboanga Peninsula (2018–2023). The total catch production in the Zamboanga Peninsula from 2018 to 2023 was estimated at 1,657,331.2 metric tons (mt). The largest contribution came from the Southeast Sulu Sea, accounting for 81.9% of the total catch. This was followed by the Moro Gulf with 9.7% and the East Sulu Sea with 7.1%, while other significant fishing grounds accounted for approximately 1% of the total production. The Southeast Sulu Sea accounts for the largest share of the total catch, indicating its significance as the region's primary fishing ground, and its consistently high contribution further highlights its importance to fishery production in the Zamboanga Peninsula.

Table 1. Catch distribution per fishing ground in Zamboanga Peninsula (2018–2023).

Fishing Ground	Catch (mt)	Percentage (%)
South Sulu Sea	1,358,064.8	81.9
Moro Gulf	161,374.2	9.7
East Sulu Sea	118,270.9	7.1
Sibuguey Bay	8,479.8	0.5
Basilan Strait	5,791.9	0.3
Celebes Sea	4,407.2	0.3
Tawi Tawi Bay	935.7	0.1
Dapitan Bay	6.8	0.0
Total	**1,657,331.2**	**100.0**

Table 2 shows the species composition caught in the Southeast Sulu Sea (2018–2023). The species composition in Sulu Sea based on catch shows that *Sardinella lemuru* contributed to the majority of the landed catch accounting for 1,124,555.1 MT or 82.8% of the entire catch followed by *Decapterus macrosoma* with catch amounting to 77,298.8 MT (5.7%), *Selar crumenophthalmus* with 40,061.9 MT

Table 2. Species composition caught by all gears in the Southeast Sulu Sea (2018–2023).

Top	Species	Catch (mt)	Percentage (%)
1	*Sardinella lemuru*	1,124,555.1	82.8
2	*Decapterus macrosoma*	77,298.8	5.7
3	*Selar crumenophthalmus*	40,061.9	2.9
4	*Amblygaster sirm*	21,630.1	1.6
5	*Rastrelliger kanagurta*	19,902.0	1.5
6	*Katsuwonus pelamis*	12,857.0	0.9
7	*Thunnus albacares*	10,060.1	0.7
8	*Decapterus tabl*	6,739.6	0.5
9	*Decapterus macarellus*	5,779.0	0.4
10	*Auxis thazard*	4,930.8	0.4
11	*Decapterus kurroides*	3,732.3	0.3
12	*Euthynnus affinis*	3,471.7	0.3
13	*Octopus sp.*	2,912.4	0.2
14	*Rastrelliger faughni*	2,494.7	0.2
15	Other Significant Species	21,639.4	1.6
	Total	**1,358,064.8**	**100.0**

(2%), *Amblygaster sirm* with 21,630.1 MT (1.6%) and *Rastrelliger kanagurta* with 19,902.0 MT (1.5%).

Table 3 shows the composition of fishing gear in the Southeast Sulu Sea (2018–2023). This shows that purse seine accounted for the largest proportion of the catch at 96.7%, followed by ring net at 1.2%, while hook and line, jigger, and multiple hook and line contributed 0.6%, 0.4%, and 0.4%, respectively, and other fishing gears accounted for 0.7% of the total catch. The results indicate that purse seine is the predominant fishing gear in the Southeast Sulu Sea.

Table 3. Fishing gear composition of catches in the South Sulu Sea (2018–2023).

Fishing Gear	Catch (mt)	Percentage (%)
Purse seine	1,313,667.7	96.7
Ring Net	15,887.9	1.2
Hook and Line	7,592.6	0.6
Jigger	6,104.2	0.4
Multiple Hook and Line	4,968.7	0.4
Others	9,843.6	0.7
Total	**1,358,064.8**	**100.0**

Table 4 shows that the largest species group contributing to the overall catch is the small pelagic at 98.3%, followed by oceanic tuna at 0.7%, neritic tuna at 0.6%, and demersal fishes at 0.2%.

Table 5 shows the species composition caught using purse seine in the Southeast Sulu Sea (2018–2023). *S. lemuru* accounted for 85.2% of the total catch, followed by *D. macrosoma* at 5.8% and *S. crumenophthalmus* at 2.8%. Other species, including *A. sirm* (1.6%), *Rastrelliger kanagurta* (1.4%), *Decapterus tabl* (0.5%), and *Katsuwonus pelamis* (0.5%), contributed less than 1%. These results are similar to the findings of De Guzman et al. (2018), with the same dominant species caught from a different area but the same sea, the whole East Sulu Sea (using all gears of fishing), with only varying percentages of volume caught in 2013: *S. lemuru* with 60.6%, *A. sirm* at 13.22%, *S. crumenopthalmus* at 8.9%, *R. kanagurta* at 8.8% and *D. macrosoma* at 8.2% comprising the top 5 of species caught in East Sulu Sea in 2013. The results from the Sulu Sea almost mirror the Philippines' top commodities in 2022, with sardines ranking 3rd and scads and mackerels at lower spots, 4th and 7th on the list (BFAR 2023). The sheer volume and dominance of *S. lemuru* caught in the Sulu Sea heavily skew the distribution of species caught in the area, indicating a high dependence on this species; this can have ecological and economic implications, especially if *S. lemuru* is continuously exploited by local fisheries in the coming years.

Table 4. Species group caught using purse seine in the Southeast Sulu Sea (2018–2023).

Species Group	Catch (mt)	Percentage (%)
Small Pelagic	1,291,928.9	98.3
Oceanic Tuna	9,064.8	0.7
Neritic Tuna	7,984.6	0.6
Demersal fishes	2,210.9	0.2
Pelagics	1,696.0	0.1
Cephalopods	765.4	0.1
Other Large Pelagics	16.0	0.0
Batoids	1.2	0.0
Sharks	0.1	0.0
Grand Total	**1,313,667.7**	**100.0**

Table 5. Species composition of catches using purse seine in the Southeast Sulu Sea (2018–2023).

Top	Species	Catch (mt)	Percentage (%)
1	*Sardinella lemuru*	1,118,742.9	85.2
2	*Decapterus macrosoma*	76,273.2	5.8
3	*Selar crumenophthalmus*	37,176.8	2.8
4	*Amblygaster sirm*	21,451.7	1.6
5	*Rastrelliger kanagurta*	18,890.3	1.4
6	*Decapterus tabl*	6,710.5	0.5
7	*Katsuwonus pelamis*	6,211.9	0.5
8	*Decapterus kurroides*	3,712.1	0.3
9	*Decapterus macarellus*	3,671.1	0.3
10	*Auxis thazard*	3,337.9	0.3
11	*Euthynnus affinis*	2,641.7	0.2
12	*Thunnus albacares*	2,570.6	0.2
13	*Rastrelliger faughni*	2,479.7	0.2
14	*Auxis rochei*	1,862.1	0.1
15	Other Significant Species	7,935.4	0.6
	Total	**1,313,667.7**	**100.0**

Figure 2 shows the annual species catch composition caught using purse seine in the Southeast Sulu Sea (2018–2023).

S. lemuru progressively dominates the relative abundance of captured fish species between 2018 and 2020, rising from 79.7% in 2018 to 85.4% in 2019 and peaking at 92.7% in 2020. The observed trend suggests increasing dependence on a single species, which could be harmful to the long-term sustainability of fisheries. On the other hand, throughout the same time period, the relative abundance of other commercially significant species, including *R. kanagurta*, *D. macrosoma*, and *S. crumenophthalmus*, has gradually decreased. A considerable decline in species diversity was evident by 2020, with each of the other species accounting for less than 2% of the overall catch. *S. lemuru* relative abundance decreased steadily between 2021 and 2023, dropping from 86.2% in 2021 to 85.3% in 2022 before declining to 74.8% in 2023. Other species' relative abundance started to rise at the same time; species such as *D. macrosoma*, *S.*

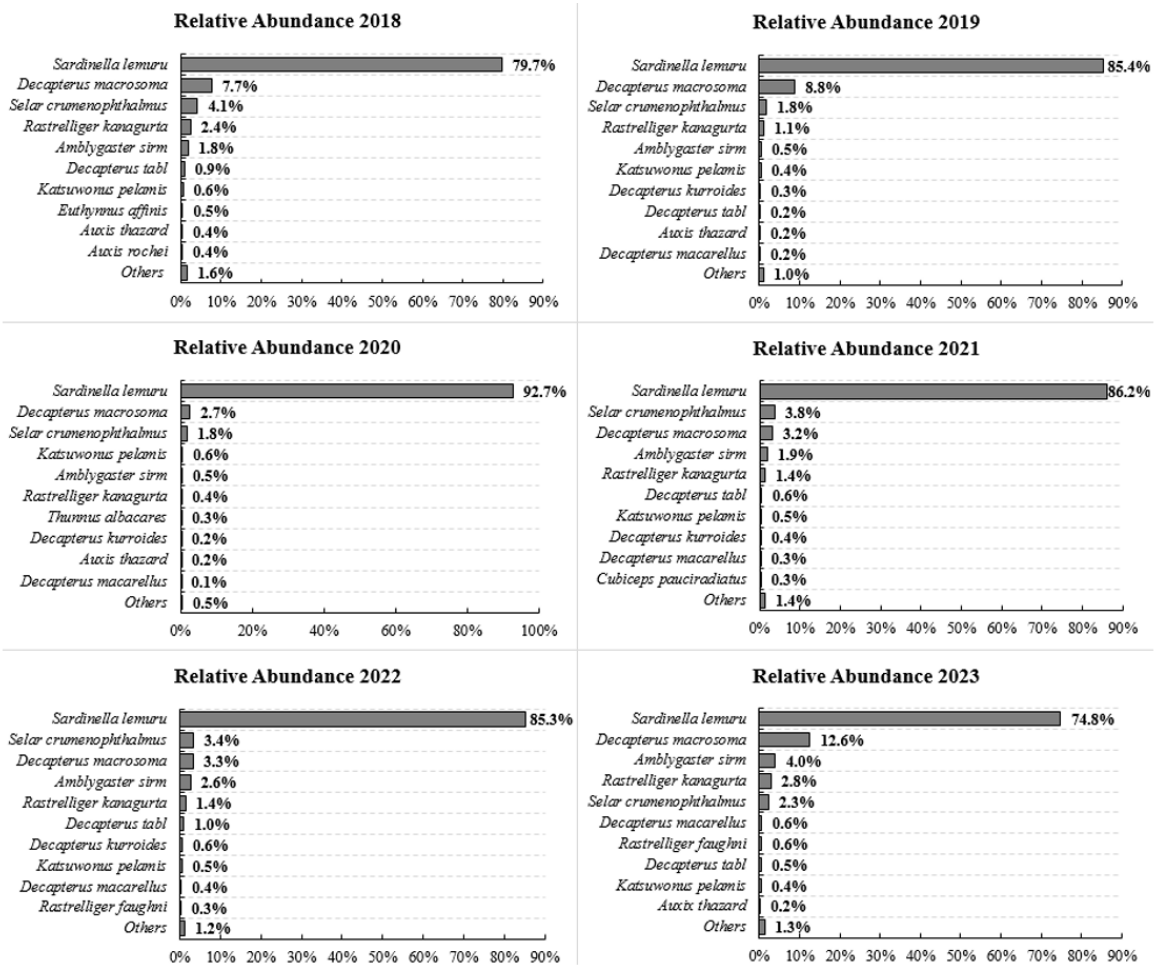

Figure 2. Annual species catch composition caught using purse seine in the Southeast Sulu Sea (2018–2023).

crumenophthalmus, *A. sirm*, and *R. kanagurta* began to increase their relative abundance in recent years. In 2023, *D. macrosoma* reached 12.6%, marking its highest level over the period, while *A. sirm* rose to 4.0%, suggesting recovery or increased catch targeting for this species. These observations align with local government data from BFAR (2021) for a time frame similar to the sampling period in this study, in which the availability and dominance of *S. lemuru* decreased significantly over the years, while the diversity of landed species increased. These changes in catch abundance might be attributed to lower biomass in the area suggested by data (BFAR 2021) or the effectivity of the local Sardines Ban during spawning season in the area (usually December-March) giving the dominant species, *S. lemuru* sanctuary from fishing pressure in certain parts of the year, thus lowering dominant species volume in specific months. Another possible reason might be the effectiveness of species-specific fishing methods throughout the sampling years, wherein target species are easily pinpointed and caught by fisherfolk in the Sulu Sea, leading to increased volumes of specific small pelagic species such as scads and mackerel, thereby increasing catch diversity. The decline in volume observed from 2018 to 2023 is a cause for concern for the local government, as it could jeopardize future efforts to ensure food security in markets that depend on production from the Sulu Sea. On the other hand, the increasing diversity of catch in the Sulu Sea is a promising development because it might reduce fishing pressure on heavily fished species such as *S. lemuru* and, in the near future, balance and reduce pressure from a single stock, thereby achieving sustainable fisheries in the area.

Table 4 shows the species group composition caught using purse seine in the Southeast Sulu Sea (2018–2023). Small pelagic fishes comprised 98.3% of the total catch, followed by oceanic tuna (0.7%) and neritic tuna (0.6%). Demersal fishes, pelagics, and cephalopods contributed 0.2%, 0.1%, and 0.1%,

respectively, while other species groups, including large pelagics, batoids, and sharks, accounted for small proportions. These results indicate that the purse seine fishery is highly selective for small pelagic species. This pattern may be attributed to the economic importance of sardines in the Zamboanga Peninsula, where sardine canning factories are located, resulting in strong market demand for this species.

Figure 3 shows the catch trend of small pelagic species caught in the Southeast Sulu Sea using purse seine (2018–2023). The figure shows a peak in 2020; this fluctuation might be attributed to higher biomass availability, favorable conditions, and increased fishing effort during this period. A drop of about 220,000 metric tons was observed the following year (2021), which might suggest overfishing in the previous year; it then fell to 200,000 metric tons the next year (2022) and further to 150,000 metric tons in 2023. The decline in the production of small pelagic fishes is similar to the Bureau of Fisheries and Aquatic Resources (2023) published data for Region IX production, which shows the same trend of fluctuation from 2018 to 2023, with a rise in 2020 followed by a steady decline from 2021 onwards. Based on the graph presented, a further decrease in production may be observed in the coming years if the local government fails to implement effective interventions to preserve local small pelagic populations and their environment.

3.1. Growth, Mortality, Exploitation, and Catch Probability Parameters (L∞, K, M, F, Z, E, L_{25}, L_{50}, and L_{75})

3.1.1 *Sardinella lemuru*

Sardinella lemuru, locally known as "tamban," has been the dominant species of fish caught from 2018 to 2023, garnering over 80% of the fish caught. *S. lemuru* has been observed to have varying life spans according to different studies. In Indian and Indonesian waters, it has been observed that they have a lifespan of 3–4 years (Merta 1995; Pet et al. 1997), while in some parts of Australia they are observed to have longer lifespans of 6–7 years based on their otolith ring counts (Gaughan and Mitchell 2000). Data from 2018 to 2023 were divided to accommodate the average lifespan of S. *lemuru* across multiple growth models, with 3 years for growth parameters (Hunnam 2021).

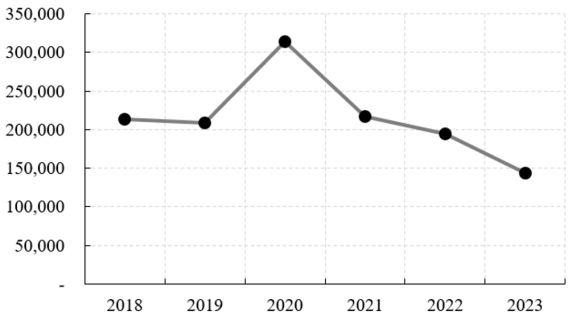

Figure 3. Catch trend of small pelagic species caught using purse seine in the Southeast Sulu Sea (2018–2023).

3.1.1.1 Length Infinity and Growth Constant

Table 5 shows the growth parameters of *S. lemuru*. The asymptotic length (L∞) and growth constant (k) of S. lemuru caught in Southeast Sulu have remained the same over six years, at 20.6 cm and 1.11 yr^{-1}, respectively. This phenomenon can denote (without looking at other population parameters) that in the span of six years, *S. lemuru* stocks caught by purse seine in the Southeast Sulu Sea may have experienced constant temperature, food availability, and habitat quality. Purse seine fishing pressure might not have adverse effects on the stock present in the area, indicating a healthy stock, or on the other hand, it may suggest that *S. lemuru* stocks are "chronically exploited," which requires analysis of the stock's population parameters (Beverton and Holt 1957). The L_∞ results were significantly different from the findings of De Guzman et al. (2018) conducted in the East Sulu Sea and Basilan Strait (bodies of water connected to the South Sulu Sea), wherein in 2013 it was observed that the L_∞ of *S. lemuru* have reached 20.25 cm and a k value of 0.64 yr^{-1}; these values are much lower than the study results, though a significant factor in the difference can be attributed to the difference in methodology, where in De Guzman et al. (2018) majority; assessed all forms of commercial methods of fishing other than purse seine. The difference between the values of L_∞ and k can also be attributed to the varying conditions of their respective habitats and availability of resources spatially and temporally, where results signify an improvement of the condition of their habitats from 2013 to 2018–2023 (Pauly 1984; Beverton and Holt 1957; Froese 2004; Shepherd and Cushing 1980) which may be the apparent result of the better implementation of local fishing regulation laws present in the area, namely DA-BFAR, BAC no. 255, or the Sardines Fish ban occurring usually from December to March (BFAR 2011), which protects local *S. lemuru* stocks in the area, including the Southeast Sulu Sea. These changes can be better observed by the value of Ø′ or "Phi prime," a unitless value used for comparison of the growth between stocks spatio-temporally, wherein stocks of *S. lemuru* from 2018 to 2023 have a higher Ø′ (2.673) than stocks studied by

De Guzman et al. (2013) (2.419); this means that *S. lemuru* stocks from 2018 to 2023 are faster growing and bigger compared to stocks from 2013.

3.1.1.2 Mortality estimates

Table 6 shows the mortality estimates of *S. lemuru*. Natural mortality "M" (at 28°C), or the rate of mortality due to natural causes, remains constant in all sampling years; a higher value of M signifies that the species is dying more because of natural causes such as disease, age, and predation, also meaning that the stocks have shorter life spans. On the other hand, F, or fishing mortality, is the rate of mortality due to harvesting of the stock; higher values of F mean that the stock is more likely to die from being caught by fishing, a sign of overfishing in the area (Pauly 1980). From 2018 to 2023, M remained constant throughout the sampling period, implying that there was a steady amount of fish dying from natural causes during this span of time with a value of 2.12 yr^{-1} (a high value characteristic of small pelagic species), while F constantly fluctuated, with the highest value being 4.38 yr^{-1} in 2021 and the lowest at 2.8 yr^{-1} in 2018; this signifies that the highest amount of harvested fish was in 2021 and the lowest in 2018. Throughout the sampling period, F has consistently been higher than M, indicating overfishing (Froese and Pauly 2000) in the Southeast Sulu Sea by fisheries. Total mortality, or Z values, are always >4, which means there are high mortalities in each year due to fishing and natural causes; in comparison, the Z value of *S. lemuru* from De Guzman et al. (2018) has a Z value of 3.67 yr^{-1}, signifying lower total mortality in 2013 than in 2018–2023. However, higher Z values do not necessarily mean an overfished stock.

3.1.1.3 Exploitation ratio

According to Gulland (1971), Maximum Sustainable Yield (MSY) is attained when Natural Mortality (M) is equal to Fishing Mortality (F) (M=F); Gulland's Rule states that a threshold for a stock to be still considered sustainable must be at E<0.5, wherein E<0.5 is considered ideal and sustainable, and E>0.5 indicates that the stock is overly exploited and is being unsustainably harvested. Throughout the sampling period, *S. lemuru* E values exceed the 0.5 threshold (Table 6), indicating that *S. lemuru* stocks were overexploited from 2018 to 2023. In comparison with the study conducted by De Guzman et al. (2018), in which the E value of *S. lemuru* was recorded to be 0.59, the E value of 0.63 recorded in 2023 (see Table 7) far exceeds the established threshold. This further raises concerns about the effectiveness of existing regulations in managing this particular stock.

This continuous exploitation is supported with the constant value for L_∞ and k and high fishing mortality values, implying that *S. lemuru* caught by purse seine in the Southeast Sulu Sea are constantly overfished throughout the years; the consistent heavy fishing pressure on this species can have a cascading negative effect in the local environment and economy, especially in local markets that heavily depend on *S. lemuru* like Zamboanga City, where several industries are dependent on the production of sardines and its products, like canned sardines (PSA 2016). Constant exploitation of *S. lemuru* can lead to a state called "stock collapse," in which the stock cannot be replenished through natural reproduction. An example of this is the collapse of the Northern cod (*Gadus morhua*) fishery in Canada in 1992, which led to the closure of several cod-dependent industries and severe unemployment, heavily affecting coastal communities dependent on the cod stock (FAO 2022). This is not far from happening today in the case of *S. lemuru* if heavy fishing pressure is maintained. Thus, better regulation and fishing practices must be observed in the following years to avoid stock collapse.

3.1.1.4 Probability of catch

Table 8 shows the probability of catch of *S. lemuru*. L_{25}, L_{50}, and L_{75} denote the percentages of catch retained in the fishing gear at 25%, 50%, and 75%, respectively (Froese 2004). These values indicate the length of fish likely to be captured in the selected fishing gear; in this case, purse seine.

Table 6. Growth parameters (length infinity and growth constant) for the top 5 species caught in the Southeast Sulu Sea (2018–2023).

Species	L_∞	k	Ø′
Sardinella lemuru	20.6 cm	1.11 /year	2.673
Decapterus macrosoma	26.77 cm	1.03 /year	2.868
Amblygaster sirm	22.93 cm	1.07/year	2.750
Selar crumenophthalmus	28.86 cm	1.02/year	2.929
Decapterus macarellus	33.9 cm	0.97/year	3.047

Table 7. Mortality estimates (natural mortality, fishing mortality, total M=mortality and exploitation ratio) of *Sardinella lemuru*.

Year	M	F	Z	E
2018	2.12	2.8	4.92	0.57
2019	2.12	3.31	5.43	0.61
2020	2.12	2.78	4.9	0.57
2021	2.12	4.38	6.5	0.67
2022	2.12	3.28	5.4	0.61
2023	2.12	3.6	5.72	0.63

Table 8. Probability of catch (L_{25}, L_{50}, L_{75}) of *Sardinella lemuru*.

Year	L_{25}	L_{50}	L_{75}
2018	12.9 cm	13.51 cm	14.02 cm
2019	14.36 cm	14.77 cm	15.21 cm
2020	13.38 cm	14.16 cm	14.69 cm
2021	14.07 cm	14.6 cm	15.08 cm
2022	13.35 cm	14 cm	14.54 cm
2023	14.3 cm	14.73 cm	15.19 cm

Throughout the sampling period, L_{25}, L_{50}, and L_{75} are constantly fluctuating, but their spread is relatively narrow (≈1.1–1.2 cm), indicating high gear selectivity of the purse seine targeting a narrow range of *S. lemuru* sizes. L_{50} size fluctuates but is observed to rise throughout 2018–2023 from 13.51 cm initially to 14.73 cm by the end of the sampling period; this implies that purse seine fisheries have steadily become more selective towards larger *S. lemuru* individuals, indicating a positive change, which might be caused by local regulation laws implemented in the Southeast Sulu Sea.

Published values of length at first maturity, or Lm, are recorded to be at 14.3 cm (FishBase 2025). Given this value of Lm, evidence of growth overfishing can be obtained from the data of purse seine fishing in the Southeast Sulu Sea from 2018 to 2023. If L_{50} > Lm, it indicates growth overfishing, in which more juveniles are caught than mature individuals. On the other hand, if L_{50}<Lm, it means that mature individuals are caught more than juveniles. From 2018 to 2023, fluctuations in L_{50} above and below Lm are observed; values below Lm occur in 2018, 2020, and 2022, indicating that stocks are overfished during these years, with 2018 having the smallest L_{50} at 13.51 cm. While *S. lemuru* have L_{50} above Lm in the years 2019, 2021, and 2023, fluctuating from being overfished to acceptable in recent years, an indication of inconsistent observation of regulation laws of *S. lemuru* in the Southeast Sulu Sea or an overall fluctuation of biological parameters in the Southeast Sulu Sea is needed for local fish stocks (King 2007). Stricter implementation of the annual Sardines Ban must be observed in the Southeast Sulu Sea, along with larger mesh sizes for purse seine nets to improve catch selectivity for larger *S. lemuru* in the area.

3.1.2 *Decapterus macrosoma*

Decapterus macrosoma, locally known as galunggong, is the second most caught fish by purse seine in the Southeast Sulu Sea. *D. macrosoma* has an average lifespan of 3 years, according to various literature (Magallanes et al. 2022; Shiraishi 2010; Ashi 2024). Analysis of *D. macrosoma* was conducted over 3 years, dividing the 6 years of sampling into 2018–2020 and 2021–2023.

3.1.2.1 Length Infinity and Growth constant

Table 6 shows the growth parameters of *D. macrosoma*. The study recorded an L_{∞} of 26.77 cm and a k value of 1.03 yr^{-1} throughout 2018–2023. There are varying recorded values of L_{∞} and k for *D. macrosoma*; 26.18 cm for L_{∞} with a k of 1.0 yr^{-1} in *D. macrosoma* caught in Antique, Philippines, from 2019 to 2020 using ring nets (Magallanes et al. 2022). A study from Palawan, Philippines, recorded a smaller 25.5 cm L_{∞} and a lower k of 0.85 using the trawl method of fishing (Ingles and Pauly, 1984). A much lower L_{∞} and k values in the East Sulu Sea and Basilan Strait (connected bodies of water to the South Sulu Sea), with L_{∞} = 22.1 cm and k = 0.37 yr^{-1} in 2013 was recorded using purse seine as the dominant method (De Guzman et al. 2018). Based on the results of this study, it can be further extrapolated that, while there is a significant improvement in parameters such as L_{∞}, k, and Ø, there is a noticeable disparity in terms of the probability of catch. According to De Guzman et al. (2018), the L25 value for *D. macrosoma* was recorded at 19.0 cm in 2013, which is considered an improvement compared to the recently recorded L_{25} (12.62 cm) in 2023. The improvement in growth parameters can be attributed to existing regulations, such as Gear Restrictions, which limit the use of fine-mesh nets. Other environmental and biological factors can also contribute to the growth of *D. macrosoma,* such as higher primary productivity, nutrient upwelling, and improved environmental conditions (e.g., temperature, water quality, and stable salinity conditions). The significant difference in growth can also be attributed to the availability of improved and more precise data.

Also, a notable improvement in L∞ and k, as reflected by the growth performance index (Ø′), has been observed, increasing from 2.267 in 2013 to 2.868 in 2018–2023. This suggests that individual *D. macrosoma* have exhibited greater growth performance over the years. Food availability and better environmental conditions are the best explanation for the difference in values of Ø′ from 2013 to 2018–2023. Growth parameters, results-wise, imply that there is less fishing pressure from 2013 to 2018–2023 from purse seines in the same area(s), and individuals are allowed to reach their maturity before harvesting more in recent years than in 2013, though exploitation values and mortality estimates from other

species and more recent data are also needed to prove this hypothesis.

3.1.2.2 Mortality estimates

Table 9 shows the mortality estimates of *D. macrosoma*. Study results show that the Natural Mortality (M) estimate remains constant throughout the sampling period at 1.88 yr^{-1}, the same value as that reported by Magallanes et al. (2022) for *D. macrosoma* caught in Antique, Philippines, from 2019 to 2020 using ring nets. These values are typical of short-lived tropical small pelagic species such as *D. macrosoma*, and the same M values reported in other studies confirm that both areas might have similar environmental parameters. Temporally, data from 2013 provided by De Guzman et al. (2018) may otherwise suggest that the year 2013 had better environmental parameters than in recent years, with an M value of 1.02 yr^{-1}, but highly uncharacteristic for the results from its time, with lower L_{∞} and k than in more recent years of study (though connected to bodies of water). The discrepancy may be attributed to De Guzman et al. (2018) studying other methods of fishing other than purse seine. Fishing mortality values for *S. lemuru* fluctuated over the years but remained consistently higher than natural mortality, suggesting that fishing contributed more substantially to total mortality than natural causes (Magallanes et al. 2022; De Guzman et al. 2018). Total mortality values are never lower than 3.5 yr^{-1} from 2018 to 2023, signifying high mortality of *D. macrosoma* throughout the sampling years, especially in 2022, with a Z value of 5.33 yr^{-1}, the year with the highest amount of *D. macrosoma* removed from the local stock. These high and varying Z values are attributed to the fluctuating F values throughout the years, implying a shift in fishing efforts throughout the sampling years, perhaps to meet local demands of *D. macrosoma* in the market or the banning of *S. lemuru*—the dominant species caught by purse seine in the Sulu Sea, putting more pressure on *D. macrosoma* stocks in certain parts of the year.

Table 9. Mortality estimates (natural mortality, fishing mortality, total M=mortality and exploitation ratio) of *Decapterus macrosoma*.

Year	M	F	Z	E
2018	1.88	2.93	4.81	0.61
2019	1.88	2.97	4.85	0.61
2020	1.88	1.98	3.86	0.51
2021	1.88	2.06	3.94	0.53
2022	1.88	3.45	5.33	0.65
2023	1.88	3.21	5.09	0.63

3.1.2.3 Exploitation ratio

The E values of *D. macrosoma* (see Table 9) exceeded the threshold of 0.5 across most years of sampling, indicating that the stocks in the Southeast Sulu Sea experienced relatively high levels of exploitation from 2018 to 2023 (Gulland 1971). This pattern is consistent with the findings of Magallanes et al. (2022) for 2019–2020 and De Guzman et al. (2018) for 2013, which reported exploitation ratios of 0.60 and 0.71, respectively, both exceeding the 0.5 threshold. Although a decrease in E was observed in 2020 and 2021, with a value of 0.51, this should not be interpreted as evidence of improved stock status because the decline was not sustained across the sampling period. The observed fluctuations in exploitation may instead reflect variations in fishing pressure, gear selectivity, management regulations, and environmental conditions rather than a definitive improvement in overall stock status. In actual conditions, *D. macrosoma* stocks caught from the Southeast Sulu Sea through purse seine are heavily exploited and may lead to stock collapse in the future if not properly managed in the following years, severely affecting the local market and economy in the area and putting even more pressure on other species to meet local demands for fish production.

3.1.2.4 Probability of Catch

Table 10 presents the probability of capture of *D. macrosoma*. The estimated probability-of-capture curve shows a relatively narrow size range of approximately 1.72 cm between L_{25} and L_{75}, indicating that purse seine fishing during 2018–2023 selected a relatively restricted range of fish sizes. This pattern is similar to that observed for *S. lemuru*, suggesting relatively narrow size selectivity of the purse seine fishery. De Guzman et al. (2018) reported higher L_{25} and L_{50} values of 19.04 cm and 19.97 cm, respectively, compared with the more recent estimates of 12.62 cm and 13.37 cm. Notably, the estimated L_{50} during 2018–2023 was consistently below the reported length at first maturity (L_m) of 16.8 cm for *D. macrosoma* (FishBase 2025). This indicates that a substantial proportion of *D. macrosoma* may be vulnerable to capture before reaching sexual maturity, raising concerns about growth overfishing and the reproductive potential of the stock.

The consistently low L_{50} values suggest that the current purse seine fishery is selecting *D. macrosoma* at relatively small sizes, which may reduce the opportunity for individuals to reproduce before

Table 10. Probability of catch (L_{25}, L_{50}, L_{75}) of *Decapterus macrosoma.*

Year	L_{25}	L_{50}	L_{75}
2018	12.67 cm	14.14 cm	14.82 cm
2019	12.49 cm	14.12 cm	14.86 cm
2020	13.33 cm	14.82 cm	15.6 cm
2021	14.24 cm	14.75 cm	15.24 cm
2022	12.65 cm	13.37 cm	13.88 cm
2023	12.62 cm	13.37 cm	13.89 cm

capture. Although these results provide evidence of a significant risk of growth overfishing, they should not, by themselves, be interpreted as definitive evidence that the stock is already severely overfished or approaching collapse. Continued monitoring of length structure, recruitment, spawning biomass, fishing mortality, and exploitation rates is necessary to determine the extent of stock depletion. If the current pattern of harvesting immature individuals persists, recruitment and spawning-stock potential may be negatively affected over time, potentially increasing fishing pressure on other small pelagic species such as *S. lemuru*. Management measures that improve size selectivity and reduce the capture of immature *D. macrosoma* should therefore be considered to support the long-term sustainability of the Southeast Sulu Sea fishery.

3.1.3 *Amblygaster sirm*

Amblygaster sirm, locally known as "kasig," is the third most abundant small pelagic fish caught by purse seine in the Southeast Sulu Sea. Reports of the lifespan of *A. sirm* vary considerably among geographic regions and studies. In Kiribati, Milton (1992) reported a relatively short lifespan of approximately 2 years based on otolith-derived age estimates. Similarly, a lifespan of 1–3 years was reported in Egypt, while a 1-year observation was documented in Sri Lanka (Yassein et al. 2021; Athukoorala 2015). In contrast, FishBase (2025) reports a maximum recorded lifespan of 8 years for the species, although this value may represent the upper end of the species' longevity rather than the typical lifespan of individuals in the fishery. Given the variation among reported estimates and the absence of a locally derived maximum age for *A. sirm* in the Southeast Sulu Sea, a 3-year lifespan was adopted as an operational assumption for the Von Bertalanffy Growth Function (VBGF), following the approach used by Yassein et al. (2021). This assumption provides a practical basis for the growth analysis but it should be interpreted cautiously, as lifespan absolutely varies relative to environmental conditions, population structure, fishing pressure, and geographic location.

3.1.3.1 Length Infinity and Growth Constant

Table 6 presents the growth parameters of *A. sirm*. Similar to *D. macrosoma* and *S. lemuru, A. sirm* exhibited consistent L∞ and K values throughout the six-year sampling period, with an L∞ of 22.93 cm and a K of 1.07 yr^{-1}. These estimates differ substantially from those reported by De Guzman et al. (2018) for 2013, who estimated an L∞ of 24.1 cm and a K of 0.40 yr^{-1}. The lower L∞ and higher K observed during 2018–2023 suggest a population characterized by a smaller asymptotic size and faster growth compared with the 2013 estimates. Such a combination may be associated with increased fishing pressure, higher mortality, or differences in environmental and habitat conditions, as populations exposed to greater mortality may exhibit changes in their observed growth characteristics (Pauly 1984; Beverton and Holt 1957; Froese 2004; Shepherd and Cushing 1980). However, these growth parameters alone cannot definitively establish that increased fishing pressure or unfavorable habitat conditions caused the observed changes. Further assessment of mortality, exploitation, recruitment, and other population parameters is therefore necessary to substantiate this interpretation. The observed pattern nevertheless suggests that *A. sirm* in the Southeast Sulu Sea during 2018–2023 may attain smaller maximum sizes while exhibiting a faster growth rate than the population reported in 2013.

3.1.3.2 Mortality estimates

Table 11 shows the mortality estimates of *A. sirm. A. sirm* has a constant natural mortality of 2.01 yr^{-1}, typical of small pelagic fishes (high natural mortality), similar to the M value of *S. lemuru* and *D. macrosoma* which are constant within the study period, and another similarity is that the value of Fishing Mortality fluctuates from each year, ranging from 3.07 yr^{-1} (highest) to 0.76 yr^{-1} (lowest) in recent years. The varying value of F can be attributed to changes in fishing effort and targeting of *A. sirm* over the years, and the declining trend in F suggests that from 2018 to 2023, purse seine fisheries have reduced their targeting and selectivity towards this species in the Southeast Sulu Sea. The findings of De Guzman et al. (2018) from 2013 can better illustrate this trend of Fishing Mortality, in where they obtained a value of 1.37 yr^{-1} for F in 2013 in East Sulu Sea and then a F value of 3.07 yr^{-1} in 2018 in Southeast Sulu Sea (connected bodies of water comprising Sulu Sea) with a lack of analysis data from 2014 to 2017; an assumption can be made that there was a fluctuation of F similar

Table 11. Mortality estimates (natural mortality, fishing mortality, total M=mortality and exploitation ratio) of *Amblygaster sirm.*

Year	M	F	Z	E
2018	2.01	3.07	5.08	0.60
2019	2.01	1.29	3.30	0.39
2020	2.01	1.36	3.37	0.40
2021	2.01	2.26	4.27	0.53
2022	2.01	0.89	2.90	0.31
2023	2.01	0.76	2.77	0.27

to the observed values in this study, going from a low value then a higher value in the year then a peak in F value the next year then a sharp drop of F values the next year as observed in table 3.3.10., this trend of rise and drop of F can be attributed to the effectivity of Sardines Fish Ban in the area, and gear and species selectivity; since *A. sirm, S. lemuru* along with *D. macrosoma* are schooling fishes, and they are observed to school with each other since they occupy the same ecological niche and are caught together in large-scale fishing operations, i.e., purse seine fishing (Willette 2011). The fishing mortality of these three species fluctuated over the sampling period, with *S. lemuru* and *D. macrosoma* generally exhibiting consistently higher F values than *A. sirm*. This pattern suggests that purse seine fishing may exert greater fishing pressure on *S. lemuru* and *D. macrosoma*, whereas *A. sirm* experienced comparatively lower fishing mortality during several years. However, the subsequent spikes in F observed for *A. sirm* indicate that fishing pressure on the species periodically increased, potentially reflecting changes in its availability, catchability, recruitment, or fishing effort. The relatively lower F values observed for *A. sirm* during earlier years may have allowed greater survival and contributed to increased availability in subsequent years, although this relationship cannot be established from fishing mortality alone. Meanwhile, the declining Z values of *A. sirm* generally correspond with the reduction in F, particularly where natural mortality (M) remained relatively stable, since total mortality (Z) is influenced by both fishing and natural mortality.

3.1.3.3 Exploitation ratio

Mirroring the fishing mortality values (see Table 11) *A. sirm* E values fluctuate to a peak value exceeding 0.5, then drop to a value less than 0.5 in the next two years from 2018 to 2023. Data from studies in the Philippines have consistent values of E > 0.5 (De Guzman et al. 2018; Baclayo 2016). The declining values of E throughout the sampling period of the study can signify that local preservation efforts like the Sardines Fishing Ban are effectively protecting *A. sirm* stocks from overexploitation, and better gear selectivity and strategy of purse seine fisheries can help alleviate overexploitation from other stocks such as *S. lemuru* and *D. macrosoma* decreasing pressure from these overfished stocks.

3.1.3.4 Probability of catch

Table 12 shows the probability of catch of *A. sirm*. Data from 2018 to 2013 indicates that *A. sirm* stocks are overfished; since the majority of L_{50} values exceed the published Lm of 15 cm (FishBase 2025), the exception is 2019, wherein there is a notable increase in the sizes of *A. sirm* caught by purse seine in the Southeast Sulu Sea, *A sirm* L_{50} valued in 2013, shows the same result with L_{50} (15.33 cm) exceeding the value of Lm (De Guzman et al. 2018). A drop of values can be observed in 2020; this drop may signify that most of the caught *A. sirm* stocks are juveniles and newly recruited fish, considering most of adult *A. sirm* were caught in 2019, L_{50}=15.7, which is above Lm and the highest value within the sampling period, strong evidence that most of the remaining fish are juveniles. An average spread of ≈0.94 cm from L_{25} to L_{75} is observed, indicating narrow size selectivity throughout the sampling period. Bigger mesh sizes in purse seines must be observed to avoid more growth overfishing in the future.

3.1.4 *Selar crumenopthalmus*

Selar crumenopthalmus, locally known as "matambaka," is the most caught fish by purse seine in the Southeast Sulu Sea. *S. Crumenopthalmus* has varying life spans according to various literatures, with reports ranging from 3 to 6 years (FishBase 2025; Uehara 2021). The analysis for L_{∞} and k are analyzed by three years of following observations from FishBase.

3.1.4.1 Length Infinity and Growth Constant

Table 6 shows the growth parameters of *S. crumenopthalmus*. Constant L_{∞} and k values

Table 12. Probability of catch (L_{25}, L_{50}, L_{75}) of *Amblygaster sirm.*

Year	L_{25}	L_{50}	L_{75}
2018	14.3 cm	14.72 cm	15.2 cm
2019	15.3 cm	15.7 cm	16.18 cm
2020	10.87 cm	11.25 cm	11.68 cm
2021	14.32 cm	14.74 cm	15.22 cm
2022	14.37 cm	14.80 cm	15.25 cm
2023	13.88 cm	14.59 cm	15.13 cm

are observed within the sampling years; these are consistent with prior species analyzed, suggesting consistent fishing pressure present in the area. *S. Crumenopthalmus* are observed to have an L_∞ of 28.86 cm and a k of 1.02 yr^{-1} with an Ø′ of 2.929. Comparing the results of the study of De Guzman et al. (2018), *S. Crumenopthalmus* from 2013 in the Sulu Sea has been observed to have a shorter L_∞ and a lower k value: 27.1 cm and 0.34 yr^{-1}, respectively. This might be an underestimation of catch length estimates, since they also analyzed catches from other fishing gear besides purse seine, or an overall improvement in habitat condition from 2013 to the recent analysis in 2023. Observations from multiple areas in the Philippines describe varying values for L_∞ and k; in Sarangani Bay, an L_∞ of 22.0 cm and a k of 1.9 yr^{-1} were observed, and Pujada Bay had an L_∞ of 23.3 cm and a k of 1.2 yr^{-1}, while the highest recorded value of L_∞ so far is from Camotes Sea, with 28–31 cm with a k value of 0.86–1.35 yr^{-1} (FishBase 2025). These varying values of L_∞ and k can be attributed to varied habitat conditions from area to area and availability of food plus the pressure from local fishing efforts.

3.1.4.2 Mortality estimates

Table 13 shows the mortality estimates of *S. crumenophthalmus*. Natural mortality remained constant within the years, and the same with the other species analyzed. Fishing mortality values fluctuated, with the highest value of F being 3.87 yr^{-1} in 2018 and the lowest being equal to M 1.83 yr^{-1} in 2019. *S. Crumenopthalmus* are often caught by purse seine along with *S. lemuru, D. macrosoma* and *A. sirm* or form multi-species schools with the aforementioned species (Dalzell et al., 2008). De Guzman et al. (2018) obtained a value of 0.55 yr^{-1} F in 2013, where they observed *S. crumenopthalmus* has higher natural mortality M (0.55 yr^{-1}) than fishing mortality F (0.91 yr^{-1}); these results were not present in the study results wherein F is always more than or equal to M, which means that. *S. Crumenopthalmus* stocks are more likely to die by fishing than by natural causes in 2018–2023. Z values fluctuate along with F, with the highest value in 2018 and the lowest the next year at 3.66 yr^{-1} in 2019. This trend suggests that in 2018, stocks of *S. Crumenopthalmus* were recovering until 2019 and 2020; after this period of recovery, stocks were increasingly harvested in the subsequent years, 2021–2023.

Table 13. Mortality estimates (natural mortality, fishing mortality, total M=mortality and exploitation ratio) of *Selar crumenophthalmus.*

Year	M	F	Z	E
2018	1.83	3.87	5.70	0.68
2019	1.83	1.83	3.66	0.50
2020	1.83	1.94	3.77	0.51
2021	1.83	3.00	4.83	0.62
2022	1.83	3.01	4.84	0.62
2023	1.83	3.63	5.46	0.67

3.1.4.3 Exploitation ratio

S. crumenopthalmus E values (Table 13) observed a trend similar to constant falling and rising throughout the sampling period of 2018–2023; these values, except in 2019, exceeded the threshold of 0.5, which means the majority of *S. crumenopthalmus* stocks were overexploited, with 2019 as the exception, with a value of E=0.5, which signifies that stocks in 2019 were already at their maximum sustainable yield. On the other hand, E values for *S. crumenopthalmus* in 2013 were at an all-time low of 0.38 (De Guzman et al. 2018). These varying values from 2013 to the study period might indicate that, in recent years, purse-seine fisheries have developed better strategies to selectively capture *S. crumenopthalmus* stocks from the Sulu Sea, i.e., improved technology, more selective nets, and increased fishing effort directed towards capturing *S. crumenopthalmus*.

3.1.4.4 Probability of catch

Table 14 shows the probability of catch of *S. crumenophthalmus*. S. *crumenopthalmus* has an Lm of 17.7 cm (FishBase 2025). In this regard, from 2018 to 2023, the stock of *S. crumenopthalmus* captured by purse seine in the Southeast Sulu Sea are overfished, with L_{50} higher than the published Lm of 17.7 cm. More juveniles are caught than adults *S. crumenopthalmus* in the recent years, these trends along with continuous exploitation of *S. crumenopthalmus* stock in the area. Though there is a fluctuation of L_{50} values from year to year, with 2021 being nearest to the value of Lm, it still is severely overfished, especially in the year

Table 14. Probability of catch (L_{25}, L_{50}, L_{75}) of *Selar crumenophthalmus.*

Year	L_{25}	L_{50}	L_{75}
2018	14.3 cm	14.72 cm	15.2 cm
2019	15.3 cm	15.7 cm	16.18 cm
2020	10.87 cm	11.25 cm	11.68 cm
2021	14.32 cm	14.74 cm	15.22 cm
2022	14.37 cm	14.80 cm	15.25 cm
2023	13.88 cm	14.59 cm	15.13 cm

2022, wherein the value of L_{50} observed is 14.72 cm, characteristic of stocks where bigger fishes were harvested the prior year. This constant growth can signify stock collapse in the near future if not properly managed by the local government.

3.1.5 *Decapterus macarellus*

Some species that belong to the top species caught lack monthly catch data for proper analysis; these stocks have inconsistencies in catch data, namely, *R. kanagurta*, *Decapterus tabl*, and *Decapterus kurroides*; they are skipped due to lack of data for yearly analysis, and instead, *Decapterus macarellus* takes their place for analysis due to data consistency and to avoid data bias on stock estimates.

Decapterus macarellus, also known as "galunggong" has varying recorded lifespans across several literatures, from 2–4 years (Silooy et al. 2019) to observations of 4–7 years (FishBase 2025). For convenience of sampling of small pelagic fishes and consistency, 3 years of catch data of *D. macarellus* are assessed for growth parameters L_{∞} and k.

3.1.5.1 Length Infinity and Growth Constant

Table 6 shows the growth parameters of *D. macarellus*. *D. macarelllus* captured by purse seine in the Southeast Sulu Sea, like prior species, has a constant 33.9 cm and 0.97 yr^{-1} L_{∞} and k throughout six years of sampling from 2018 to 2023 with a Ø′ value of 3.047. These values are way far from *D. macarelllus* caught in Guimaras Strait with an L_{∞} and k of 19.80 cm and a k value of 1.0 $yr^{-1}$with a Ø′ value of 2.59 and on the other in Pujada Bay with L_{∞} and k of 24.3 cm and 1.8 yr^{-1}, respectively (FishBase 2025), which means *D. macarellus* caught in the Southeast Sulu Sea grow larger with slower growth rates than *D. macarellus* caught in other study sites. This signifies regional differences in sampling gear, ecological conditions, and seasonality of these stocks in their respective areas.

3.1.5.2 Mortality estimates

Table 15 shows the mortality estimates of *D. macarellus*. Through observing *D. macarellus* estimates it can be noted that there is a constant M>F value throughout the sampling years and Z values do not exceed 3.5 yr^{-1}. The constant M>F values signify that *D. macarellus* are more likely to die by natural reasons than by fishing efforts. These findings differ from Silooy et al. (2019), which reported a fishing mortality of 1.36 yr^{-1} and a natural mortality of 1.23 yr^{-1}, the opposite of this study's results. This low value of F means that *D. macarellus* are less likely to be caught by purse seine in the Southeast Sulu Sea and are allowed to live their whole lifespans with bigger lengths and slow growth (L_{∞} and k).

Table 15. Mortality estimates (natural mortality, fishing mortality, total M=mortality and exploitation ratio) of *Decapterus macarellus.*

Year	M	F	Z	E
2018	1.69	1.31	3.00	0.44
2019	1.69	1.21	2.90	0.42
2020	1.69	0.91	2.60	0.35
2021	1.69	1.4	3.09	0.45
2022	1.69	1.69	3.38	0.50
2023	1.69	1.12	2.81	0.40

3.1.5.3 Exploitation ratio

Throughout 2018–2023, *D. macarellus* remained below or equal to the overexploitation threshold; the highest value, 0.5 (see Table 15), was obtained in 2022, matching its MSY. Compared to *D. macarellus* caught in the Banda Sea in Indonesia that have an E value of 0.53 (Silooy et al. 2019), *D. macarellus* stocks from the Southeast Sulu Sea are in a good state and are healthier than surveyed stocks from Indonesia. *D. macarellus* stocks should be properly managed to keep their exploitation status healthy over the next few years. Since all assessed species gather in a "multi-species school" (Cury 2000), strict implementation of the Sardines Fish Ban is needed to preserve these schooling species. On a different note, better targeting in purse seine fisheries towards *D. macarellus* until it reaches MSY can help alleviate overfishing in other species, especially *S. lemuru,* which has been exploited over the years. This will help balance catch composition toward less-exploited stocks rather than depending on and exhausting stocks such as *S. lemuru*, which will eventually lead to stock collapse in the long run.

3.1.5.4 Probability of catch

Table 16 shows the catch probability of *D. macarellus*. Published data for *D. macarellus* L_m are 23–26 cm in Indonesia (Munandar 2024); L_{50} values for D. macarellus caught by Purse Seine in the Southeast Sulu Sea, based on published values in Indonesia, suggest severe growth overfishing (which may vary by region and habitat conditions). This initial assumption is supported by the narrow average spread of 1.17 cm between L_{25} and L_{75}, suggesting a narrow size selectivity toward smaller *D. macarelllus.* Although

Table 16. Probability of catch (L_{25}, L_{50}, L_{75}) of *Decapterus macarellus.*

Year	L_{25}	L_{50}	L_{75}
2018	14.30 cm	14.68 cm	15.27 cm
2019	13.91 cm	14.31 cm	14.73 cm
2020	14.77 cm	15.51 cm	16.04 cm
2021	15.97 cm	17.33 cm	18.01 cm
2022	15.16 cm	15.62 cm	16.10 cm
2023	15.30 cm	15.85 cm	16.27 cm

exploitation ratio and growth parameters are higher than recorded values, this may not hold in the future if the stock continues to be overfished, as shown by the overall increase in E values over the years. Better management of stocks, bigger mesh size for purse seine nets, and better selective methods towards bigger *D. macarelllus* must be observed if the stock is to prosper and continually feed the local demand in the area.

4. CONCLUSION

The results obtained from the analysis of the most dominant small pelagic species caught by purse seine in the Southeast Sulu Sea from 2018 to 2023—*Sardinella lemuru, Decapterus macrosoma, Amblygaster sirm, Selar crumenopthalmus,* and *Decapterus macarellus*—reveal a clear pattern of persistent and consistent exploitation and growth overfishing, with only a few exceptions. Despite signs of environmental improvement inferred from the constant or increasing values of growth parameters such as L_{∞} and k, the continuous trend of Fishing Mortality (F) exceeding natural mortality (M) in almost all assessed species indicates that these stocks are under heavy fishing pressure (Froese and Pauly 2000; Beverton and Holt 1957).

The exploitation ratios (E) of *S. lemuru, D. macrosoma*, and *S. crumenopthalmus* consistently exceed the Gulland (1971) threshold of 0.5, indicating they were overexploited throughout the sampling period. For *A. sirm* and *D. macrosoma*, while these species are previously overexploited, they show signs of recovery in recent years (2022–2023) and (2020–2021), respectively, which may be due to improved regulation and the implementation of the annual Sardines Fish Ban in the area (BFAR 2011). In contrast, *D. macarellus* appears to be the least exploited among the five species, with E values always ≤0.5 and fishing mortality consistently lower than M, suggesting minimal fishing pressure compared to other species and a healthier stock status in the region.

Despite this, probability-of-capture data (L_{25}, $L_{50,}$ L_{75}) suggest widespread growth-overfishing among all five species, with most L_{50} values falling below their respective length-at-first-maturity (L_m) thresholds (FishBase 2025; Munandar 2024), particularly for *D. macrosoma* and *D. macarellus*. The narrow spread of L_{25} to L_{75} values (~1.1–1.2 cm) across species further implies high selectivity of purse seine gear toward a specific and often immature size range, making juveniles more vulnerable to harvest. This presents a dangerous precedent for the future reproductive potential of these stocks.

If this current trajectory continues, the risk of stock collapse, as historically seen in the Canadian cod fishery (FAO 2022), becomes increasingly possible for dominant species such as *S. lemuru* and *D. macrosoma*, potentially disrupting the economic and food security landscape of sardine-reliant communities such as Zamboanga.

5. RECOMMENDATION

Based on these findings, there is a need for immediate and strengthened fisheries management interventions to prevent further stock depletion and ensure the long-term sustainability of small pelagic resources in the Southeast Sulu Sea.

Prioritize strict enforcement and possible expansion of the existing Sardines Fishing Ban (DA-BFAR, BAC No. 255). While the current seasonal closure appears to contribute to partial recovery and increased species diversity, the persistence of high exploitation rates (E > 0.5) indicates that present measures are insufficient. Extending the duration, improving monitoring, and ensuring compliance among commercial fishers can enhance its effectiveness.

Gear regulation must be improved, particularly by implementing larger mesh sizes in purse seine nets. The consistent observation that L50 values fall below the length at first maturity (Lm) across most species indicates widespread growth overfishing. Increasing mesh size will allow juveniles to escape, ensuring individuals reach reproductive age and contribute to stock replenishment.

Fishing effort should be regulated and redistributed. Given the heavy dependence on *S. lemuru* and the continued exploitation of other key species such as *D. macrosoma* and *S. crumenophthalmus*, effort should be reduced for overfished stocks and, where feasible, redirected toward relatively underexploited species like *D. macarellus*. This can help balance fishing pressure and reduce the risk of stock collapse.

Strengthening monitoring, control, and surveillance (MCS) systems. Improved data collection, standardized sampling, and consistent reporting of

catch and effort data will enhance stock assessment accuracy and support evidence-based decision-making. Investments in technologies such as vessel monitoring systems (VMS) and electronic catch documentation are recommended.

Strengthen community engagement and fisher education programs. Strengthening awareness of the long-term impacts of overfishing and promoting compliance with regulations can improve stewardship among local fishing communities, particularly in sardine-dependent areas like Zamboanga.

Continuous research and periodic reassessment of stock status. Regular updates to growth, mortality, and exploitation parameters will help management detect early warning signs of stock decline, enabling them to deploy and adjust management strategies accordingly.

Only through strategic, gear-based selectivity, biological monitoring, and consistent enforcement of seasonal closures can long-term sustainability be achieved for Southeast Sulu Sea's small pelagic fishery.

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AUTHOR CONTRIBUTIONS

Ignacio DB: Supervision, Conceptualization and Design of the Study, Analysis and/or interpretation of data, and Revision. **Revillas CB:** Acquisition of data, Analysis and/or interpretation of data, and Revision. **Mejos JS:** Acquisition of data, Analysis and/or interpretation of data, Writing-original draft, and Revision. **Kunting AK:** Project Supervision. **Lakibul AA:** Analysis and/or interpretation of data, and Revision. **Lague VM:** Analysis and/or interpretation of data, and Revision.

CONFLICTS OF INTEREST

The authors declare no actual, potential, or perceived conflict of interest for this study.

ETHICS STATEMENT

The authors affirm that all international, national, and institutional guidelines for the care and use of laboratory animals have been diligently followed and adhered to.

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