

Stock assessment of small pelagic fish in North Sulawesi waters (FMA 716)

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Abstract. Small pelagic fisheries are significant ecologically and economically, especially for small-scale fishers. The North Sulawesi Sea, which is part of the Fisheries Management Area (FMA) 716 of the Republic of Indonesia, is an important area for small pelagic fishing by *pajeko* (or mini trawl) in North Sulawesi and beyond. This study aimed to assess the stock condition of small pelagic fisheries of small pelagic fish resources in the Sulawesi Sea, North Sulawesi Province (FMA 716). The parameters measured for this study were growth, length, mortality rate, exploitation rate, and length-based spawning potential ratio (LBSPR). The results indicated that small pelagic fish stocks in the North Sulawesi Sea are in an overfished condition ($SPR < 0.2$) for the majority of fish species, including *Decapterus macarellus*, *Selar crumenophthalmus*, *Decapterus kurroides*, *Rastrelliger kanagurta*, and *Decapterus macrosoma*, with a successive LBSPR value of 0.15, 0.15, 0.14, 0.14, and 0.17, respectively. In addition, the exploitation rate of the species was also suspected to be in conditions that exceed its optimal utilization rate, with a value of $E > 0.5$. Therefore, sustainable management is essential, particularly for fish resources that are fully exploited or overexploited, to help restore their stock status.

Key Words: CPUE, fisheries management, small pelagic fisheries, LBSPR.

Introduction. Indonesia is the third-largest contributor to the world's capture fisheries production, after China and Peru. The production reached approximately 6.31 million tons in 2017 and rose to about 6.71 million tons in 2018, reflecting an increase of around 5.96% during that period (FAO 2018). One of the strategic fishing areas in Indonesia is North Sulawesi Province, which contributed 322.69 tons (5%) to national capture fisheries production in 2020, representing a 25% increase from 2015 (Ministry of Maritime Affairs and Fisheries of the Republic of Indonesia 2021b). The Sulawesi Sea is included in two fisheries management areas (FMAs), namely 715 and 716. FMA 716 shares waters with several provinces (East Kalimantan Province, North Kalimantan Province, Gorontalo Province, Central Sulawesi Province, and North Maluku Province), and FMA 715 shares water areas with Central Sulawesi Province, North Maluku Province, Maluku Province, and West Papua Province.

The Sulawesi Sea of FMA 716 is the main route of the Indonesian Archipelago that connects the Pacific Ocean and the Indian Ocean (Jul-Larsen et al 2003). Moreover, the main commercial fish species caught by this fishery in deeper waters of the Sulawesi Sea or South China Sea are tuna (family Scombridae) and tuna-like species and scads (dominated by mackerel scad *Decapterus macarellus* and shortfin scad *Decapterus macrosoma*) (Zhang et al 2016; Su et al 2018). One factor that affects the high

productivity of small pelagic fisheries in the waters of the Sulawesi Sea, FMA 716, is habitat conditions that support the life of fish resources, such as oceanographic factors and marine ecosystem conditions. Puspasari et al (2021) found that the catch per unit effort (CPUE) of small pelagic and reef fish in North Sulawesi increased during La Niña and declined during El Niño, reflecting the strong influence of ENSO-driven oceanographic variability on fishing success.

Small pelagic fisheries play a vital role in the social and economic development of regions, particularly those with abundant fish resources. Scad fish, in particular, is a valuable economic commodity due to its widespread use as a food source, contributing to the improvement of community welfare, especially among coastal fishing communities (Su et al 2018). Scad fish have potential as a natural flavoring ingredient, serving as an alternative to monosodium glutamate, and can also be processed as fish floss (Chairita et al 2009). In addition, small pelagic fish also act as a link between the upper and lower trophic levels in the structure of the food web. These fish contribute significantly to global fish production, accounting for about 30% of the total marine catch each year (FAO 2020).

Globally, the production and status of small pelagic fish have significantly fluctuated, this being primarily caused by environmental variability, overfishing, and climate change. Regions such as the upwelling systems in the Eastern Pacific (e.g., off the coasts of Peru and Chile) and the Eastern Atlantic (e.g., off the coast of West Africa) have become major producers of small pelagic fish. However, this production varies greatly over time due to oceanographic phenomena such as the El Niño-Southern Oscillation, which affects sea surface temperature and nutrient availability, directly impacting fish stocks (Chavez et al 2003; Barange et al 2018).

In many regions, small pelagic fish stocks are under significant pressure due to overfishing. The high demand for direct consumption as well as raw materials for fishmeal and fish oil in aquaculture and livestock feed leads to intense exploitation of these species (Pikitch et al 2014). In Japan, the sardine, anchovy, chub mackerel, and Pacific saury stocks around Japan were heavily overfished in the 1990s–2000s due to high fishing effort and demand, which hindered recovery, but subsequent reductions in exploitation rates and favorable recruitment have led to partial stock rebuilding since the mid-2000s (Yatsu 2019). In Peru, anchovy catches dropped sharply during El Niño events, when warmer ocean waters reduced food availability and disrupted spawning processes (Chavez et al 2003).

In addition to high fishing pressures, climate change factors also present a major challenge in small pelagic fisheries, as rising sea temperatures impact the distribution, abundance, and health of small pelagic fish populations. Shifts in fish distribution towards higher latitudes and deeper waters have been observed as fish seek more favorable conditions, which affect local fisheries and food security (Fréon et al 2005; Cheung et al 2010). In the Atlantic Ocean, mackerel populations have shown a shift northward due to rising ocean temperatures, which has a direct impact on local fishing activities in the southern region (Astthorsson et al 2012).

Given the ecological and economic importance of small pelagic fisheries, especially for smallholder fishers, and the challenges posed by declining fishery stocks, small pelagic fisheries need to be managed sustainably. This research was conducted to determine the production and status of small pelagic fisheries stocks in FMA 716, especially in the North Sulawesi Province area, so that it can be a reference for sustainable management.

Material and Method

Description of study site. This study was conducted in the waters of North Sulawesi, Indonesia, specifically within FMA 716. Fish specimens were gathered from eight landing sites between February 2019 and May 2021. The eight fish landing ports are Tumumpa, Calaca, Kema, Likupang Dua, Bukide, Bukide Timur, Para, and Tidore (Figure 1).

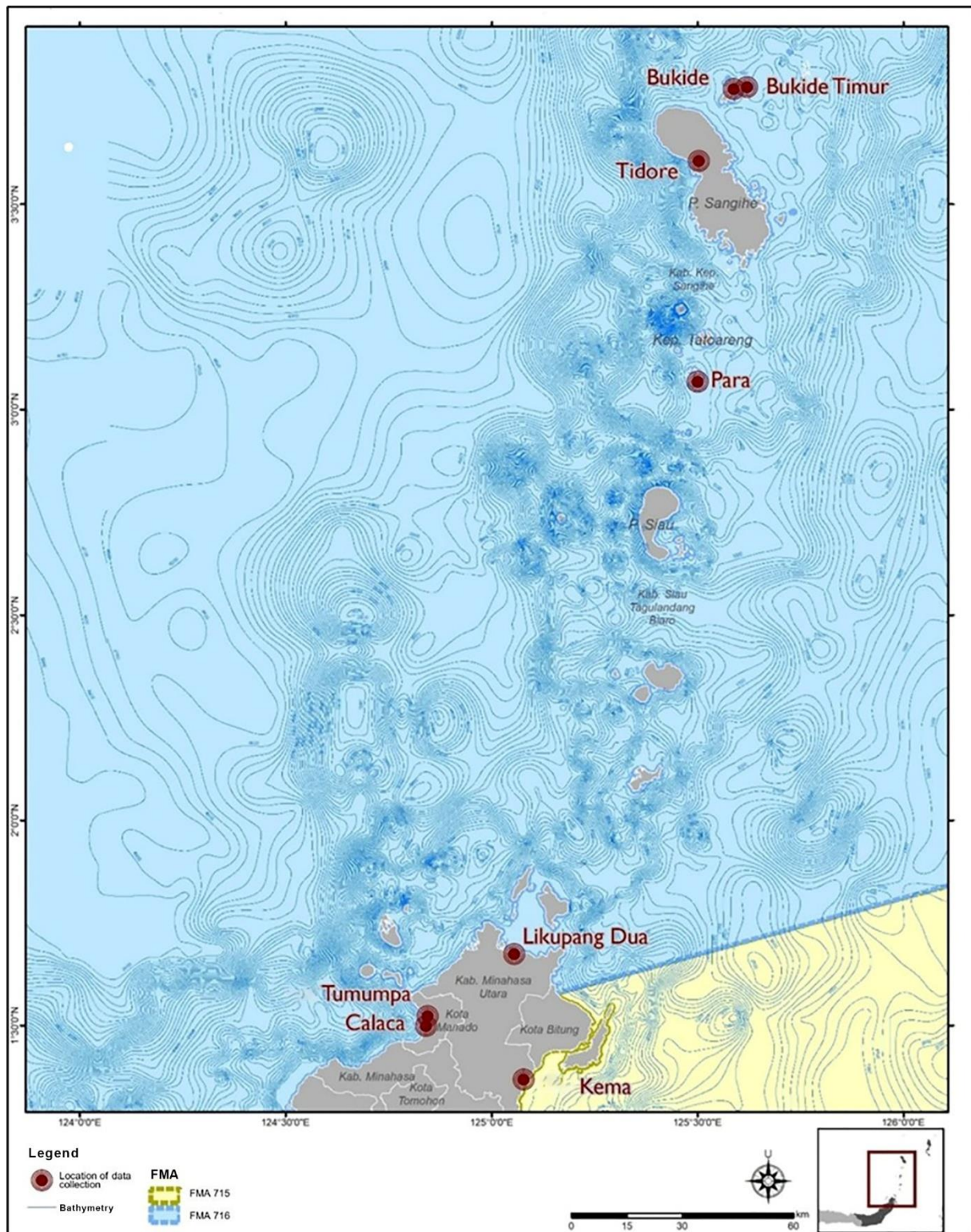


Figure 1. Location of small pelagic fish data collection in North Sulawesi Province.

A number of 39,392 specimens representing six species of small pelagic fish were recorded: redbill scud *Decapterus kurroides* (3,475 fish), mackerel scud *Decapterus macarellus* (20,211 fish), shortfin scud *Decapterus macrosoma* (2,537 fish), Indian mackerel *Rastrelliger kanagurta* (3,415 fish), goldstripe sardinella *Sardinella gibbosa* (1,261 fish), and bigeye scud *Selar crumenophthalmus* (8,493 fish).

The total length of each fish was measured at the landing sites using a measuring board with 0.1 cm precision, with colored lines indicating every additional 10 cm (Figure 2).

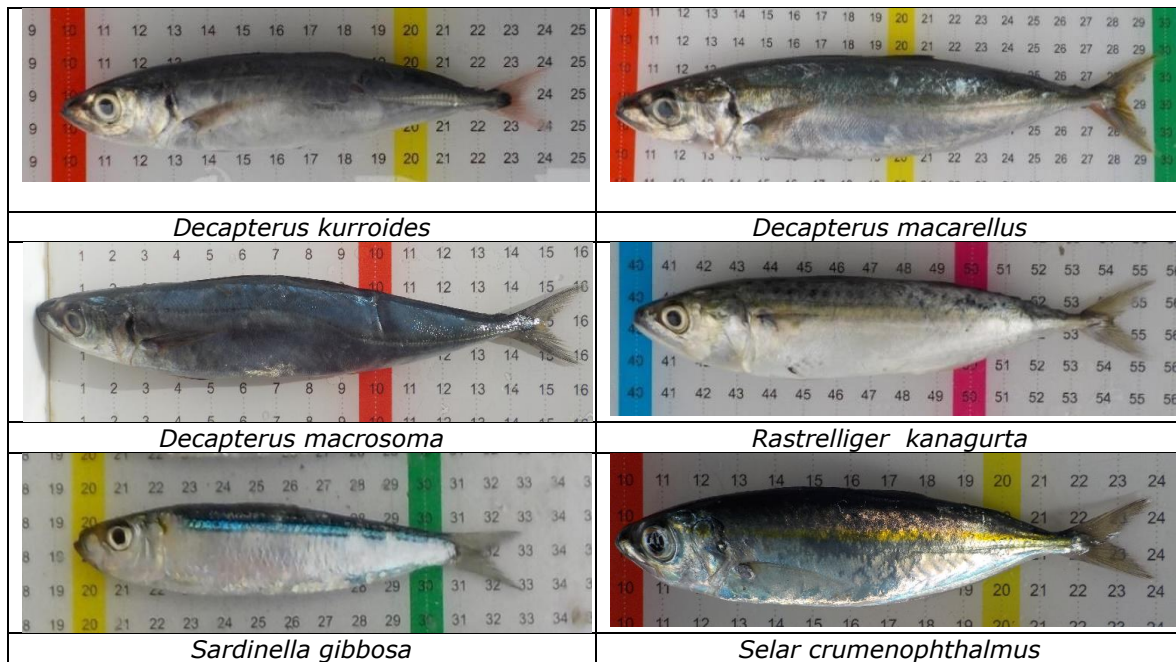


Figure 2. Measurement of total fish length.

Data analysis. The stock condition of small pelagic fish was assessed using the length-based spawning potential ratio (LBSPR), which is among the most useful biological reference points that can be used to inform fisheries management decisions for data-poor fisheries (Hordyk et al 2015). It is defined as the proportion of the unfished spawning potential remaining when under fishing pressure (Walters & Martell 2004). Based on this biological reference point, the LBSPR can be established, which is a widely used technique in data-poor stock assessments (Prince et al 2015). Moreover, the population parameters used to evaluate stock status included growth parameters, mortality rates, and exploitation level (Badrudin 2015).

Growth parameters. The study of growth parameters focuses on understanding how a fish's body size changes with its age. Estimation of growth parameters includes asymptotic length (L_{∞}), which is the average length of fish at a very old age (cm), growth coefficient (k), and $t_{\infty 0}$, which is the theoretical age of fish when the length of the fish is zero (years). Analysis of growth parameters is used to determine fisheries management indicators. The k is defined as a parameter that determines how quickly a fish reaches its L_{∞} (Sparre & Venema 1998). According to Pauly (1980), fish that have a high k value generally have a relatively short lifespan. The k is obtained using the Von Bertalanffy model with the following equation (Sparre & Venema 1998):

$$L_t = L_{\infty} [1 - e^{-k(t-t_0)}]$$

where: L_t = length at age t (cm); L_{∞} = asymptomatic length/average length (cm) of the largest (very mature) fish in the population; k = growth coefficient (year^{-1}); and t_0 = the theoretical age of the fish when the length of the fish is zero (years), and e = the base of the natural logarithm (Euler's number), approximately 2.718.

The analysis of the k was performed using the ELEFAN method available on the RStudio software. The conjecture of t_0 is calculated based on the empirical equation of Pauly (1984):

$$\text{Log}(-t_0) = -0.392 - 0.275 \text{Log}L_{\infty} - 1.038 \text{Log}K$$

Average length (\bar{L}) is one of the indicators that is used as a reference point in fisheries management (Trenkel et al 2007; Cope & Punt 2009). If the rate of exploitation

increases, then in general, the average length of fish will decrease. The average length of the fish caught can be obtained through the following equation:

$$\bar{L} = \frac{\sum_{i=1}^n L_i}{n}$$

where: \bar{L} = average length; L_i = fish length; n = number of fish samples.

Mortality and exploitation rate. Mortality refers to the overall death rate (Z) within a fish population, which includes both natural causes (M) and fishing activities (F) occurring within a year. The relationship between Z and F can be used to estimate the exploitation rate (E), which reflects the extent to which fishery resources are being utilized (Osio et al 2015). The E serves as an indicator of fishing pressure on a population, with a benchmark value of 0.5 representing maximum sustainable yield (MSY) conditions, where fishing mortality equals natural mortality ($F = M$) (Gulland 1971; Pauly 1984).

Estimation of M and Z was conducted using RStudio software. M was estimated using methods proposed by Pauly (1980), while Z was estimated through a catch curve analysis adjusted to length data, known as the linearized length-converted catch curve. Once Z and M values are determined, F can be calculated from their relationship:

$$F = Z - M$$

Furthermore, Pauly (1984) stated that the E can be determined by comparing F with Z as follows:

$$E = \frac{F}{Z}$$

Length parameters. Two length parameters were measured: length at first maturity (L_m) and length at first capture (L_c). The L_m refers to the average size at which fish begin to reach sexual or gonadal maturity. According to Cope & Punt (2009), the L_m value can be used as a reference point in fisheries management. The estimation of L_m was carried out by analyzing fish length distribution data with the method proposed by Froese & Binohlan (2000), as follows:

$$\log \log L_m = 0.8979 * \log \log L_\infty - 0.0782$$

where: L_m = length of first maturity; L_∞ = asymptomatic length.

The L_m values of all fish species were derived from the analyzed primary data sources.

The L_c refers to the size at which the fishing gear retains 50% of the fish, while the other 50% can escape (Sparre & Venema 1998). The average L_c is calculated using the Beverton & Holt formula (Sparre & Venema 1998):

$$L_c = -\frac{a}{b}$$

where L_c = estimated length value; the values of a (*intercept*) and b (*slope*) are obtained from the following linear regression equation:

$$\ln\left(\frac{1}{SLC} - 1\right) = a - bL$$

where: L = length center value (cm); SLC = cumulative relative length frequency.

The analysis to estimate the average length of fish caught was initially conducted using the RStudio software. According to Froese & Binohlan (2000), to prevent overfishing, fish should be allowed to spawn at least once before being caught. Therefore, the ideal L_c should be greater than L_m .

Length-based spawning potential ratio (LBSPR). LBSPR is the proportion of the average reproductive potential of a resource caused by the capture pressure. The spawning potential ratio (SPR) describes the comparison of spawning stock biomass per recruit (SSBR) below different levels of capture mortality to the theoretical SSBR before capture (virgin stock). In the absence of fishing activities, the SPR of a fish stock can reach 100% of its natural reproductive capacity. Therefore, SPR is used to assess the reproductive potential of a fish population. It is commonly applied as a reference point in fisheries management, particularly in data-limited fisheries, to indicate stock health and guide sustainable exploitation (Sparre & Venema 1998; Prince et al 2015).

The parameters required for LBSPR analysis include the natural mortality to growth rate ratio (M/K), the asymptotic length (L_{∞}), and the length at first maturity (L_m). To determine the SPR value, biomass is calculated for each fish length group, along with the spawning stock biomass (SSB). SBB is calculated using the following equation:

$$SSB = \sum_{t=L_m}^{t=\lambda} N_t \cdot W_t$$

where: SBB = spawning stock biomass; N_t = population at a given time; W_t = average "weight-at-age"; $t\lambda$ = the maximum age (or the last age class considered in the model); t_m = the age at first maturity (the age when fish first become sexually mature and contribute to spawning).

The SSB is first estimated at the unfished or "pristine" level (B_0). The SPR is then determined for different combinations of length at first capture (L_c) and fishing mortality (F) by dividing the exploited spawning biomass (SSB_F) by the unfished spawning biomass ($SSB_{F=0}$):

$$SPR = \frac{SSB_F}{SSB_{F=0}}$$

where: SPR = spawning potential ratio;

SSB_F = spawning stock biomass under a given level of fishing mortality F;

$SSB_{F=0}$ = spawning stock biomass in the absence of fishing (unfished biomass).

The LBSPR analysis produces values ranging from 0 to 1, equivalent to 0-100% in percentage terms. Badrudin (2015) noted that for teleost fishes, the ecological reference point (ECR) is set at 20%; values below this threshold indicate a risk of reduced recruitment. As management benchmarks, the proxy for MSY is set at 30-40% SPR, while the proxy for maximum economic yield (MEY) is 50% of the ECR. The SPR values in this study were estimated using the LBSPR method (Hordyk et al 2015), available online at <http://barefootecologist.com.au/lbspr>.

Results. The k for *D. macarellus*, *D. kurroides*, and *D. macrosoma* was estimated at 0.88-0.94 year⁻¹, whereas *S. crumenophthalmus*, *R. kanagurta*, and *S. gibbosa* showed values of 0.73, 0.79, and 0.85 year⁻¹, respectively (Table 1). The maximum estimated lifespan (A_{max}) of these species ranged from 4 to 6 years.

Mortality parameters. Natural mortality (M) of the six species ranged from 1.06 to 1.52 years⁻¹. The fishing mortality (F) values among the observed species range from 0.71 to 2.45, with *R. kanagurta* exhibiting the highest F value (2.45), indicating the most intense fishing pressure, while *S. gibbosa* shows the lowest (0.71). Similarly, in terms of total mortality (Z), *S. gibbosa* has the lowest value at 1.78, suggesting relatively lower overall mortality, whereas *R. kanagurta* again shows a higher Z value of 3.38, reflecting greater combined fishing and natural mortality (Table 1).

Length at first maturity (L_m). The L_m values for *D. kurroides*, *D. macarellus*, *D. macrosoma*, *R. kanagurta*, *S. gibbosa*, and *S. crumenophthalmus* ranged between 14.17 and 23.95 cm. Among these species, *D. macarellus* matures at the largest size of 23.95 cm, followed by *S. crumenophthalmus* at 19.19 cm, *R. kanagurta* at 18.95 cm, *D. macrosoma* at 16.81 cm, *D. kurroides* at 16.73 cm, and *S. gibbosa*, which reaches maturity at the smallest size of 14.17 cm (Table 1).

Table 1

Population parameters and stock conditions of small pelagic fish in the Sulawesi Sea, North Sulawesi Province (FMA 716)

Species	Growth parameters				Mortality				Length indicators					% immature	Status indicator	
	L_{∞}	K	t0	Amax	M	Z	F	E	Lmin	Lmax	L _{Average}	Lm	Lc		F/M	SPR
<i>Decapterus kurroides</i>	28.16	0.94	-0.17	4	1.38	3.36	1.98	0.59	8.31	25.81	15.41	16.73	11.91	66	1.78	0.14
<i>Decapterus macarellus</i>	37.56	0.88	-0.17	4	1.52	2.70	1.18	0.61	9.50	38.01	20.08	23.95	13.29	75	1.54	0.15
<i>Decapterus macrosoma</i>	28.93	0.89	-0.18	4	1.25	2.89	1.65	0.57	8.37	27.01	15.39	16.81	12.25	68	1.32	0.17
<i>Rastrelliger kanagurta</i>	32.35	0.79	-0.20	6	1.38	3.38	2.45	0.64	8.50	31.50	17.48	18.95	14.99	66	1.78	0.14
<i>Sardinella gibbosa</i>	23.40	0.85	-0.20	4	1.06	1.78	0.71	0.40	7.00	24.00	14.88	14.17	10.63	56	0.67	0.48
<i>Selar crumenophthalmus</i>	26.42	0.73	-0.23	5	1.21	2.78	1.66	0.60	7.91	26.14	16.05	19.19	13.51	86	2.20	0.15

Notes: L_{∞} = asymptotic length (cm); K = growth coefficient (year^{-1}); t0 = lifespan of fish at length = 0 (years); Amax = maximum lifespan (years); M = natural mortality (year^{-1}); Z = total mortality (year^{-1}); F = fishing mortality (year^{-1}); E = exploitation rate; Lmin = minimum length of the entire sample measured (cm); Lmax = maximum length of the entire sample measured (cm); L_{Average} = average length (cm); Lm = length of the fish at the first maturity (cm); Lc = length of fish at first capture (cm); %Immature = the percentage of fish caught before adulthood; F/M = catch rate ratio; SPR = spawning potential ratio.

Length at first capture (Lc). The Lc values for the six species vary as follows: *D. kurroides* – 11.91 cm, *D. macarellus* – 13.29 cm, *D. macrosoma* – 12.25 cm, *R. kanagurta* – 14.99 cm, *S. gibbosa* – 10.63 cm, and *S. crumenophthalmus* – 13.51 cm (Table 1). Among these, *R. kanagurta* has the highest Lc value, while *S. gibbosa* has the lowest, indicating that *S. gibbosa* is generally captured at a smaller size compared to the other species.

Length-based spawning potential ratio. This study revealed that SPR values were as follows: 0.15 for both *D. macarellus* and *S. crumenophthalmus*, 0.14 for both *D. kurroides* and *R. kanagurta*, 0.17 for *D. macrosoma*, and 0.48 for *S. gibbosa*. These low SPR values suggest that the reproductive capacities of these species may be severely reduced, raising concerns about their long-term sustainability (Table 1).

Discussion. The k values ranged from 0.88 to 0.94 years⁻¹, indicating that the studied species generally exhibit moderate to fast growth rates, with *D. macarellus*, *D. kurroides*, and *D. macrosoma* growing slightly faster than the others, which is typical for short-lived, small pelagic fish. However, a study by Xu et al (2023) in the South China Sea reported k values between 0.26 and 0.37 year⁻¹ for *D. macarellus*, suggesting slower growth in that region. These comparisons support the notion that growth rates can vary regionally, and the relatively higher k values in the present study may reflect favorable environmental conditions or species-specific responses in the local habitat. According to Froese & Binohlan (2000), the value of k > 0.3 year⁻¹ falls into the high category. The maximum lifespan (A_{max}) for these types of fish is between 4 and 6 years, indicating a short-lived life cycle that makes them more susceptible to overfishing if not properly managed. When compared with recent studies, the findings are consistent or slightly higher. Fish with high k values generally have a high risk of natural mortality (Sparre & Venema 1998).

This study revealed that M ranged from 1.06 to 1.52 years⁻¹. Purwanto et al (2022) reported that M values for small pelagic species, including *D. macarellus* found in the Maluku Sea in FMA 715, ranged from 1.10 to 1.60 year⁻¹ which is comparable to this study. Furthermore, F values among the observed species ranged from 0.71 to 2.45, with *R. kanagurta* exhibiting the highest F value (2.45), which is under the most significant fishing pressure, potentially exceeding sustainable limits, as indicated by its high F and Z values relative to M. In contrast, *S. gibbosa*, with both low F and Z values despite moderate M, appears to be experiencing lower fishing impact. The E is also a key parameter to describe the level of utilization of fish resources because it is used to estimate the fishing pressure in a population. The E value is greatly influenced by the F; the higher the F, the higher the E. According to Gulland (1971) and Pauly (1984), the optimal E for fishing activities is 0.5 or under MSY conditions (F = M). The E of *D. macarellus*, *S. crumenophthalmus*, *D. kurroides*, *R. kanagurta*, and *D. macrosoma* was 0.61, 0.60, 0.59, 0.64, and 0.57, respectively. These conditions show that the utilization rate exceeds the optimal utilization rate (E > 0.5), so that the utilization of fish resources of *D. macarellus*, *S. crumenophthalmus*, *D. kurroides*, *R. kanagurta*, and *D. macrosoma* is indicated to be in a condition of overfished. As for *S. gibbosa*, it has an E that is still at a moderate level (under-exploited), with a value of E < 0.5, namely E = 0.4. The results of this study indicate a change in stock status. These M values are influenced by several natural events, such as predation processes, disease, famine, and aging (Sparre & Venema 1998). This imbalance highlights the need for targeted management measures to reduce exploitation of heavily fished species like *R. kanagurta*, while maintaining the sustainability of less-impacted species such as *S. gibbosa*.

The Lm values for the observed species range between 14.17 cm and 23.95 cm. This condition is likely because the average size of the fish caught is predominantly immature. The Lc values range from 10.63 cm to 14.99 cm. This is evident from the ratio between the Lc and the Lm. *D. macarrelus* has an Lc size of 13.29 cm, which is much smaller than its Lm of 23.95 cm, with an estimated 75% of the catch being immature. Similarly, *D. kuroides* shows an Lc of 11.91 cm, smaller than its estimated Lm of 16.73 cm, with 70% of the individuals caught classified as immature. *S. crumenophthalmus* has an Lc value of 13.51 cm, which is below the Lm size of 19.19 cm, and the proportion of

immature individuals is approximately 85.65%. *R. kanagurta* has an Lc value of 14.99 cm, which is below the Lm of 18.95 cm, with 53.75% of the catch being immature. *D. macrosoma* has an Lc of 12.25 cm, which is smaller than the estimated Lm of 16.81 cm, with an immature percentage of 68%. According to Froese (2004), if most of the fish caught are estimated not to have spawned at least once, then their fishing activities have a high risk of overfishing. Considering the high percentage of immature fish, it indicates the likelihood of growth overfishing - a condition where the catch primarily consists of small-sized fish that have not yet reached gonadal maturity. The dominance of small fish catches can be caused by the small mesh size and the fishing area in the nursery area. According to Indonesia's Minister of Marine Affairs and Fisheries Regulation No. 18 of 2021, the minimum mesh size for purse seine fishing gear used to catch small pelagic fish shall be no less than 1 inch (± 25.4 mm).

The analysis of LBSPR shows that several species have SPR values below the critical threshold of 20%, indicating they may be experiencing an overfished condition. SPR serves as a key indicator in fisheries management, providing a reference point for assessing the status and level of exploitation of fish stocks. For teleost fish species, the threshold reference point is typically set at 20%. When SPR values fall below this level, it signals that the stock has declined and is experiencing overfishing (Badrudin 2015).

Therefore, sustainable management of small pelagic fisheries in the North Sulawesi water (FMA) 716 is essential, particularly for fish stocks identified as fully exploited or overexploited. These stocks should be prioritized to improve their condition and ensure the sustainability of the fishery resources (FIKP2B 2022). According to Regulation No. 18 of 2021 issued by the Indonesian Ministry of Marine Affairs and Fisheries (MMAF), the use of purse seines and other fishing gear for catching small pelagic fish must comply with the minimum allowable net mesh size of 1 inch to ensure the protection of juvenile fish and support the sustainability of fish stocks. Additionally, it mandates the monitoring of designated fishing zones, particularly those that serve as nursery and feeding grounds for small pelagic species (Indonesia Ministry of Marine and Fisheries 2021). This policy is designed to reduce the capture of juvenile fish, giving them time to grow and reach their first reproductive stage.

Conclusions. Assessment of stock status in the North Sulawesi region of FMA 716 revealed that *D. macarellus*, *S. crumenophthalmus*, *D. kurroides*, *R. kanagurta*, and *D. macrosoma* are in an overexploited condition, exhibiting spawning potential ratio (SPR) estimates of 0.15, 0.15, 0.11, 0.14, and 0.17, respectively. All values are below the commonly accepted biological reference point of 20%, indicating a critical reduction in reproductive capacity. The only species that is under-exploited is sardines (*S. gibbosa*) with an SPR value of 0.48. Therefore, sustainable management is essential, particularly for fish resources that are overfished, to help restore their stock status.

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Conflict of interest. The authors declare that there is no conflict of interest.

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