Growth parameters and spawning potential ratio of scad (*Decapterus* spp.) fish in the Java Sea, Indonesia

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Abstract. Small pelagic fish resources in the Java Sea, including the scad (*Decapterus* spp.) species, have relatively high potential. The decreasing biomass stock of scad is indicated by a decrease in the size of the dominant fish caught, so proper management is needed. Management of fisheries resources can use the precautionary approach concept. The precautionary approach management concept includes indicators of natural history and population dynamics through analysis of fish growth parameters and the spawning potential ratio. Fish length measurements were carried out on 2,880 fish in three fishing ports whose fleets fished in the Java Sea waters for 1 year (52 weeks). The scad fish's total length (TL) was measured using a vernier caliper with an accuracy of 1 mm. Estimated growth parameters were determined using the von Bertalanffy growth formula through the FiSAT II software, and spawning potential ratio analysis was carried out. The fish growth coefficient was below one, so fish growth was in poor condition. Female scad reached maximum size faster with a theoretical age of around 2.52 years. The stock of female scad resources in the Java Sea has a higher chance of being caught than that of male scad fish. The spawning potential ratio value of 0.55 illustrates that the stock of scad fish is included in the Under Exploited category, so fishing can still be done by paying attention to resource sustainability. The mini purse seine mesh used by fishermen to catch scad is quite selective to the size of the catch.

Key Words: fishing pressure, gear selectivity, precautionary approach, small pelagic stock assessment, sustainable fisheries management.

Introduction. Small pelagic fish resources in the Java Sea, including the scad fish, have relatively high potential (Syamsuddin et al 2023). Utilizing pelagic fish resources can support and develop the economy, especially for fishermen in the north of Java Island and the south of Kalimantan Island (Ghifary et al 2021; Limbong et al 2023a). Scad fish (*Decapterus* spp.) is included in the category of small pelagic fish resources with crucial economic value and thus significantly contributes to fisheries production in the Java Sea. The shortfin scad (*Decapterus macrosoma* Bleeker, 1851) species live and is distributed in the eastern Java Sea and the Makassar Strait. Indian scad *Decapterus russelli* (Rüppell, 1830) is distributed in the western Java Sea and the North Natuna Sea. According to Khatami et al (2019), the rate of small pelagic fish catches in the Java Sea has exceeded sustainable limits due to the many types of fishing gear operating in the Java Sea. The catching of scad fish in the Java Sea continues to increase with the use of fishing technology, such as the use of lights and fish aggregating devices, so that since 1992, it has been at a saturation level (Atmaja & Nugroho 2019), and the status of scad fish biomass tends to continue to decline (Atmaja et al 2017). A decrease in the size of the dominant fish caught indicates the decreasing fish biomass stock. The size of fish landed at the port can indicate the condition of fish resources in the waters (Limbong et al 2023b; Telussa et al 2022), so appropriate management policies can be implemented.

According to Garcia (2003), fisheries resource management uses two main concepts: ecosystem-based management and the precautionary approach. The precautionary approach needs to be carried out in the context of sustainable development in the fisheries sector to ensure that future fisheries exploitation continues to benefit future generations (Kenny et al 2018). According to Adibrata et al (2018), excessive fishing activities will reduce the total biomass in the long term, ultimately reducing the income of small-scale fishermen. The concept of management with a precautionary approach includes indicators of natural history and population dynamics. Management with a precautionary approach through the study of fish biology needs to be carried out to provide information on the development of fish resource management (Jakobsen et al 2016; Karr 1991). The status of scad fish resources can be known by studying biological aspects, such as the analysis of the spawning potential ratio and fish growth parameters. Information on life history parameters is important because it can be used to estimate stock status, such as potential spawning ratio (Ernawati et al 2021; Panggabean et al 2023).

The spawning potential ratio provides an overview of the relative reproductive index used to determine the condition of exploited fishery stocks (Prince et al 2015). It is further stated that the spawning potential ratio approach is a biological reference point for fishery resource management (Prince et al 2020). SPR analysis can also explain the proportion between the reproductive potential or spawning biomass stock of a resource stock that has not interacted with fishing (unfished condition) and resources that have interacted with fishing at varying levels (Walters & Martell 2004). The reproductive aspect is a biological indicator that can be used as a consideration for carrying out fisheries management. In addition, growth parameter analysis, mortality rate, and exploitation are necessary to determine the status of fish resources for fisheries management purposes. The biological aspect of fish is a more efficient indicator in estimating the condition of fish resources in less supportive data conditions (Limbong et al 2022, 2023b).

The need for comprehensive information on the biology of the scad fish and the mortality rate in the Java Sea waters is feared to disrupt the sustainability of scad resources. Management of scad resources needs to be carried out in a controlled manner, followed by supervision for the sustainability of scad resources. However, more scientific information is needed to carry out the management process based on reproductive biology indicators and population dynamics. Therefore, further studies are needed to manage scad resources based on reproductive biology indicators and population dynamics so that scad resources can be utilized optimally. If the utilization of this fish is not controlled from now on, it will threaten the sustainability of scad resources in the future.

Material and Method

Study area and data collection. The locations for scad fish sampling were Eretan fishing base, West Java; Tasikagung fishing base, and Sarang fishing base, Central Java on the Java island of the Republic of Indonesia (Figure 1). Samples of the three fishing ports were determined based on purposive sampling with the consideration that: (1) the scad fish landed were caught in the Java Sea waters, (2) the fishing fleet used a mini purse seine fishing gear, and (3) weekly data on scad fish catches were available for 1 year of observation, and some enumerators had been trained to observe and measure the biological aspects of the fish.

Biological aspects of scad fish data were sampled every week for 1 year (52 weeks) from November 2023 to October 2024 with a total sample size of 2,880 fish. From each fishing base 960 specimens were collected. Fish sampling was carried out using the systematic random sampling method. The total length of the scad fish was measured by using a vernier caliper with an accuracy of 1 mm.

Figure 1. Sampling locations on the shores of the Java Sea (map generated using ArcGIS 10.8).

Statistical analysis*.* Estimation of growth parameters such as asymptotic length ($L\infty$), which is the average size of kite length at a very old age, and growth coefficient (K) is determined using the von Bertalanffy growth formula through the FiSAT II Ver 1.2.2 software issued by FAO-ICLARM. The von Bertalanffy growth model equation is:

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

Where L_t is the length of the fish at age of t (unit of time), L_∞ is the maximum length theoretically (asymptotic length), K is the growth coefficient (per unit of time), t_0 is the theoretical age when the length equals zero. After obtaining the L_∞ and K values, the t_0 value is calculated using Pauly's empirical equation (Pauly 1983) as:

$$Log_{-t_0} = -0{,}3922 - 0{,}2752Log(L_\infty) - 1{,}038Log(K)$$

Theoretically, the maximum age (t_{max}) of fish from a certain population can be calculated using the von Bertalanffy growth parameters (Pauly 1980):

$$t_{max} = \frac{3}{K + t_0}$$

The natural mortality rate (M) is related to the value of the von Bertalanffy growth parameters K and L_∞. Fish that proliferate have high M values and vice versa. The M value is related to the $L\infty$ value because large fish have fewer predators than small fish. Fishing mortality occurs due to fishing activities (Sparre & Venema 1999). According to Pauly (1980) in Sparre and Venema (1999), environmental factors that affect the natural mortality rate are the average water temperature, asymptotic length (L_∞) and growth rate (K). The determination of the natural mortality rate is estimated using the empirical formula of Pauly (1980) in Sparre and Venema (1999) with the equation:

$$LogM = -0{,}0066 - 0{,}279Log(L_\infty) + 0{,}6543Log(K) + 0{,}463Log(T)$$

Where M is natural mortality, L_∞ is the asymptotic length in the von Bertalanffy growth equation, K is the growth rate, and T is the mean annual sea surface temperature (°C) obtained through Ocean Color website (https://oceancolor.gsfc.nasa.gov). The total mortality rate (Z) was estimated using a linearized catch curve based on length composition data. The natural mortality rate (M) was estimated using Pauly's (1980) empirical formula in Sparre and Venema (1999), which converted length data to age data using the inverse von Bertalanffy growth equation:

$$t(L) = t_0 - \left(\frac{1}{K}Ln\left(1 - \frac{L}{L_\infty}\right)\right)$$

Next, the time required for the fish to grow from L_1 to L_2 (Δt) is calculated:

$$\Delta t = t(L_2) - t(L_1) = \left(\frac{1}{K}Ln\left(1 - \frac{L_\infty - L_1}{L_\infty - L_2}\right)\right)$$

The third step is to calculate $t + \frac{\Delta t}{2}$, namely through the equation:

$$t\frac{(L_1 + L_2)}{2} = t_0 - \left(\frac{1}{K}Ln\left(1 - \frac{L_1 + L_2}{2L_\infty}\right)\right)$$

The equation is then derived as a linearized catch curve converted to length:

$$Ln\frac{C(L_1, L_2)}{\Delta t(L_1, L_2)} = C - Zt\frac{(L_1 + L_2)}{2}$$

Based on the equation above, we get $t\frac{(L_1+L_2)}{2}$ as the (x) axis and $Ln\frac{C(L_1,L_2)}{\Delta t(L_1,L_2)}$ as the ordinate (y), so Z is the same as -b (slope). The fishing mortality rate (F) can be estimated using the equation:

$$F = Z - M$$

The exploitation rate can be interpreted as the number of fish caught compared to the total number of fish that died due to all natural and fishing factors (Pauly 1983). According to Gulland (1983) in Pauly (1983), the fishing mortality rate (F) or optimum exploitation rate is $F_{optimum}$ = M and $E_{optimum}$ = 0.5. The exploitation rate (E) is determined by comparing the fishing mortality rate (F) to the total mortality rate (Z) (Pauly 1983):

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

Spawning potential ratio (SPR) analysis was conducted on the length-based frequency. Spawning potential ratio analysis was conducted using an online application, from The Barefoot Ecologist website (http://barefootecologist.com.au), and supporting parameter values were added. The results of the SPR analysis were then compared with the reference values of Walters and Martell (2004), where the status of fish resources was classified into three groups, namely, 1) classified as Under Exploited if SPR> 40%, Moderate if 20% <SPR<40%, and 3) Over Exploited if SPR<20%.

Results. The growth parameter analysis of scad fish (*Decapterus* spp.) consists of asymptotic length (L_∞), growth coefficient (K), theoretical age of fish when the length is equal to zero (t_0), and maximum age of scad fish (t_{max}). The growth parameters of male, female and combined scad fish can be seen in Table 1. Generally, the growth parameter values between male, female or combined scad fish are not too different. The growth equation of scad fish using the von Bertalanffy model in the study obtained $L_t = 24{,}4(1-e^{-0{,}46(t+0{,}377)})$. The growth curve of scad fish can be seen in Figure 2. The asymptotic length (L_∞) of the scad fish sampled in this study was around 24.4 cm. The asymptotic size of the female scad fish is more extended (L_∞=24.6 cm) than the female scad (L_∞=24.3 cm). The largest size ever found, according to FishBase (Froese & Pauly 2025), for the Indian scad (*Decapterus russelli*) is around 45 cm, and the shortfin scad (*Decapterus macrosoma*) is around 35 cm (Paxton et al 1989).

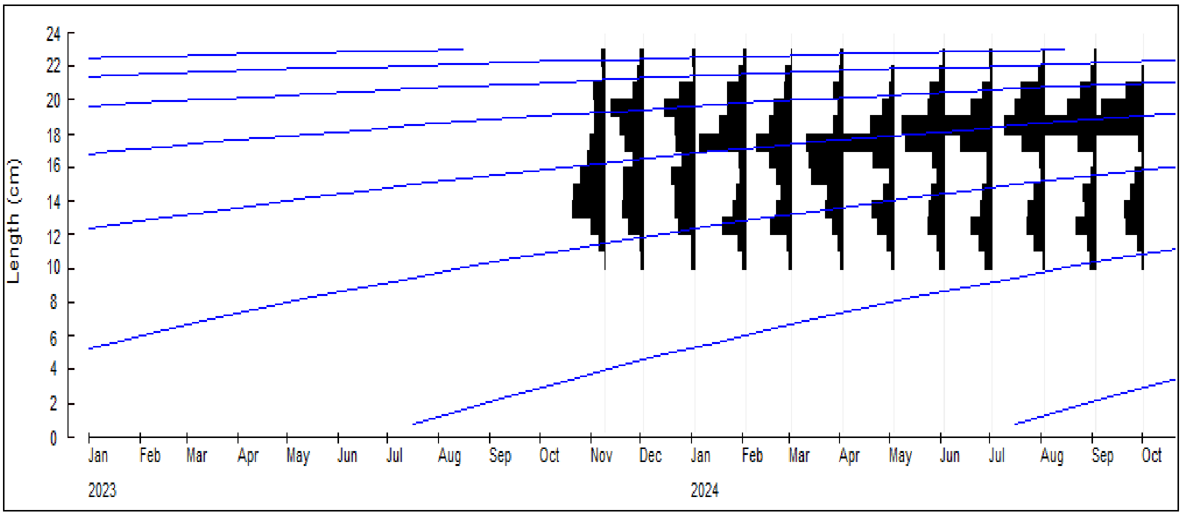

Figure 2. Growth curve of scad fish in the Java Sea based on FISAT II.

The combined growth coefficient of scad fish is 0.46 per year; male scad fish is around 0.44 per year, while female scad fish has a higher growth coefficient of 0.71 per year. The difference in growth coefficient values suggests that female scad fish reach their maximum size faster than male scad fish. The theoretical maximum age of scad fish (t_{max}) is around 3.99 years; male scad fish is around 4.19 years, and female scad fish is around 2.52 years. All fish growth coefficient values are below one, or fish growth is in poor condition.

Table 1

Growth parameters of scad fish (*Decapterus* spp.) in the Java Sea

Species	*Sex*	*Number of samples*	*Growth parameters*			
			L_∞ (cm)	*K ($year^{-1}$)*	*t_0 (year)*	*t_{max} (year)*
Decapterus spp.	Male	1,670	24.3	0.44	-0.395	4.19
	Female	1,210	24.6	0.71	-0.240	2.52
	Combined	2,880	24.4	0.46	-0.377	3.99

Fish mortality parameters include natural mortality (M) and fishing mortality (F). Based on this study, the natural mortality of scad is higher (M = 1.19/year) compared to fishing mortality (F = 0.62/year). The female scad has a higher fishing mortality (F) of 1.08/year compared to the male scad of 0.32/year with an exploitation ratio (E) of 0.41/year. Based on this analysis, the stock of female scad resources in the Java Sea is more likely to be caught than that of male scad (Table 2).

Table 2

Mortality rate and exploitation of scad fish (*Decapterus* spp.) in the Java Sea

Species	*Sex*	*Parameters*			
		M ($year^{-1}$)	*F* ($year^{-1}$)	*Z* ($year^{-1}$)	*E*
Decapterus spp.	Male	1.16	0.32	1.48	0.22
	Female	1.58	1.08	2.66	0.41
	Combined	1.19	0.62	1.81	0.34

The length-based spawning potential ratio (LB-SPR) estimates the stock condition of scad fish in the Java Sea. The spawning potential ratio compares the stock's spawning ability (or reproductive capacity) in an exploited condition with the stock's spawning ability (or reproductive capacity) in an unexploited condition. The estimated spawning potential ratio of scad fish is 55%, and the SL_{50} value is around 20.27 (Figure 3). The spawning potential ratio value of 0.55 indicates that the scad fish stock is in the Under Exploited category, so fishing can still be carried out. The spawning potential ratio (SPR) value of scad fish reaches 100% of its natural potential before any fishing activities, and the reproductive potential will decrease if there are already fishing activities. The length size selectivity (SL_{50}) of scad fish caught using mini purse seine nets in the Java Sea was around 20.27 cm, above the value of the first mature gonad size of scad fish (L_m = 18.9 cm). This value explains that the mesh of the fishing gear used by fishermen to catch scad fish is quite selective to the size of the catch.

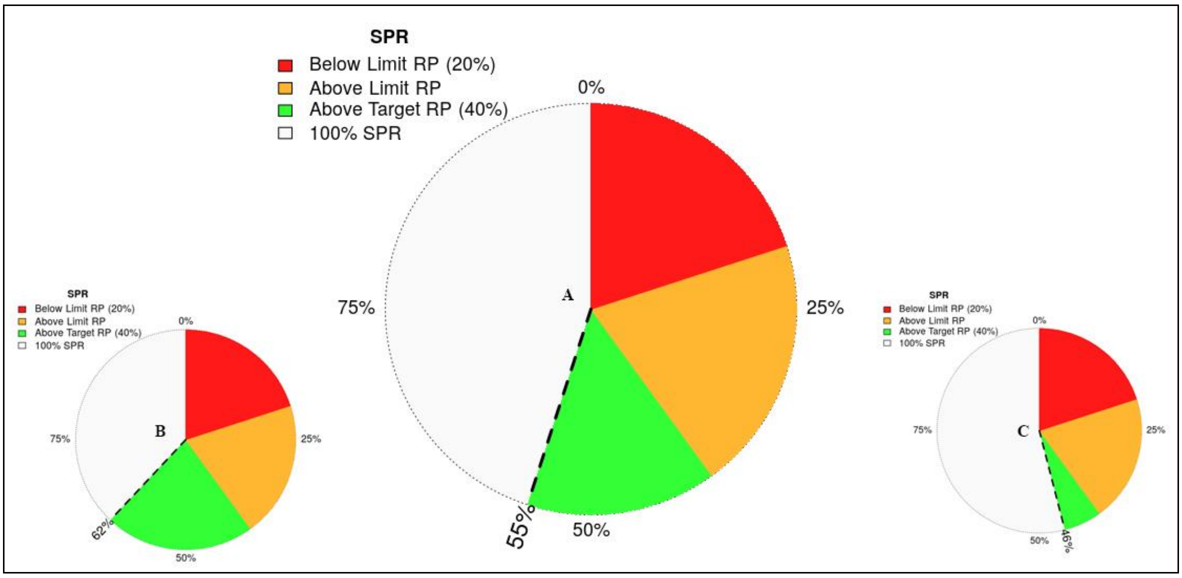

Figure 3. Estimated spawning potential and SPR reference points of scad fish (A), male scad (B), and female scad (C).

Discussion. Growth can be defined as an increase in length or weight over time (Pauly & Cheung 2018). Fish growth parameters will always vary even when carried out on the same type of fish. This difference can occur due to differences in study areas, sampling periods, differences in the number of samples, or the methods used. If small fish dominate the fish sample, a higher growth coefficient will be obtained; conversely, if larger fish dominate the fish sample, a lower growth coefficient will be obtained (Denechaud et al 2020). The asymptotic length (L_∞) of scad fish (*Decapterus* spp.) in the Java Sea is relatively large compared to scad fish caught in various waters in Indonesia. Scad fish caught in the waters of the Malacca Strait have an asymptotic length of around 22.9 cm (Alnanda et al 2020), while in the waters of North Gorontalo, it is around 23.6 cm (Auliyah & Olii 2022). The asymptotic length of fish is determined from the growth coefficient (K). The higher the growth coefficient, the faster it reaches its maximum length and generally has a shorter lifespan (Higgins et al 2015; Murua et al 2017).

Differences can influence differences in asymptotic length in habitat conditions and pressure from fishing activities in each water. Habitats with sufficient nutritional content or availability of natural food can support optimal fish growth. At the same time, intensive fishing activities do not allow fish to grow larger, so the asymptotic length becomes smaller (Lapointe et al 2013).

The growth coefficient value of scad fish in the Java Sea is below 1; only female fish have a growth coefficient (K) value of more than 0.5. The growth rate coefficient of fish is high if it is 0.5-1 (Bintoro et al 2019). However, Alnanda et al (2020) state that rapid fish growth occurs if the growth coefficient value is more than 1. Female scad fish in the Java Sea have a higher growth coefficient value and a shorter lifespan. Sparre and Venema (1999) stated that the faster the growth rate of the fish, the faster the fish will reach its asymptotic length and die quickly. The lifespan of male scad fish in the Java Sea ranges from 4.19 to 6.11 years. According to Ronquillo (1974), the lifespan of the Indian scad can reach 12 years, although currently, many studies state that the lifespan of scad fish is in the range of 5 years (Widodo 1988). The lower the growth coefficient value, the longer it takes for the species to approach its asymptotic length. Suman et al (2020) stated that different growth parameter values (K and L_∞) are caused by internal and external factors such as heredity, parasites, disease, temperature, and food availability. When approaching the asymptotic length (L_∞), the fish will experience growth stagnation, where the growth coefficient value (K) can also affect the speed of the fish to reach its asymptotic length.

The exploitation rate (E) is greatly influenced by the fishing mortality rate (F). The higher the fishing mortality rate, the higher the exploitation rate (Froese et al 2016; Jacobsen et al 2014). As a result of the high fishing mortality rate (F) for scad fish, the natural mortality rate (M) will decrease. Determining the natural mortality of fish is difficult, but an approach with several models can be used to estimate the natural mortality of fish stocks. According to Jensen (1996), the optimal mortality modelling is when the M/K value is 1.5 and the L_m/L_∞ value is 0.66. The M/K value in this study ranges from 2.6, and the L_m/L_∞ value is 0.77, so it can be concluded that the results of estimating growth parameters, mortality rates, and exploitation of scad fish in the Java Sea are accurate. The status of fish resource stocks can be determined by several indicators: the exploitation rate (E) and the spawning potential ratio. Stock status is critical for fisheries managers to determine control rules in the fishing process. Female scads have a higher exploitation ratio than males, which can interfere with recruiting small fish to the Java Sea waters.

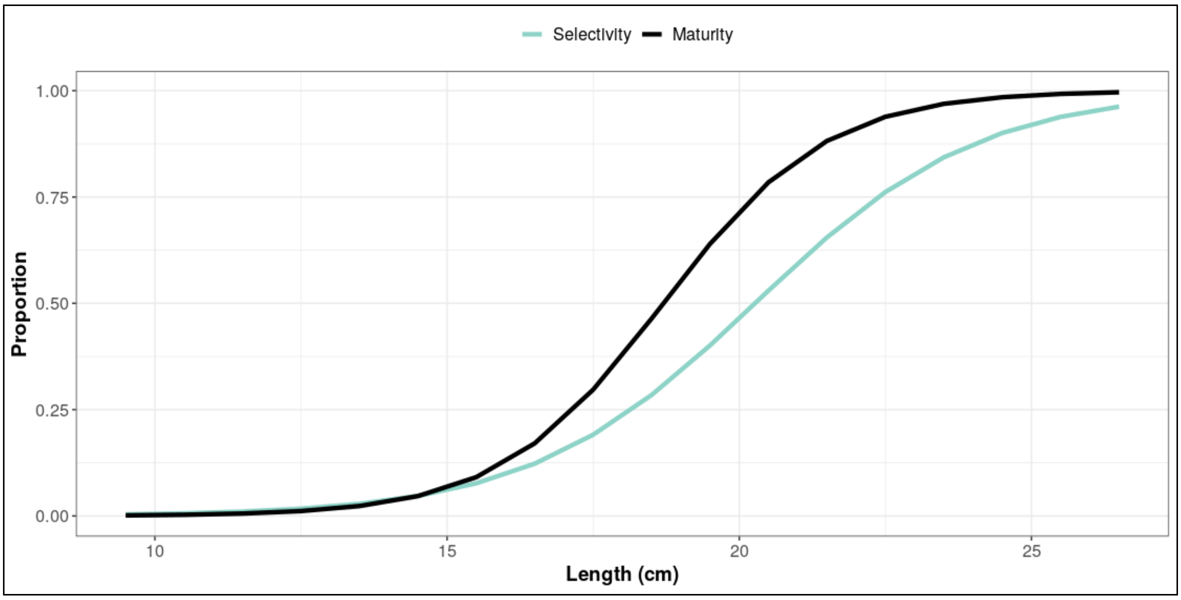

Figure 4. The specified size of the maturity curve (black) and estimated selectivity curve (green).

Fluctuations in the number of fish resource stocks are influenced by many factors (Britten et al 2016). Fishing factors are one of the main factors that change the number of fish resource stocks in waters. According to Zhan (1995), population mortality in fish stocks is mainly influenced by natural mortality when the Z/K level is equal to or less than 3. However, when the Z/K level exceeds 3, fishing activities become the main contributor to population mortality. The study's results on scad fish in the Java Sea have a Z/K value of 3.9, so it can be concluded that the fishing factor is the leading cause of the reduction in the number of scad resource stocks in the Java Sea. Selectivity analysis is determined by using a logistic function to estimate the length at capture at 50% (SL_{50}) and 95% (SL95) levels per year. The length at first capture (SL_{50}) is greater than the length at first maturity (L_{50}) at least the fish have spawned once before being captured (Figure 4). Therefore, the principle of sustainability still occurs.

The spawning potential ratio value of male scad is 62% higher than that of female scad, which has a value of 46% (Figure 2). In general, the spawning potential ratio value is still above the target reference point value suggested by Brooks et al (2010), which is 40%, so the stock status of scad resources in the Java Sea is still classified as sustainable (under-exploited). The same thing was also found in the waters of the South China Sea, where the spawning potential ratio value of scad is 41%, so fishing is still in the under-exploited category (Priatna et al 2021). The range of spawning potential ratio in water is 0-100%, where the spawning potential ratio value of 0 provides information on utilizing complete fish resources. In comparison, the spawning potential ratio value of 100% occurs if the status fishery resource utilization is below optimum or the waters are still natural (Hordyk et al 2015). A low spawning potential ratio indicates a reduced ability of the spawning stock to maintain fish abundance in the environment because the biological capacity to produce adults in the population structure has decreased (Lowerre-Barbieri et al 2017). Long-lived (low M) and relatively slow-growing (low K) species are more sensitive to exploitation and take the longest to recover. The length of recovery from overexploitation should be a primary consideration in management options for rebuilding overfished stocks.

Conclusions. This study successfully provides an overview of the condition of the scad (*Decapterus* spp.) resources based on the aspects of growth and spawning potential ratio. Mortality of scad in the Java Sea is predominantly due to fishing factors, as seen from the Z/K value exceeding 3, which is 3.9. The status of scad resources in the Java Sea based on the spawning potential ratio is in the under-exploited category so that fishing can still be carried out by paying attention to resource sustainability. Scad in the Java Sea has laid eggs once before being caught with a mini purse seine; therefore, sustainability still applies. Female scads have a higher exploitation ratio than males, so it can interfere with the ability to recruit small fish to the Java Sea waters. Female scad reaches its maximum size faster than male scad. The theoretical maximum age of male scad in the Java Sea is around 4.19 years, and female scad is around 2.52 years.

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

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