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Length-based stock assessment of the blue swimming crab *Portunus pelagicus* (Linnaeus, 1758) in the northern coast of Java, Indonesia

Heri Widiyastuti and Tirtadanu*

Research Center for Fishery, National Research and Innovation Agency (BRIN), Nanggewer Mekar, Bogor, Indonesia

Abstract

The blue swimming crab *Portunus pelagicus* is heavily exploited in the northern coast of Java (NCJ), due to its high economic value as an export commodity. Without any management measures, the continued fishing efforts could lead to the depletion of the blue swimming crab (BSC) stock, threatening the economy of fishing communities. Stock assessment is crucial to evaluate stock status and to develop management recommendations. Length frequency and some biological data for 2019 was used to perform a length-based assessment of BSC fisheries in the NCJ. This study revealed that a high fishing mortality and a low selectivity of gillnet fishery had resulted in recruitment overfishing of BSC, with a spawning potential ratio of 0.20±0.05. The current fishing mortality has exceeded 37% of the optimum level and the current selectivity is below the optimal value of a 12 mm carapace width. A combination of management measures including 37% reduction in fishing effort, gear modification to attain 12 mm selectivity, closure of the spawning area in August and habitat restoration, could be implemented to ensure the sustainability of blue swimming crabs in the northern coast of Java.

*Correspondence e-mail:
tirtadanu91@gmail.com

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Introduction

The Java Sea is the habitat for many economically significant fishery commodities, particularly demersal and crustacean resources . With shallow waters of less than 200 m depth and a muddy substrate with high nutrient content, the Java Sea is one of the main fishing areas in Indonesia. The blue swimming crab (BSC) fisheries in the northern coast of Java (NCJ) has been active since 1970s, serving as a primary source of income for local fishers and supporting the development of the fisheries industry in Indonesia. BSC in some areas of Indonesia has been exploited heavily as an export commodity with high economic value. The increasing fishing efforts for BSC in the Java Sea have led to significant rise in yields from about 10,000 t in 2005 to more than 30,000 t in 2015 (MMAF, 2016).

Stock assessment of BSC in the Java Sea is crucial to understand the current stock status and developing management strategies for its sustainability. A previous study in 2012 reported an over-exploited stock condition for BSC in the Java Sea (Ernawati *et al.*, 2017). Furthermore, Nugroho *et al*. (2017) found recruitment overfishing for some demersal fishes in the region. High fishing pressure on the overfished stock will lead to depletion of BSC, resulting in substantial economic loss. Furthermore, unsustainable fishing practices, such as trawl and dredge fisheries, can degrade the environmental substrate and endanger all benthic organisms. Therefore, the most recent information on stock status and biological reference points is critical for developing the harvest control rule for BSC fisheries in the Java Sea.

Some studies have suggested effort limitation, minimum legal size and area closure during the spawning season to rebuild the over-exploited BSC (Johnston *et al.*, 2011; Wiyono and Ihsan, 2018). These management recommendations were derived from the stock assessment outputs, which used various fisheries data as inputs. Most BSC fisheries in NCJ are operated by traditional fishers who land their catch at various sites, making the collection of high-quality catch and effort data challenging. However, a length-based stock assessment can be performed for data-limited fisheries (Hordyk *et al*., 2016).

Assessing the stock status is an essential information for developing management tools for the exploited stock. A length-based assessment has been performed to assess the stock status of various species with data-limited fisheries (Filous *et al*., 2019; Amorim *et al*., 2020; Prince *et al*., 2020; Tirtadanu *et al*., 2021). In this study, length frequency data, along with some biological parameters were used to perform a length-based yield per recruit and spawning potential ratio analysis for BSC in the NCJ. The objectives of this study were to investigate the stock status and to develop management recommendations for BSC fisheries on the northern coast of Java.

Materials and methods

Data collection

The samples of BSC were obtained from the gillnet catch in Cirebon, fishing ground on the northern coast of Java (Fig. 1). The gear having 3.5 inch mesh size was operated with a 3 GT fishing vessel. This study used female BSC collected from March to November 2019. There were 996, 786 and 832 data points on carapace width, weight and gonad maturity stages respectively.

Data analysis

Logistic model was used for estimation of length at first capture (Lc_{50}) and length at first maturity (Lm_{50}) (Schnute and Richard, 1990; Sparre and Venema, 1992). The von Bertalanffy growth parameters *viz*, asymptotic length (L_∞) and growth rate (K), were estimated using the electronic length frequency analysis with simulated annealing (ELEFAN SA) method in TropFishR packages from the R program (R Development Core Team, 2008; Xiang *et al*., 2013; Mildenberger *et al*., 2019). The theoretical age at zero length (t_0) was estimated following the equation of Pauly (1983):

$$\text{Log}(-t_0) = (-0.3922) - 0.2752 \log(L_\infty) - 1.038 \log(K) \quad \text{(1)}$$

The length-weight relationship (Ricker, 1975) and relative condition factor (Le Cren, 1951) were estimated using the equations:

$$W = aL^b \text{ and } K_n = \frac{W}{W'} \quad \text{(2)}$$

where a is a constant, b is the growth coefficient, L is carapace width (mm), W is the observed weight (g), and w is the calculated weights of BSC. The relative condition factor (Kn) was calculated monthly with a 95% confidence interval.

The total mortality (Z) was measured based on the length-converted catch curve analysis (Sparre and Venema, 1992). Four empirical natural mortality methods were used to understand the uncertainty on the mortality parameters and biological reference point, using the equations :

$$\log M_1 = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T \quad \text{(3)}$$

$$M_2 = \frac{\ln(0.01)}{t_{max}} \quad \text{(4)}$$

$$M_3 = \frac{\beta K}{e^{K}(C_{i.}t_{max} - t_0) - 1} \quad \text{(5)}$$

$$M_4 = n\ 4.188K^{0.73}L_\infty^{-0.33} \quad \text{(6)}$$

where M_1, M_2, M_3, and M_4 are the natural mortality by Pauly (1980), Alagaraja (1984), Zhang and Megrey (2006) and Then *et al.* (2015) methods, respectively; L_∞ is asymptotic length, K is the growth rate, T is the average of the coastal water temperature of 29°C based on Martono (2016), t_{max} is maximum age, t_0 is theoretical age at zero length, Ci is the constant of 0.44 and β is the coefficient of growth from the length-weight relationship.

The length-based yield per recruit analysis was used based on the Thompson and Bell model using the TropFishR in the R program (Thompson and Bell, 1934; R Development Core Team, 2008; Mildenberger *et al.*, 2019). The isopleth graph was used to

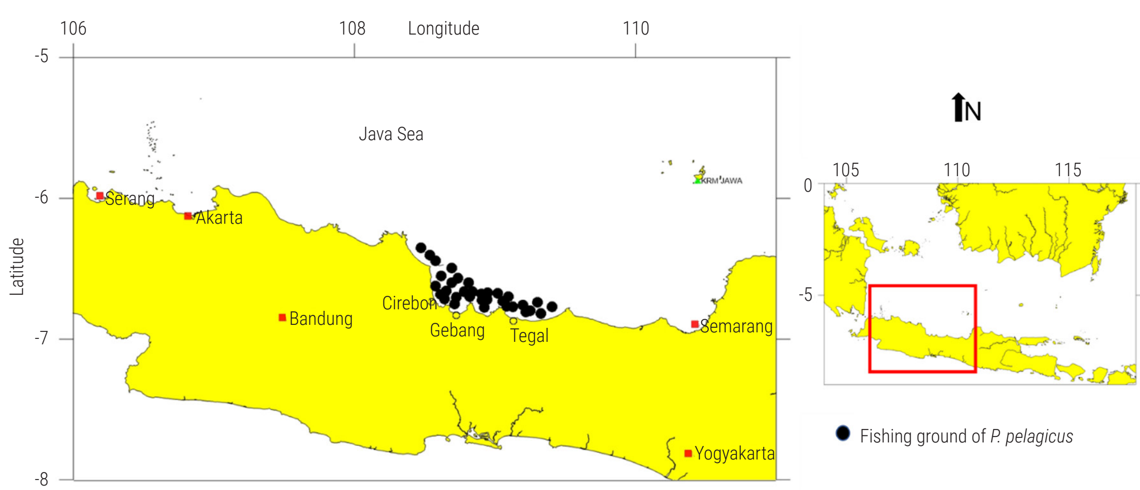

Fig. 1. Fishing ground of *P. pelagicus* on the northern coast of Java

understand the impact of fishing mortality and length at first capture on the yield per recruit. The length at first capture, which gives the maximum yield per recruit (Lc_{max}), was determined to know the level of growth overfishing on the BSC fisheries.

The length-based spawning potential ratio was used to understand the stock status of the BSC fisheries by using the LBSPR package in the R program (R Development Core Team, 2008; Hordyk *et al.,* 2016; Mildenberger *et al.,* 2019). The spawning potential ratio (SPR) is the ratio between the spawning stock biomass per recruit in the presence of fishing with the spawning stock biomass per recruit in the absence of fishing (Goodyear, 1993). Some variations on the asymptotic length and natural mortality were used to understand the uncertainty of the spawning potential ratio. The current spawning potential ratio was compared to the 40%SPR as the optimal reference point to determine the stock status of BSC fisheries on the northern coast of Java.

Results and discussion

Life-history parameters

The size of *P. pelagicus* captured by gillnet in NCJ ranged from 65 to 170 mm with an average of 113.66±0.80 mm (mean±95% confidence interval, CoI) (Fig. 2). *P. pelagicus* in the NCJ were smaller than those in Palk Bay, India and the Gulf of Suez, Egypt, with the size ranging from 72 to 195 and 70 to 197 mm carapace width, respectively (Mahmoud *et al*., 2022). The length at first capture by gillnet (Lc_{50}=102) was smaller than the length at first maturity (Lm_{50}=108 mm), meaning that *P. pelagicus* are captured before they reproduce and are recruited to the fishery. Studies have reported that gillnets captured more proportion of small-size *P. pelagicus* than traps in some areas in Indonesia (Hufiadi, 2017; Azkia *et al*., 2022). The high proportion of immature *P. pelagicus* caught can threaten its sustainability in NCJ, hence management measures need to be implemented to permit the species to grow, reproduce and recruit to the fishery.

Blue swimming crab is a short-lived species having a maximum age of about 2 to 3 years, with the length at first maturity attained at the age of 9 months. *P. pelagicus* in NCJ has L_∞ of 178 mm and K of 1.11 year^{-1} (Fig. 3). The theoretical age when the species has zero length (t_0) was -0.087 year. The von Bertalanffy growth equation can be shown as $L_t = 178[1-e^{-1.11(t+0.087)}]$. Tirtadanu and Chodrijah (2019) reported a lower growth rate of *P. pelagicus* in Kwandang waters (K=0.96 year^{-1}), while Ihsan *et al.* (2014) found larger values in Pangkep coast (K=1.5 year^{-1}). The growth rate of *P. pelagicus* is also affected by environmental variables. Azra *et al*. (2019) reported that the

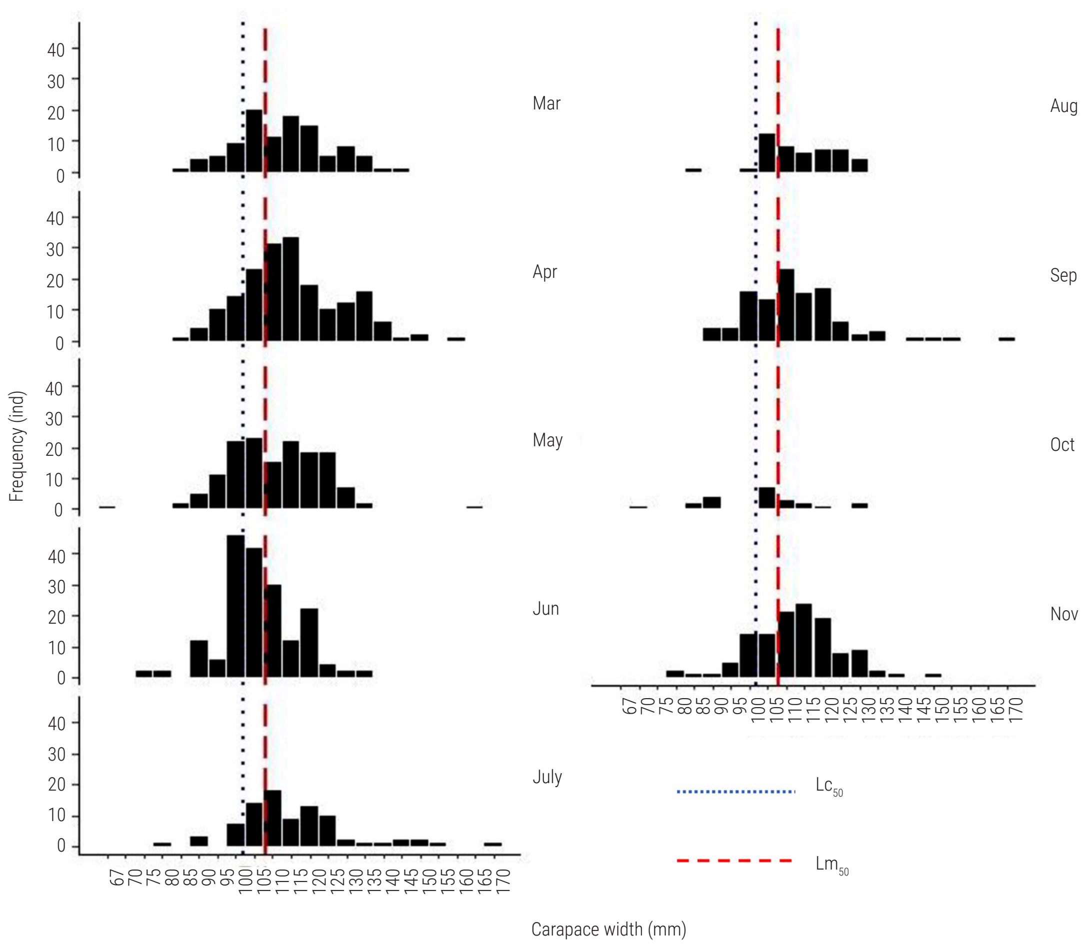

Fig. 2. Size composition, length at first capture (Lc_{50}) and length at first maturity (Lm_{50}) of *P. pelagicus* in the northern coast of Java

Fig. 3. von Bertalanffy growth curve of *P. pelagicus* in the northern coast of Java

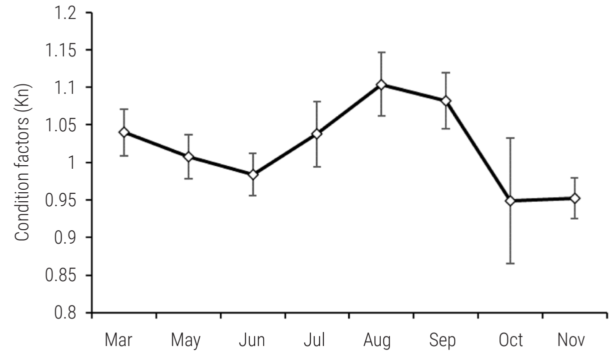

Fig. 5. Relative condition factor (Kn) of *P. pelagicus* in the northern coast of Java

high-temperature of 32°C could decrease the intermolt period of *P. pelagicus*, causing lower growth rate.

The length-weight relationship of *P. pelagicus* follows the equation W=0.00005(L)$^{3.06}$ (Fig. 4). *P. pelagicus* in NCJ has an isometric growth pattern (b=3) and the 95% confidence interval of b was between 2.95 and 3.17, showing that the environmental condition is still suitable for the growth of BSC. The average weight was about 99.20±2.69 mm (mean±95% CoI). The asymptotic weight (W_∞) was 378 g and the length at first maturity (Lm_{50}) was attained at a weight of 82 g.

The relative condition factor (Kn) of *P. pelagicus* from March to November ranged from 0.95 to 1.10 (Fig. 5). The monthly peak values of condition factors were found in August (Kn=1.1) and it decreased to lowest value in October (Kn=0.95). The peak condition factor in August indicate the spawning season of the *P. pelagicus* population and the lowest in October shows that most of them have released their eggs. Ernawati *et al*. (2017) also found the peak spawning season in August . The dry season in August can influence the spawning season, resulting in higher salinity. Female *P. pelagicus* commonly migrate to the deeper waters for spawning, influenced by higher salinity (Naimullah *et al.*, 2020).

Biological reference points and management implications

The total mortality (Z) of *P. pelagicus* in NCJ was 5.55 year^{-1} (Fig. 6). By using some variations of empirical natural mortality methods, the natural mortality ranged from 1.09 to 2.24 year^{-1}, with a mean of 1.70±0.51 year^{-1} (mean±95% CoI) (Table 1). The natural mortality by using Zhang and Megrey's (2006) method gave the lowest estimate of M (M=1.09 year^{-1}), while Pauly's (1980) method estimated the highest M (M=2.24 year^{-1}). Using all the values on natural mortality, the current exploitation rates ranged from 0.60 to 0.80, with a mean of 0.69±0.09. The largest exploitation rate was found using Zhang and Megrey's (2006) method, with the current fishing mortality of 4.46 year^{-1}. The BSC have been exploited heavily as denoted by the current exploitation rates (E_{cur} = 0.69±0.09), which were higher than the optimal value of 0.5.

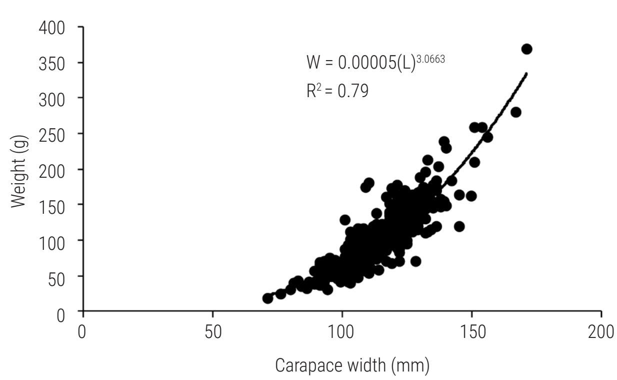

Fig. 4. Length-weight relationship of *P. pelagicus* in the northern coast of Java

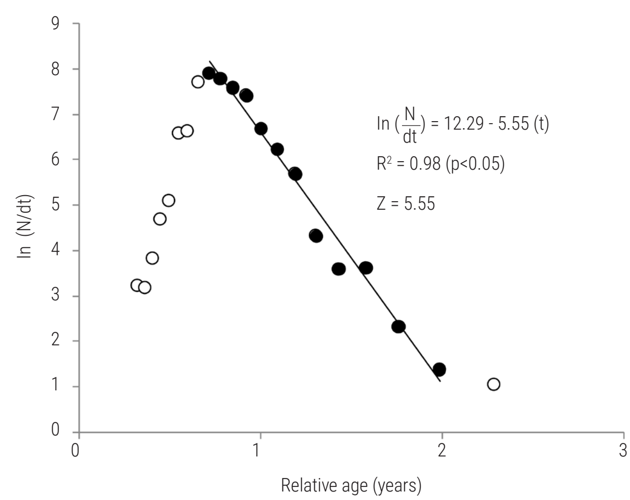

Fig. 6. Length converted catch curve of *P. pelagicus* in the northern coast of Java

Table 1. Natural mortality (M), fishing mortality (Z) and exploitation rate (E) of BSC in the northern coast of Java using some variations on the empirical natural mortality methods

Methods of M	M (year^{-1})	F (year^{-1})	E (year^{-1})
Pauly (1980)	2.24	3.31	0.60
Alagaraja (1984)	1.71	3.84	0.69
Zhang and Megrey (2006)	1.09	4.46	0.80
Then *et al.* (2015)	1.75	3.80	0.68
Mean of M	1.70	3.85	0.69
±95% CoI	±0.51	±0.51	±0.09

Using Zhang and Megrey's (2006) empirical natural mortality rate of 1.09 $year^{-1}$ and the current fishing mortality of 4.46 $year^{-1}$, the current yield per recruit was calculated as 57.8 g $recruit^{-1}$ to achieve the maximum yield per recruit (57.9 g $recruit^{-1}$), fishing mortality need to be reduced to 2.79 $year^{-1}$ (F_{max}) or decreased by 37% from the current level (Fig. 7). The current fishing mortality exceeds 37% of the reference point F_{max}, indicating that BSC fisheries in the NCJ is experiencing overfishing. Previous studies have documented declining BSC stock due to overfishing in certain areas such as Western Australia and Thailand waters (Johnston *et al*., 2011; Kunsook *et al.,* 2014). Overfishing can lead to economic loss, threaten fishers' livelihood and collapse the fisheries sector. However, under the current fishing conditions, optimal yields can be achieved by increasing the length at first capture to 121 mm (~12 cm) carapace width (Lc_{max}). The yield per recruit can be increased by 9% from the current yield per recruit by increasing the length at first capture to 121 mm. The yield per recruit at Lc_{max} was estimated as 63.7 g $recruit^{-1}$. Gear modification will be needed to increase gear selectivity. Boesono *et al.* (2018) found that, traps with pony fish as baits helps catch larger sized *P. pelagicus* in the Java Sea.

Life-history parameters significantly influence the estimation of spawning potential ratio (SPR). A low estimate of asymptotic length and an overestimate of natural mortality can lead to a lower spawning potential ratio. A high F/M ratio (F/M > 1) indicates fishing pressure that exceeds the optimal limit for BSC fisheries. Compared to Pauly's (1980) natural mortality input (SPR=28%), the spawning potential ratio using Zhang and Megrey's (2006) natural mortality input (SPR=10%) yielded more precautionary results (Fig. 8). Using different values of L_∞ (169 , 178 , 187 mm) and M/K (0.98, 1.54, 1.58, 2.02), the spawning potential ratio ranged from 0.08 to 0.35, with a mean of 0.20±0.05 (mean +95% CoI) (Table 2). These estimates of current SPR are lower than the optimal values of 40%SPR, indicating recruitment overfishing in BSC fisheries in the NCJ. The recovery of the breeding stock is essential to enhance the recruitment of BSC in the Java Sea.

Reducing fishing mortality and increasing gear selectivity are critical for recovering the spawning stock biomass of *P. pelagicus*.

Table 2. Spawning potential ratios of *P. pelagicus* on the northern coast of Java using some variations in the asymptotic length and natural mortality

Methods of M	L_∞	M/K	SPR
Pauly (1980)	169	2.02	0.35
	178	2.02	0.28
	187	2.02	0.23
Alagaraja (1984)	169	1.54	0.24
	178	1.54	0.19
	187	1.54	0.15
Zhang and Megrey (2006)	169	0.98	0.13
	178	0.98	0.10
	187	0.98	0.08
Then et al. (2015)	169	1.58	0.25
	178	1.58	0.20
	187	1.58	0.16
Mean ± 95% of CoI			0.20 ± 0.05

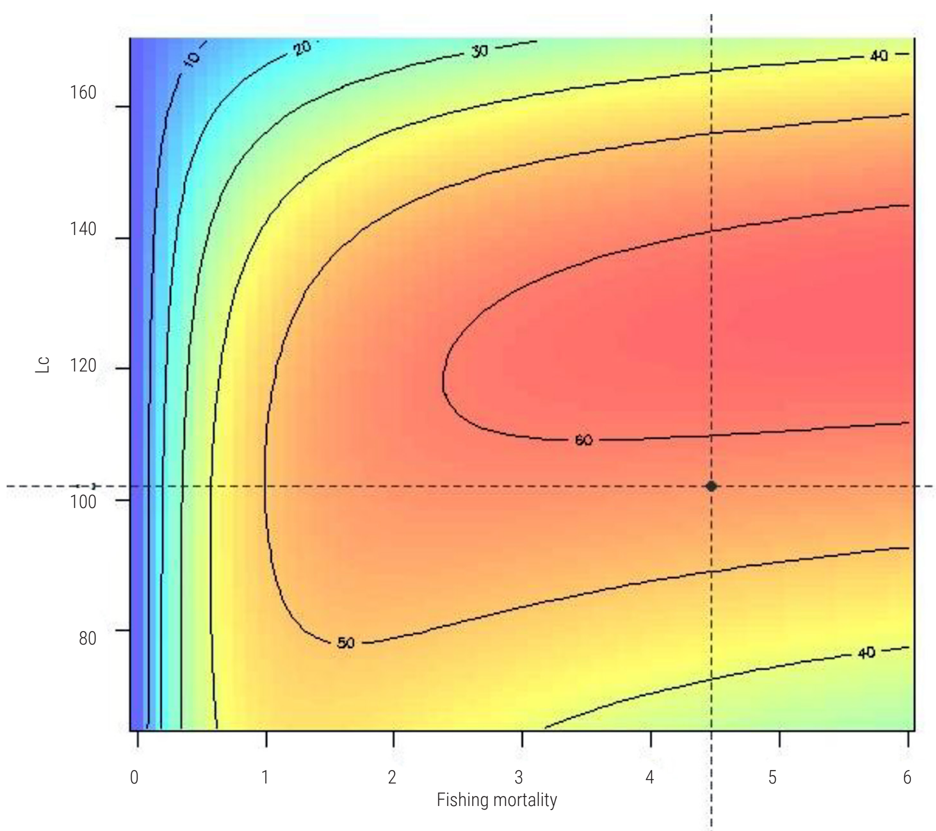

Fig. 7. Isopleth of yield per recruit analysis of *P. pelagicus* in the northern coast of Java. Circle dots represents the yield per recruit at the current fishing mortality and the current length at first capture

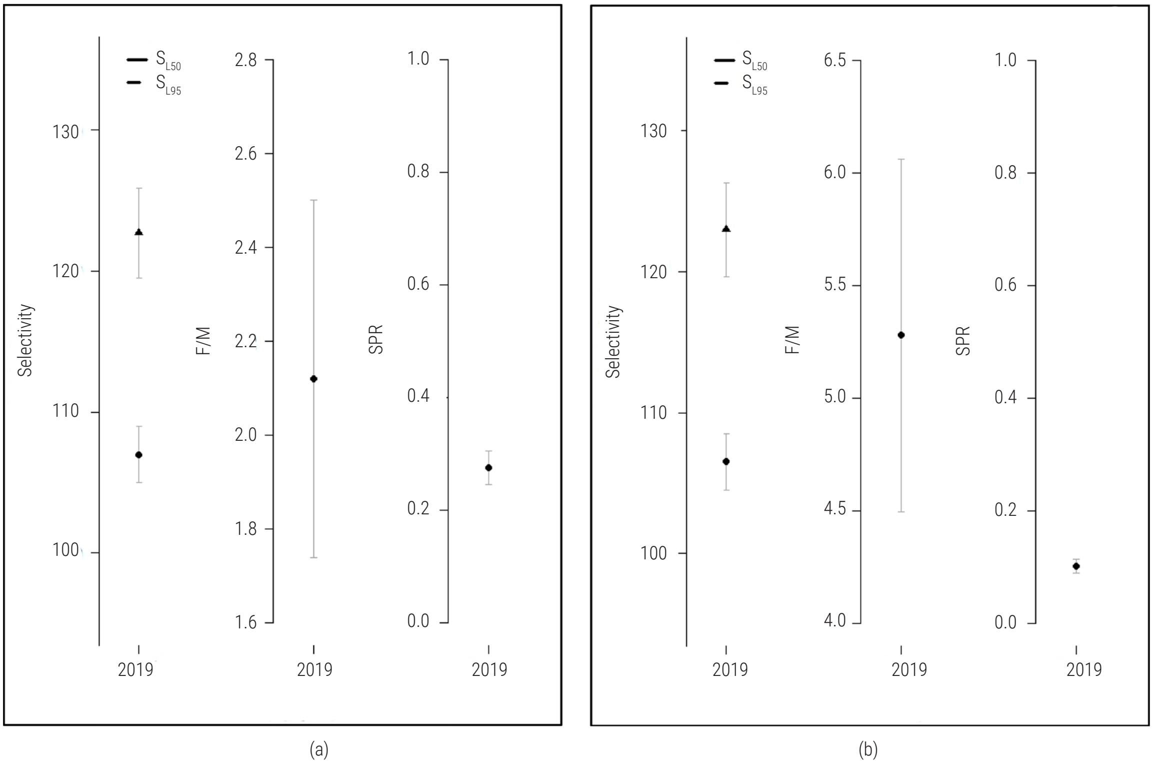

Fig. 8. F/M ratio and spawning potential ratios of *P. pelagicus* in the northern coast of Java using natural mortality from (a) Pauly's (1980) method and (b) Zhang and Megrey (2006) method (b). Results were analysed using LBSPR package in R program

Johnston *et al.* (2011) recommend limiting fishing efforts to enhance the depleted breeding stock of *P. pelagicus* in Western Australia. Nurdin *et al.* (2022) suggested a minimum legal size of 12 cm carapace width for BSC in the Spermonde Archipelago. Improving habitat conditions is also critical for the stock recovery of BSC. Mark *et al.* (2021) reported low chlorophyll-a levels and predation as factors hindering the stock recovery of BSC. Kunsook *et al.* (2014) suggested seagrass restoration to rebuild BSC populations in the Gulf of Thailand.

Without effective management measures, continued fishing mortality will hinder recruitment, leading to declining yields and economic loss. Therefore, implementing management measures is essential to increase the spawning stock biomass of *P. pelagicus* in the NCJ such as, reducing current efforts (fishing trips) by 37%, implementing seasonal closures from August to September in identified spawning areas, modifying fishing gear to increase the selectivity to 12 cm carapace width and restoring habitat in the Java Sea. Cooperation among government agencies, fishers, traders and fishery industries is critical to achieving the multiple objectives of sustainable blue swimming crab fisheries.

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