Life history and spawning potential of blue swimming crab *Portunus pelagicus* (Linnaeus, 1758) in Pamekasan, Madura Island, Indonesia

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Abstract. Blue swimming crab is one of Indonesia's most valuable marine crustaceans, experiencing high fishing pressures for export, which could lead to the depletion of stocks. Knowledge of blue swimming crab spawning potential is imperative for understanding the stock's status. This study aimed to estimate the spawning potential of blue swimming crab (*Portunus pelagicus*) based on their life history parameters. Fourteen thousand five hundred thirty-three crab samples were collected from fishers caught using the collapsible traps from January to December 2021 in Pamekasan. The biological data, including carapace width, weight, sex, and maturity level, were measured. Length-based spawning potential ratio method was used to estimate the spawning potential ratio. Results showed the growth parameters, CW_{∞}= 179.55 mm, K = 0.98 $year^{-1}$, and tmax=3 years. Size at first maturity was estimated at 102 mm carapace width, while the size at first capture was 112-121 mm. Egg-berried female crabs were observed throughout the year, with two distinguishable peaks occurring in Jan-Feb and Aug-Sep. The overall estimates of the SPR met the reference point limit. This study gave insights that the stock status of BSC in Pamekasan was not at risk of recruitment impairment, but management actions should be initiated for stock rebuilding.

Keywords: blue swimming crab, growth, LBSPR, maturity

1. Introduction

The blue swimming crab *Portunus pelagicus* (Linnaeus, 1758) is one of Indonesia's five most economically important fishery export commodities in Indonesia. The pasteurized crab meat for canned products was mainly exported to USA, which imports nearly 85% of Indonesia's blue swimming crabs [1], [2]. According to Ministerial KP No. 19/2022, the level of exploitation of blue swimming crabs across the Indonesian Fisheries Management Area (FMA) ranged from fully exploited to over-exploited [3].

Blue swimming crabs are widespread across the Indo-West Pacific regions, especially in sheltered and shallow coastal waters [4]. The main fishing grounds in Indonesia were observed in the northern Java Sea, Sumatera Island coasts, and Sulawesi Island coasts [5]. Although blue swimming crabs can swim, studies revealed that crab stocks' movement occurs in small-scale areas along the coast [6]. Previous studies observed variation in the life history characteristics of blue swimming crabs among sites [5],

[7]-[10]. Therefore, analyzing the life history characteristics at the specific location is very important to formulate effective management measures for sustainable fisheries management.

The stock assessment in the sub-tropical region mainly used aged-based biomass models that require population abundance, life history parameters, and catch and effort data, which are hard to acquire in data-limited fisheries. The length-based approach was frequently used for fish stock assessment in tropical waters because they lack otolith rings, making age estimation for blue swimming crabs was also challenging because of the molting and lack of hard body parts [11]. This study used the length-based spawning potential ratio (LBSPR) for estimating stock status in data-limited fisheries because it has few data requirements and a solid theoretical foundation [11], [12].

Our research study was in Pamekasan District, Madura Island, East Java province of Indonesia. The blue swimming crabs (known locally as *rajungan*) were a target species that contributed significantly to the economy of Madura Island. Nearly 250,000 people in Madura rely on the blue swimming crab for a living, including many local women who work as processors [13]. However, the heavy fishing pressures may lead to BSC stock depletion. To address the growing concerns about the sustainability of BSC fisheries, the Indonesian Blue Swimming Crab Association (APRI) join the Fisheries Improvement Project (FIP) [14]. The objectives of this study were to estimate the life history characteristics and potential spawning ratio of blue swimming crabs (*Portunus pelagicus*) in Pamekasan, Madura Island, Indonesia.

2. Methods

2.1. Study area

The study was conducted from January to December 2021 at Pamekasan, Madura Island, Indonesia. The crab fishing activities and landing sites were centered at Pagagan Village. Therefore, the area was chosen as sampling location. The crab samples were collected from local fishers who dominantly used the collapsible crab traps (known locally as *bubu*) as the fishing gear.

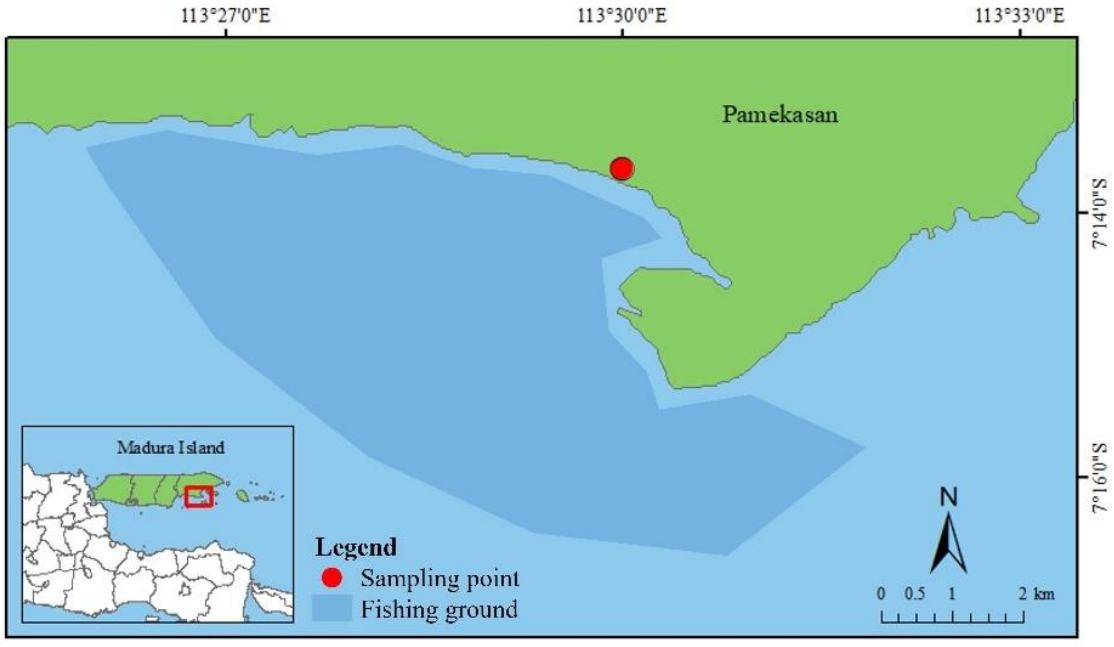
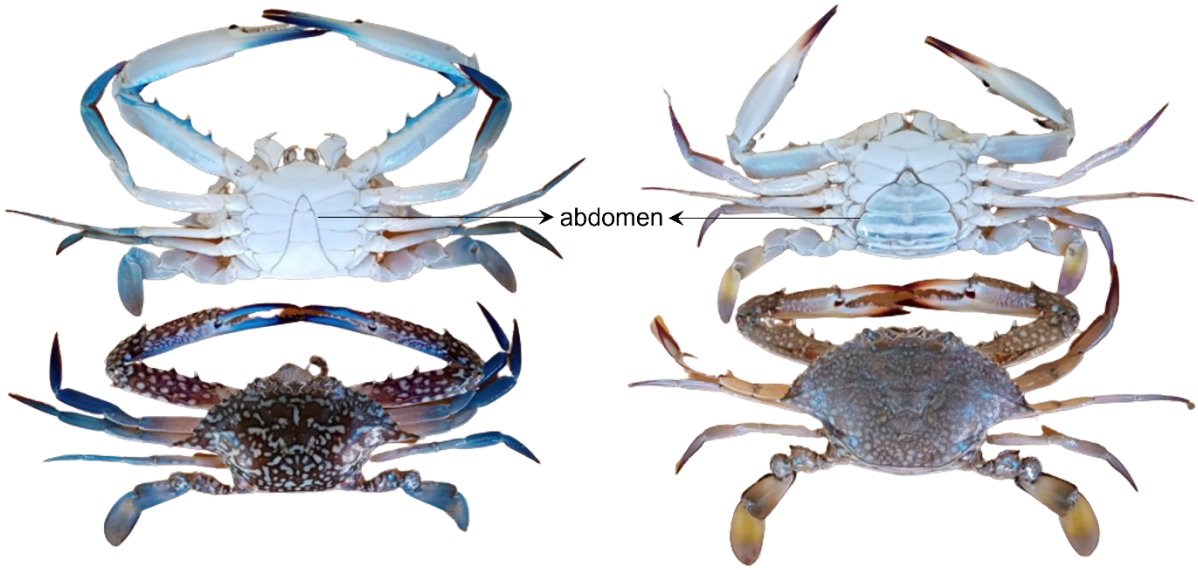


Figure 1. Sampling location of blue swimming crabs in Pamekasan, Madura Island.

2.2. Data collection

Sampling was carried out daily at landing sites with a total sample size of 14533 individual crabs during the study period in 2021. Biological variables were measured, including the carapace width (mm),

weight (g), and sexes (male/female). The carapace width of each sample was measured using a ruler with 0.1 mm accuracy, while the weight was determined using a digital scale with 0.1 g accuracy. The color and the shape of the abdomen were observed to distinguish the sex of the blue swimming crab (Figure 2). Male crabs have a dark-blue color on the carapace, legs, and claws, while female crabs have a mottled brown color. Besides, males have a narrow and inverted "T" shaped abdomen, while females have a broad and rounded abdomen, conical/oval shape [15,16]. The gonadal maturity stages of female crabs were also observed following [17].



a) Male crabs (b) Female crabs

Figure 2. Abdomen colors and shapes of blue swimming crabs (*Portunus pelagicus*).

2.3. Data analysis

2.3.1. Growth and mortality parameters

Growth parameters of *P. pelagicus* was determined using the Von Bertalanffy growth model plotted to the length frequency data [18]:

$$CW_t = CW_\infty \left(1 - \exp\left(-k(t - t_0)\right)\right) \quad (1)$$

The t_0 was calculated using the equation [19] as:

$$\log(-t_0) = -0.3922 - 0.275 \log CW_\infty - 1.038 \log k \quad (2)$$

where *CWt* is the carapace width at age t, CW_∞ is the asymptotic average maximum carapace width, k is the growth rate coefficient, t_0 is the theoretical age at which the carapace width is assumed as zero. According to [20], the maximum age of BSC (t_{max}) is equal to $\frac{3}{k} + t_0$.

The natural mortality (M) was estimated with Pauly's empirical formula [21]:

$$\log M = -0.0066 - 0.279 \log CW_\infty + 0.6543 \log k + 0.4634 \log T \quad (3)$$

where T is the average sea surface temperature, about 29°C for Pamekasan Water. The growth and mortality parameters was estimated using ELEFAN 1 in FISAT II package.

2.3.2. Size at first maturity and size at first capture

The carapace width at first maturity for BSC (CW_m) was determined according to the relationship between carapace width frequency and proportion of matured female crabs, fitted on a logistic curve as:

$$P = \frac{1}{(1+\exp[-r(CW-CW_m)])} \quad (4)$$

where CW_m is the size of maturity at which 50% (CW_{m50}) and 95% (CW_{95}) of a crab's population is mature, r is the slope of the curve, and *P* is the proportion of matured females [22].

The size at first capture (SL) was also determined based on the relation between carapace width and frequency, fitted on logistic curve with the below equation:

$$SL = \frac{1}{1+(S_1-S_2L)} \quad (5)$$

where S_1 and S_2 are the intercept and slope of regression, *SL* is logistic curve, and SL_{50} at which 50% of population are vulnerable to being caught, is determined by $\frac{S1}{S2}$ [23].

2.3.3. Spawning potential ratio

The spawning potential ratio (SPR) is the proportion of unfished/natural reproductive production in a fishing-pressured population [24]. Estimates of SPR could be used as an indicator of stock status in data-limited fisheries [11]. For management purposes, $SPR_{20\%}$ is accepted as the biological limit reference point below which stocks risk recruitment impairment, while $SPR_{30\%}$ is widely accepted as a target level for long-term management [12]. The length-based spawning potential ratio (LBSPR) was applied to carapace width composition data. The LBSPR model requires input parameters: the mean asymptotic length ($L\infty$), the M/K ratio, and size at first maturity (CW_{50} and CW_{95}). LBSPR assessment was performed using the LBSPR web-based user interface to estimate the deterministic SPR at *http://barefootecologist.com.au/lbspr.html*. The uncertainty of LBSPR estimation was also considered through stochastic SPR, given the growth and mortality parameters (i.e. $L\infty$, k, and M) may cause the uncertainty. We used a bootstrap where 1000 iterations were run in the LBSPR package in R studio. Prior distributions for M/k with CV 0.2 and $L\infty$ with CV 0.1 were specified [25].

3. Results

3.1. Size and sex composition of blue swimming crabs

Size of blue swimming crabs (BSC) caught in Pamekasan, Madura Island, varied monthly (Table 1). Male BSC carapace width ranged from 89 mm to 165 mm, with an average value of 116.5 mm, and their weight ranged between 45.4 g and 400 g, and an average value of 127.1 g. Female BSC carapace width ranged from 80 mm to 164 mm (average of 118.3 mm), and their weight ranged between 42.4 g and 311.7 g (average of 120.7 g). Sizes of BSC caught in August and September were relatively bigger than those in other months.

Table 1. Size composition of male and female blue swimming crabs in Pamekasan, Madura Island, during the study period in 2021.

Month	Sex	Sample Size (ind)	Sex Ratio	Carapace Width (mm)			Weight (g)		
				min	max	mean±sd	min	max	mean±sd
January	Male	524	1:1.4	94	152	110.0 ± 9.4	52.7	288.0	100.9 ± 34.6
	Female	717		95	155	118.6 ± 12.4	53.4	275.2	123.9 ± 45.6
February	Male	486	1:1.6	94	150	113.9 ± 10.3	57.2	299.8	114.9 ± 39.1
	Female	757		97	155	119.4 ± 11.7	51.6	288.3	124.7 ± 45.1
March	Male	444	1:1.8	93	145	114.7 ± 9.9	53.4	242.3	115.0 ± 35.1
	Female	779		95	147	115.0 ± 9.9	53.1	281.1	108.0 ± 33.5
April	Male	675	1:1.2	90	151	116.8 ± 11.6	50.0	268.2	126.9 ± 44.3
	Female	834		80	151	115.4 ± 10.4	51.8	268.7	109.2 ± 32.6

Month	Sex	Sample Size (ind)	Sex Ratio	Carapace Width (mm)			Weight (g)		
				min	max	mean±sd	min	max	mean±sd
May	Male	648	1:1.1	92	155	119.9 ± 11.9	54.3	290.2	139.5 ± 48.3
	Female	711		82	148	116.1 ± 10.3	50.7	219.2	110.1 ± 30.2
June	Male	809	1:1.1	93	155	118.6 ± 12.2	53.6	312.3	138.3 ± 50.5
	Female	912		89	158	118.1 ± 11.2	55.6	267.7	118.8 ± 36.1
July	Male	577	1:1.5	93	165	119.3 ± 11.0	58.7	400.0	139.4 ± 45.9
	Female	857		95	151	119.5 ± 10.5	54.9	267.7	122.6 ± 35.6
August	Male	519	1:1.6	89	149	119.3 ± 11.5	58.4	285.9	140.5 ± 45.2
	Female	823		98	158	122.7 ± 11.0	63.1	267.8	135.8 ± 38.9
September	Male	377	1:1.9	92	151	118.9 ± 11.2	62.5	299.3	141.6 ± 45.1
	Female	710		92	164	122.1 ± 10.3	50.5	311.7	138.0 ± 36.5
October	Male	274	1:1.5	90	157	116.5 ± 11. 6	51.4	291.8	127.8 ± 46.4
	Female	416		87	150	117.7 ± 10.8	42.4	248.6	120.9 ± 35.3
November	Male	179	1:1.4	89	140	113.8 ± 9.6	50.8	250.5	112.2 ± 33.9
	Female	257		92	141	114.0 ± 9.2	49.5	230.3	110.3 ± 29.2
December	Male	533	1:1.3	89	140	112.0 ± 9.3	45.4	246.9	105.7 ± 31.9
	Female	715		93	153	116.8 ± 11.3	50.1	267.8	116.9 ± 39.7
Total		14533	1:1.4						

The overall sex ratio showed that females were significantly more dominant than male crabs (ratio of 1:1.4; X^2=410.7; df=1; α=0.05; critical value=3.841). Over the 12 months study period, the percentage of undersized crabs (<10 cm) captured by fishers was relatively low, less than 5%. The percentages of egg-berried females ranged from 2.2% to 8.3%, with the highest percentage observed in Jan-Feb and Aug-Sept (Figure 3).

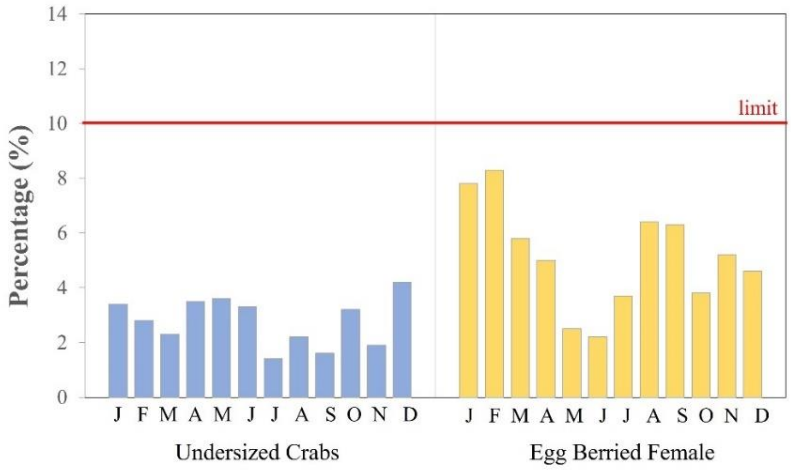


Figure 3. Percentage of undersized crabs and egg berried females caught in Pamekasan, Madura Island during the study period.

3.2. Growth and mortality parameters estimation

The blue swimming crab growth based on monthly carapace width frequency distribution is shown in Figure 4. Table 2 shows the estimates of mean asymptotic length for BSC in Pamekasan was at 179.55 mm CW, the growth rate (k) was 0.98 year^{-1}, and the maximum age can reach up to 3 years.

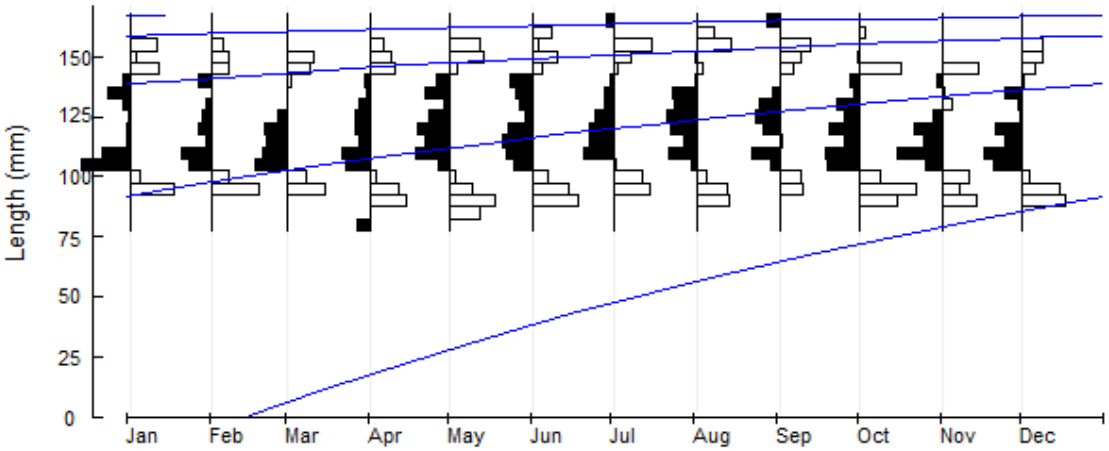


Figure 4. Carapace width frequency distribution with Von Bertalanfyy growth model of the blue swimming crab (*Portunus pelagicus*) in Pamekasan, Madura Island.

Table 2. Estimates of growth and mortality parameter estimates for the blue swimming crabs in Pamekasan, Madura Island (sex combined), and other sites (from literature).

No	Sites	L_∞ (mm)	k ($year^{-1}$)	t_{max} (year)	M ($year^{-1}$)	M/K Ratio	Reference
1	Pamekasan	179.5	0.98	3.0	1.44	1.469	This study
2	Cirebon	168.6	1.04	2.86	n.a	1.392	[5]
3	Rembang	171.4	1.5	n.a	n.a	n.a	[5]
4	Pati	187	1.13	n.a	1.18	1.268	[7]
5	Lasongko Bay	173	0.68	n.a	0.86	1.268	[8]
6	Karnakata, India	204	0.97	2.5	1.9	1.959	[9]
7	Gulf of Thailand	167	1.13	n.a	1.7	1.504	[10]

3.3. Size at first maturity and size at first capture

The carapace width at maturity was estimated at 102 mm (CWm_{50}) and 116 mm (CW_{95}) (Figure 5). Using the Von Bertalanffy growth model, the blue swimming crabs in Pamekasan could reach the CW_{50} at approximately 9 months old. The size at first capture or the size selectivity (SL_{50}) ranged from 112 mm to 121 mm, considerably bigger than the maturity size (102 mm) in all months (Figure 6). The highest estimate of SL_{50} was observed in Aug-Sep.

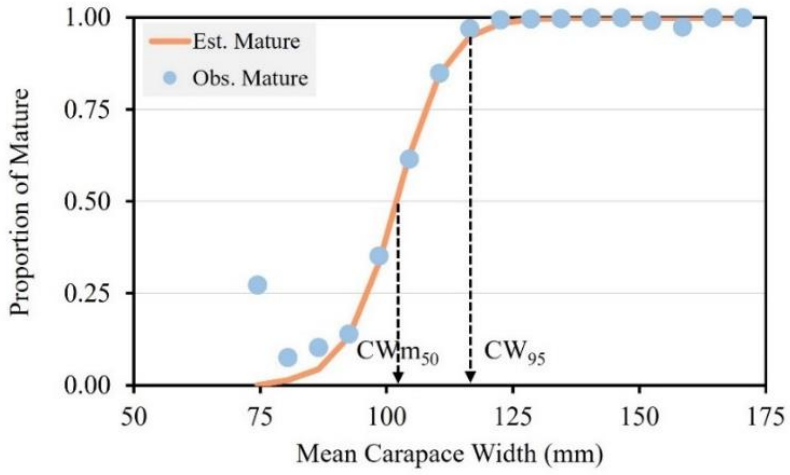


Figure 5. Carapace width-maturity logistic curve of blue swimming crabs (*Portunus pelagicus*) in Pamekasan, Madura Island. The dashed lines represent the carapace width at which 50% and 95% of individuals reach maturity.

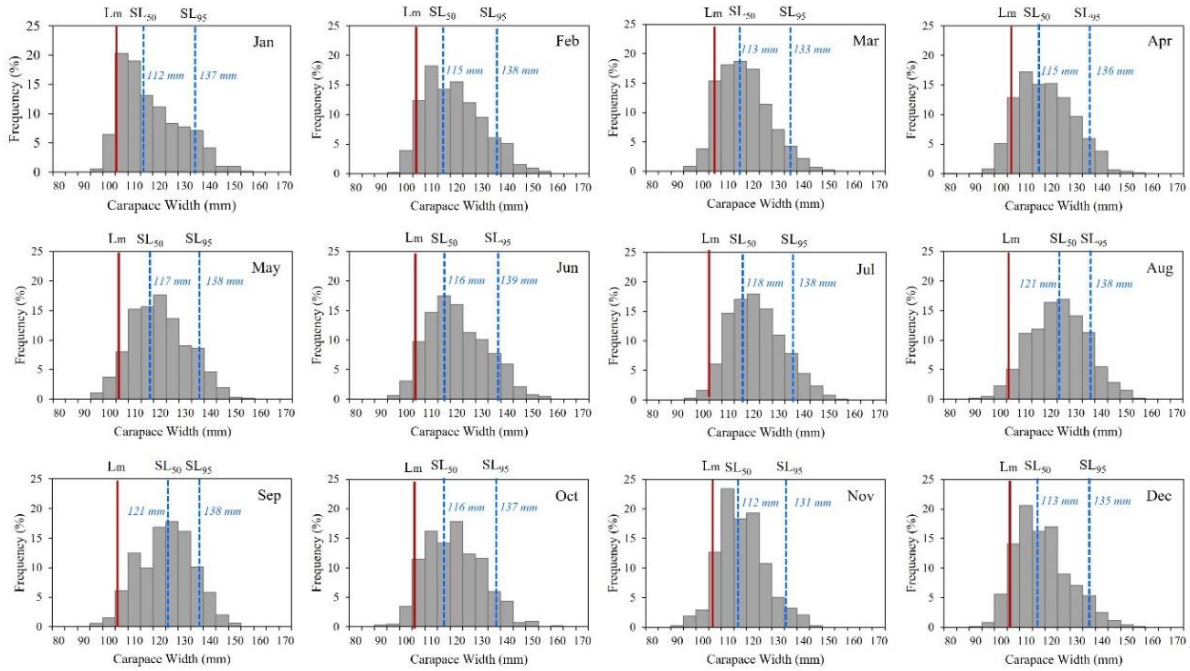


Figure 6. The size selectivity of blue swimming crab (*Portunus pelagicus*) in Pamekasan, Madura Island. The blue dashed lines denoted the length at which 50% and 95% of crabs are vulnerable to be captured (SL_{50} and SL_{95}).

3.4. Spawning Potential Ratio (SPR)

The estimates of spawning potential ratio using the deterministic model ranged between 17% and 35%, an average 24% (Figure 7). Meanwhile, the stochastic SPR that considered the uncertainty of growth parameters in Figure 8 showed the median values ranged between 18% and 31% and an average of 26% (Figure 8). Figure 7 and 8 showed a monthly variation of SPR. The higher SPR was observed in Jan-Feb and Aug-Sep, while the lowest SPR was observed in Nov. The overall SPR values met the limit reference point ($SPR_{20\%}$), at which spawning biomass should not be allowed to fall below this point. Otherwise, recruitment potential will be impaired. In several months, the SPR values have achieved the target reference point $SPR_{30\%}$, at which the stock status is maintained. Through deterministic and stochastic SPR, the blue swimming crab stock status in Pamekasan was in good condition.

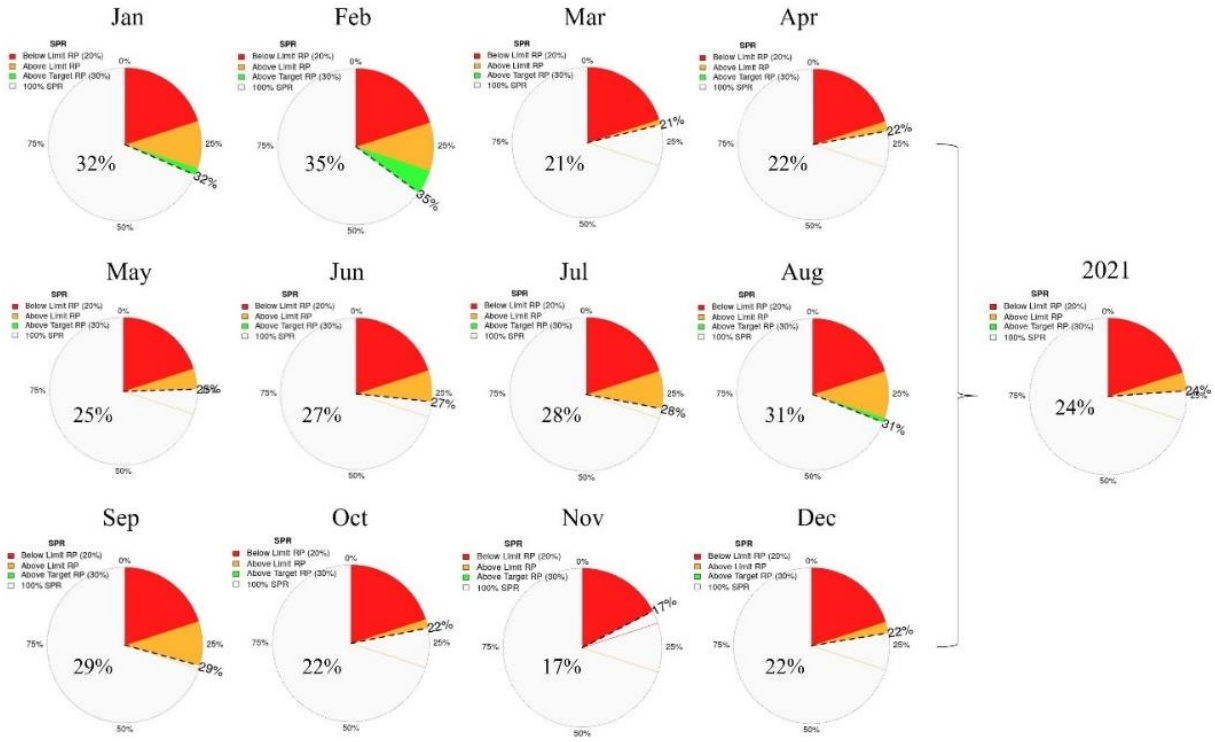


Figure 7. The deterministic SPR of blue swimming crabs (*Portunus pelagicus*) in Pamekasan, Madura Island during the study period.

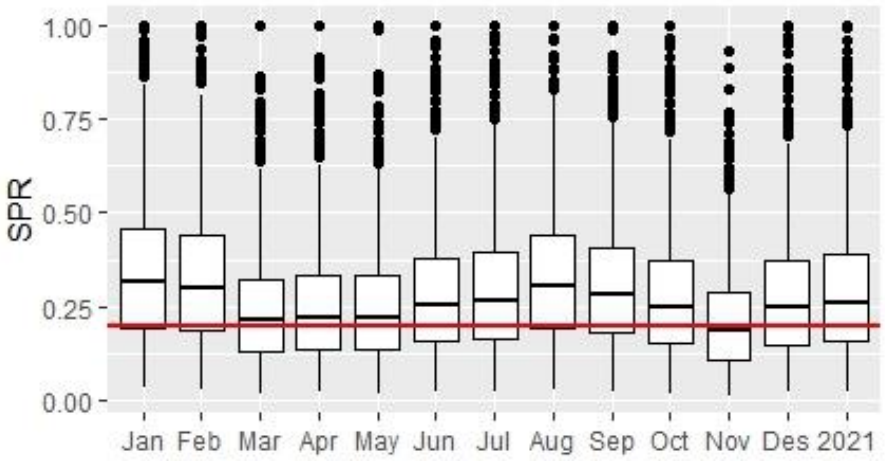


Figure 8. The stochastic SPR of blue swimming crabs (*Portunus pelagicus*) in Pamekasan, Madura Island during the study period in 2021.

4. Discussion

This study observed the size variation of blue swimming crabs throughout the year. BSC carapace width caught in Pamekasan ranged from 80 mm to 165 mm. Several studies also showed varying crabs size, such as in Bone (32.5-147.5 mm) [26], Kwandang (70-175 mm) [27], Jakarta Bay (60-150 mm) [28], Demak (58.8-168.4 mm) [5]. The size variation could be related to the fishing gear selectivity and fishing pressures. Collapsible traps dominantly caught the blue swimming crabs in Pamekasan. The average size of BSC catch in Pamekasan was approximately 110-120 mm CW, compliant with the Ministerial Decree of Marine Affairs and Fisheries No. 17/2021 that stated a size limit of BSC was 10

cm carapace width, as well as the banning of egg berried females. The study by [29] also observed that the catch size from traps mostly met the regulation compared to the catch size from gillnets and mini trawls. The selective and passive fishing gear was the collapsible trap targeting blue swimming crabs. Most crabs were still alive inside the traps, thus enabling fishers to release the undersized crabs and egg berried females back into the water.

The estimated growth parameters showed the blue swimming crabs in Pamekasan can reach asymptotic length ($L\infty$) at 179.55 mm CW, growth rate (k) about 0.98 year^{-1}, and lifespan (t_{max}) about 3 years. There was only a slight difference between the growth parameter estimates of this study and others [5], [7]-[10]. Other studies reported variation in growth parameters of blue swimming crabs (Table 4), as the $L\infty$ ranged from 167 mm to 204 mm, k value ranged from 0.68 year^{-1} to 1.1 year^{-1}, and t_{max} around 2.5 to 3 years. The maximum age of crab species P. pelagicus in the unexploited fishery could reach 3 to 4 years [30]. The life cycle of blue swimming crabs begins with several larval stages (~15-45 days) before transforming into the crab phase. According to [4], blue swimming crabs undergo four zoeal stages as plankton. Larval can drift up to 80 km offshore. The larva grows and changes shape into the megalopa stage for several days, then transforms into a crab instar. The crabs resemble the adult form at the instar stage and live as benthic organisms. About five to six months after hatching, the instar grows and molts several times until it reaches the juvenile stages with a carapace width of about 60 mm. The juvenile then grows, and once moulting it reaches full maturity.

The maturity carapace width of female crabs in Pamekasan was estimated at about 102 mm CW. This study also found that the proportion of females was higher than males. Other studies also reported the carapace width at first maturity was ~100 mm, such as in the Gulf of Thailand (106 mm) [10], Leschenault Estuary (98 mm) [6], East Lampung (103 mm) [31], Java Sea (101.5 mm) [5], Kwandang (117 mm) [27]. This study found that the size at first maturity could be attained within 9 months. The study by [6] in Koombana Bay showed that most crabs reach their first maturity and spawn when they are approximately one year ago. A higher ratio of female crabs was also found in Koombana Bay, which might have related to the tendency of female crabs to move out of the estuary once they reach maturity.

Our study shows that the size at first capture of *Portunus pelagicus* in Pamekasan was larger than at first maturity, indicating the crabs' vulnerability to being caught has already spawned. [11] found that the larger the selectivity relative to the size of maturity, the greater the spawning potential could be protected. The blue swimming crab stocks are prone to depletion when the size of selectivity is below or around the size of maturity. The size of the first capture in Pamekasan with collapsible traps was about 112 mm to 121 mm, which is much higher than the size of the first capture by other fishing gears such as mini bottom trawl in Demak (105.43 mm), gillnet in Jakarta (93.54 mm), dredge net in Cirebon (99.38 mm). Gear type selection in BSC fisheries is critical for understanding the stock status and management measures [5].

The estimated SPR generally met the limit reference point. These results were attributed to the larger size at first capture than the size at first maturity. Conservation and management measures should be implemented to facilitate stock rebuilding if the stock drops below the limit reference point. Research by [32] suggested that sustainable fisheries could be achieved by setting the minimum size limits at 20% larger than Lm. To improve the sustainable level of spawning potential, the Indonesian Blue Swimming Crab Association (APRI) recently conducted pilot projects in Pamekasan and other sites, including the use of nets with larger mesh size (4.5 inches), collapsible traps with escape vents to allow undersized crabs to exit. A local protected area was also designated to safeguard the critical habitats, e.g., spawning and nursery grounds of adults and juvenile blue swimming crabs [13]. It is hoped that these approaches could improve the size selectivity and spawning potential and minimize bycatch issues.

5. Conclusion

Research on the key life history characteristics (i.e., growth and maturity) of blue swimming crabs is important to understand the population dynamic and perform stock assessments for the BSC fishery. This study found that the blue swimming crabs in Pamekasan, Madura Island, could reach the sexual maturity stage at nine months old and maximum age of 3 years, indicating the BSC is a short-lived and rapid-grow Crustacean. The spawning potential ratio mostly met the biological limit reference point, attributed to the larger size at first capture than the size at first maturity, which means the crabs were captured after maturing and spawning. Based on the findings of this study, the stock assessment of blue swimming crabs in Indonesia could be significantly improved, with more concerns about the species' life history at a specific location.

Acknowledgments

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