Spawning and Reproductive Potential of Blue Swimming Crab (Portunus pelagicus) at Spermonde Archipelago, Indonesia

Muh. Saleh Nurdin1*, Amanda Pricella Putri2, Dewi Yanuarita Satari3, Riris Yuli Valentine4, Fauziah Azmi5, Teuku Fadlon Haser6

INTRODUCTION

Blue swimming crabs (Portunus pelagicus Linnaeus, 1758) is a renewable fishery resource with high market demand and creates employment opportunities for coastal community (Anand & Soundarapandian, 2011; Watanabe et al., 2014; De La Cruz, 2015; Ihsan et al., 2015; Kembaren et al., 2018). The capture blue swimming crabs (BSC) in Spermonde Archipelago, Indonesia, shows a decrease in stock that overlaps with an increase in fishing activities. This study aimed to analyze the ratio of spawning potential (SPR), reproductive potential, and reproductive productivity of BSCs taken from the Spermonde Islands. Spawning potential was analyzed using SPR, while reproductive potential analysis used the relative proportion of data between female, berried female and the average fecundity of each class size. The results showed that the BSC in Spermonde were growth overfishing and recruitment overfishing. The SPR of the BSC was estimated to be 7%, below the biological reference point. The highest reproductive potential index of berried females occurred in the group with a carapace width of 111-120 mm which contributed 36.84% of the total egg production. The value of reproductive productivity was 1.35 indicating a productive population. Current legislation allows the capture of BSCs with carapace sizes larger than 100 mm. Based on the data of this study, this size limit has the potential to eliminate 65.92% of the total egg production in the Spermonde Islands. To ensure the sustainability of BSCs in the Spermonde Islands, it is necessary to limit size by capturing BSCs >120 mm to protect the berried female and increase total egg production.

Keywords: minimum legal size, overfishing, fishery management
monde Island occurs throughout the year with a peak in June to September which coincides with dry seasons (Ihsan et al., 2014; Wiyono & Ihsan, 2015; Nurdin et al., 2019). The common fishing gears utilized are gill net and traps although the use of gillnets are rapidly declined because it is less productive (Nurdin et al., 2020).

BSC is the third largest fish commodity exported from Indonesia after tuna and shrimps (Hutapea et al., 2019; Sara et al., 2019), valued at US$ 246.14 million in 2015 (Muawanah et al., 2017). Yet, the largest proportion of the values comes from fishing, resulting in stock declines in several fishing grounds in Indonesia (Ernawati et al., 2014; Sara et al., 2017; Macale & Nieves, 2019) including in Spermonde Islands (Nurdin et al., 2015; Adam et al., 2016). The stock reduction can be resulting in both catch quantity, genetic diversity, and the shifting of fishing ground into the deeper area (Juwana et al., 2009; Sussanto et al., 2019; Hidayani et al., 2020).

Management efforts must be established to sustain open-access fishery resources such as BSC (Lai et al., 2010; Muawanah et al., 2017). This entails best scientific data and information in order to depict exploitation level of BSC to support its management. However, the obstacle faced by the BSC fishery in the Spermonde Islands is the unavailability of data and information regarding the spawning potential ratio (SPR) and reproductive potential. This information is fundamental in determining the exploitation status of BSC resources and regulating the minimum legal size (MLS).

Spawning potential ratio (SPR) is an estimation used to determine the stock status when data is poor and uncertain, especially for small-scale fisheries such as BSC (Hor-dyk et al., 2015; Prince et al., 2020). While population reproductive potential index and BSC reproductive productivity are used to determine the minimum legal size (MLS) (Babu et al., 2006; Yoda & Yoneda, 2009; Johnson et al., 2010). Minimum legal size is a very important tool in fishery management. It is required by the FAO standard operation procedure for fishery (Sunarto et al., 2010; Nurdin et al., 2016a; Achmad et al., 2020; Haser et al., 2022). This research aimed to analyze the SPR and reproductive potential of BSC in Spermonde Islands to evaluate current MLS legislation of BSC fishing.

**MATERIALS AND METHODS**

The research was conducted from February to November 2016 in Spermonde Archipelago (Salemo, Sabangko, Sagara, and Saugi Island) (Figure 1). These four islands are the largest BSC-producing areas in the Spermonde Archipelago. Blue swimming crab (BSC) samplings were done monthly using gillnet, danish seine, and traps. The total samples of BSC collected consisted of 1,195 individuals. Samples obtained from the field were transported to Aquatic Productivity Laboratory, Universitas Hasanuddin. The biological parameters consisted of carapace width, weight, maturity stage, and fecundity. Carapace width was measured using a digital caliper with 0.1 mm accuracy. Body weight and gonadal weight were weighed using a digital scale with 0.001 g accuracy. Each gonad was cut into three sub samples and weighed to obtain partial weight. The sub samples were immersed in Gilson solution for 24 hours to dissolve eggs’ outer membranes to allow easier egg counting.

To determine the size of the first matu-
rity of the gonads, the level of gonad maturity was measured at the first hand by observing the BSC gonad sample visually. The carapace was opened starting from the posterior and moved organs that cover the gonads just below the backside. The criteria for the gonad maturity stage (GMS) referred to the modified BSC female GMS classification from Castiglioni & Negreiros-Fransozo (2006): (1) immature phase: the ovary is not yet developed, the gonads are thinly elongated, located to the back on the other side of the feeding canal and completely covered by thin peritoneum, slightly soft pale yellow; (2) the maturation phase: the volume of the ovary is bigger, almost filling the entire chest (cephalothorax) and the color is getting more yellow. The eggs are clearly visible but are still covered by oil glands. The size is wider so that it presses the hepatopancreas; (3) mature phase: the egg granules are getting bigger and are clearly visible in orange color and can easily be separated because the oil layer that surrounds them has been reduced; and (4) spent phase: the ovaries shrink back. There are many eggs on the badomen. There are eggs left around the hepatopancreas that are not released during spawning that look like the maturing phase.

Figure 1. Study site in Spermonde Islands

Data Analysis

Spawning Potential Ratio

In an SPR study, the data required included carapace width and gonadal maturity. Analysis of carapace width will provide information on Bartalanffy growth parameters ($K$, $L_\infty$, $t_0$) and size at first captured. Gonad Maturity Stage (GMS) analysis will produce information on size at first maturity ($L_{m50}$) (Hordyk et al., 2015; Kembaren & Ernawati, 2015; Wujdi & Wudianto, 2015; Permatahati et al., 2020; Suman et al., 2020). Previous study has been done by researchers concerning input parameters required for BSC’s SPR study in Spermonde Islands using different analysis (Table 1). However, those studies only covered the study area partially. Therefore, here we updated the data by covering...
more area and employed Response Surface analysis in ELEFAN I which is integrated with FISAT II software.

Size at first maturity ($L_{m50}$) of BSC was analyzed using logistic function (King, 1995), and the size at first capture ($SL_{50}$) of BSC was analyzed using the log function as described by Sparre & Venema (1998).

The estimation of $t_0$ of BSC was calculated using Pauly formula (Pauly, 1980), and natural mortality rate ($M$) of BSC was estimated using Rickhter and Efano (Sparre & Venema, 1998). SPR was computed with input parameters which includes $M/k$ and $Lm/L\infty$ (Hordyk et al., 2015; Prince et al., 2020). SPR was considered as the ratio of spawning stock biomass per recruit in the exploited stock ($SSBR_{fished}$) with the spawning stock biomass per recruit in the absence of fishing ($SSBR_{unfished}$) as follows:

$$SPR = \frac{SSBR_{fished}}{SSBR_{unfished}}$$

SPR value was grouped into three categories which are: (1) <20% (over exploited); (2) 20-25% (fully exploited) and; (3) >30-50% (under fishing) (Prince, 2014).

Reproductive Potential

Egg samples were counted under the microscope and fecundity rate was determined following gravimetry method:

$$F = \frac{Bg}{Bs}$$

Where:
- $B_g = $ Gonad weight (g)
- $B_s = $ Weight for the sub samples of gonad (g).

The relationship of carapace width, body weight, gonad weight and fecundity was analyzed using multiple linear regression (Zar, 2010) as follows:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3$$

Where:
- $Y = $ Total fecundity
- $X_1 = $ Carapace width
- $X_2 = $ Body weight
- $X_3 = $ Gonad weight

The Index of reproductive potential (IRP) was computed using data on female relative proportion, berried female (BEF) and average fecundity for each class size. IRP computation refers to a method used by Sukumar & Neelakantan (1997); Johnson et al. (2010); Zairion et al. (2015) as the equation below:

$$IRP = \frac{(A_i \times B_i \times C_i)}{D}$$

Where:
- $A_i = $ Proportion of i class size in a group containing all females across size classes that contained BEF;
- $B_i = $ Proportion of BEF in i class size
- $C_i = $ Average fecundity at i class size and
- $D = $ Constant (148.34) at class size 91-100 mm as standard index with the value of 100.
RESULTS AND DISCUSSION

Spawning Potential Ratio

Coral conditions in Suaka Alam Perai-ran PData analysis revealed that the size at first capture (SL_{50}) was 80.53 mm, which is smaller than the size at first maturity (L_{50}) 103.99 mm (Figure 2). These results indicated that most of BSC captured during the sampling period have not attained sexual maturity. Analysis of growth and mortality parameters results in the value of L_{\infty}, K, and M were 159.75 mm, 1.03/year^{-1}, and 0.83/year^{-1} respectively.

The spawning Potential Ratio (SPR) estimation of BSC was calculated to be 7% when ratios of F/M and M/k were 3.43 and 0.81 (Table 2). The value of the SPR was far below the biological limit reference point (20%) (Prince, 2014). Accordingly, the population falls into the overexploitation category. This low SPR estimation owes to the value of SL_{50} which is smaller than L_{50} (67% of total BSC captured within the population) that causes growth overfishing. The figure of estimated SPR within this study suggests that only 7% of female BSCs (spawner) can spawn, therefore it also indicates recruitment overfishing.

Mortality due to fishing occurs more than three folds natural mortality (F/M = 3.43). The high ratio of F/M indicates that the area is under very high fishing pressure (Prince et al., 2020). BSC fishery in Sper-
monde Islands has been experiencing growth and recruitment overfishing. According to Adam et al. (2016), BSC exploitation in the islands increased from 54.09% to 85% during the period of 2012 – 2014 and it has reached its maximum limit. Fishermen use 400 – 600 bubi (traps) in only one trip while gillnets used in fishing can reach 1,000 – 1,500 m length (Nurdin et al., 2020). This condition is worsened by the low size at first capture and MLS which obstructs recruitment and results in stock declines (Chande & Mgaya, 2004; Johnston et al., 2011).

The BSC’s SPR in Spermonde Islands is considerably low compared to other fishing grounds in Indonesia. For example, BSC’s SPR in Tanah Laut was reported to be 11.1% (Suman et al., 2020), Kasiputeh 13% (Prince, 2014), and Java Sea 15% (Ernawati et al., 2017). However, it is slightly higher when compared with the SPR in Belitung Island which was only 5% (Ernawati et al., 2015). This condition indicates that BSC’s populations in Indonesian waters are over-exploited.

Table 2. Estimated Spawning Potential Ratio

<table>
<thead>
<tr>
<th>SL&lt;sub&gt;50&lt;/sub&gt;</th>
<th>SL&lt;sub&gt;95&lt;/sub&gt;</th>
<th>F/M</th>
<th>M/K</th>
<th>SPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>80.53</td>
<td>103.7</td>
<td>3.43</td>
<td>0.81</td>
<td>7</td>
</tr>
</tbody>
</table>

Reproductive Potential

Most berried female BSCs were found in the group of class-sized 111-120 mm. Egg mass index was found to be higher as body size bigger, except for those in the class of 111-120 mm (Table 3). Multiple regression analysis describes the relationship between fecundity, carapace width, and gonadal weight following the model below:

\[ Y = 20352.211 + 1973.899x_1 + 1734.836x_2 + 47339.950x_3 \]

giving medium coefficient determination \( R^2 = 0.54 \).

Research results show that BSC fecundity was increasing as gonadal weight increased. It means that gonadal size is proportional to fecundity value (Hamid et al., 2015).
Still according to Hamid et al. (2015) gonadal weight is the best indicator in fecundity estimation of BSC using linear regression. IRP estimation of the BEF range between 36.39 - 795.75. The lowest IRP presents in group class sized 111 – 120 mm (IRP = 795.75) (Table 4). This group has the highest number of BEF (36.84%) and it is estimated to produce 38.83% of total egg production with productivity estimation of 1.35.

Size-based management strategies or catch control rules based on Minister Decree No. 1, 2015, Minister Decree No. 56, 2016, and Minister Decree No. 12, 2020 as a reference point (limit reference point) is inadequate to be applied to BSC fisheries in the Spermonde Islands. This reference for MLS potentially removes BEF from group sizes 100 - 110 mm and 111-120 mm which together constitute 57.88% of total BEF and contribute to 65.92% of total egg production in Spermonde Islands. This great proportion of loss will further suppress recruitment to the BSCs stock (Johnson et al., 2010) in Spermonde.

The reproductive productivity value of this research is still within the intervals of other previous studies which ranged from 0.01-2.78 (Table 5). The highest value was found in Mangalore (2.78) (Babu et al., 2006) which occurred to the class size of 110-120 mm which is relatively similar to the class size possessing the highest reproductive productivity in this study. The lowest value was found in East Lampung (0.01) which occurs to the class size of 111-115.99 mm (Zairion et al., 2015).

<table>
<thead>
<tr>
<th>Carapace width (mm)</th>
<th>Body weight (g)</th>
<th>Gonadal Weight (g)</th>
<th>Fecundity</th>
<th>Egg Mass Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>91-100</td>
<td>60.42±1.08</td>
<td>6.59±2.94</td>
<td>1,371,369±453,278</td>
<td>10.91</td>
</tr>
<tr>
<td>101-110</td>
<td>78.88±11.83</td>
<td>10.39±3.48</td>
<td>1,300,914±401,793</td>
<td>13.17</td>
</tr>
<tr>
<td>111-120</td>
<td>99.65±8.85</td>
<td>13.90±3.31</td>
<td>1,324,800±405,330</td>
<td>13.95</td>
</tr>
<tr>
<td>121-130</td>
<td>113.28±10.06</td>
<td>17.18±5.43</td>
<td>1,335,163±275,434</td>
<td>15.17</td>
</tr>
<tr>
<td>131-140</td>
<td>162.22±58.24</td>
<td>26.33±17.10</td>
<td>1,743,750±351,503</td>
<td>16.23</td>
</tr>
</tbody>
</table>

Table 3. Mean of body weight, egg weight, fecundity and egg mass index based on body size class berried female BSC

<table>
<thead>
<tr>
<th>Description</th>
<th>Size Class (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of captured females</td>
<td>13.73 30.07 28.76 21.57 5.88</td>
</tr>
<tr>
<td>Proportion of berried female</td>
<td>7.89 21.05 36.84 28.95 5.26</td>
</tr>
<tr>
<td>Average of fecundity potential</td>
<td>13.71 13.01 11.14 13.35 17.44</td>
</tr>
<tr>
<td>Index of reproductive potential</td>
<td>100 555.09 795.75 561.96 36.39</td>
</tr>
<tr>
<td>Proportion of egg production</td>
<td>4.89 27.09 38.83 27.42 1.78</td>
</tr>
<tr>
<td>Reproductive productivity</td>
<td>0.36 0.90 1.35 1.27 0.30</td>
</tr>
</tbody>
</table>

Table 4. Index of reproductive potential and reproductive productivity of berried female
Alternative Management

Small islands constituting Spermonde such as Salemo, Saugi, Sagara, and Sabangko are the central of BSC production in South Sulawesi. BSC fishery started 35 years ago and approximately 80% of local people are BSC fishermen. Additionally, the BSCs meat processing center is also located in this region employing ± 60 people. Fishery-related activities from fishing to BSC meat processing offer the highest contribution to the economic growth of the Islands. In conjunction with market demand growth, exploitation eventually becomes very intense.

According to Musick (1999) criteria, BSCs in Spermonde Islands are highly resilient with annual fecundity >10,000 and K coefficient >0.30. Apart from that, BSC in this region has a productivity value >1 which suggests that female BSCs are particularly productive. In this study, the lowest fecundity is found to be 1,300,914 ± 401,793 and the yearly K coefficient is 1.03/year^{-1}. This high resilience might contribute to BSCs being lasted until the present. However, if exploitation continues without sustainable management and reservation based on the carrying capacity, the population can be at risk (Nurdin et al., 2021).

From the findings, the management strategy that can be applied to the crab fishery in the Spermonde Islands is MLS >120 mm. By this means, BEF which was found to be abundant at class 111-120 will be allowed to reproduce. It can also protect young BSC and improve egg production (Johnson et al., 2010; Zairion et al., 2015; Fujaya et al., 2019). Further, a BSC protection area can also be established in coral reefs and seagrass ecosystems as the BSC spawning grounds. The existence of the BSC protection area in the Spermonde Islands is beneficial for the spill over and export of planktonic eggs and/or larvae from the protected area to the surroundings (Nurdin et al., 2022).

CONCLUSION

BSC stock status in Spermonde is overfishing with an SPR value of 7%. This value is far below the biological reference points. To maintain BSC fisheries in the region, it is important to register a minimum legal size of >120 mm. This allows protection to BSC female berried and improves egg production. In turn, it will contribute to recruitment and resolve overfish.

AUTHOR CONTRIBUTION


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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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