Population Growth Model and Mortality of Pakistan Lobster (*Panulirus polyphagus*) in Estuary Waters of Tarakan City

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1. Introduction

The waters surrounding the estuarine area of Tarakan City have been known as the habitat of many important biological resources for the fishery. One of the important fishery resources is the spiny lobster (*Panulirus* spp). Lobster is an important aquatic resource in Indonesia which has high economic value (Setyanto and Halimah 2019; Setyanto et al. 2021) in fact, Indonesia is the third biggest exporter of marine lobsters in the world after Canada and the United States (Garibaldi 2012). Spiny lobsters are a group of crustaceans with no backbone, are hard-skinned, and are covered with thorns (Setyanto et al. 2018, 2020). There are six species of spiny lobsters found in Indonesia which are *Panulirus homarus*, *P. longipes*, *P. penicillatus*, *P. ornatus* (Indarjo et al. 2023), *P. versicolor* and *P. polyphagus*.

As for the estuary waters of Tarakan City, three spiny lobster species, namely *P. ornatus*, *P. versicolor* and *P. polyphagus*, are currently found. Of these three species, the mud spiny lobster (*P. polyphagus*), also known as the Paskitan lobster, is reportedly in high demand for local and international markets (Hargiyatno et al. 2013). This lobster can be differentiated from the other spiny lobsters by its light green body color with a yellowish line pattern on each segment and yellow spots on the legset (Carpenter and Neim 1998; Chodrijah et al. 2018; Widianti et al. 2021). The high market demand and the good retail price could become a major threat to the sustainability of this species (Pranata et al. 2017).

However, due to the need for more biological information on this species in the estuarine waters of Tarakan City, sustainable management efforts cannot be effectively developed. Therefore, this study was carried out to establish the growth and mortality model of the mud spiny lobster (*P. polyphagus*) population in the estuarine waters of Tarakan City.

### 2. Materials and Methods

#### 2.1. Sampling

The sampling was conducted for 5 months, from December 2021 to May 2022, within the estuarine waters of Tarakan City (Figure 1). Samples of the mud spiny lobster (*P. polyphagus*) were obtained from the catches of gill net fishers operating within the area. The sampling sites were selected based on the purposive sampling method. There were 14 sites, mainly fishing grounds for *P. polyphagus*, chosen for this study. Each sampling was conducted during the low tide for five consecutive days. Data including total length (TL) (Figure 2A), total body weight (TBW) (Figure 2B), and sex of the lobster (Figure 2C and D) were recorded following the method described by Sukamto et al. (2017). Other ecological data such as water depth, turbidity, pH, salinity, and temperature in each sampling site were recorded using a multiprobe water quality checker (Dissolved oxygen Analyzer D09100). The data analysis was conducted to obtain the length-weight relationship, sex ratio condition index, size/age structure, von Bertalanffy model, and mortality.

Figure 1. Map of the ecological habitat of *Panulirus polyphagus* in estuary waters of The Tarakan City
2.2. Data Analysis

2.2.1. Sex Ratio

The sex of the lobster can be marked on the lobster leg (Andrykusuma et al. 2022). The sex ratio is a comparison between males and females (Effendie 2002). The lobster samples were sorted according to sex. The sex separation was done according to the swimmerets’ size or the lobster Field’s pleopod (Kizhakudan and Patel 2010; Ikhwanuddin et al. 2014). Male lobster is characterized by smaller swimmerets (Ikhwanuddin et al. 2014), the presence of gonopore (in juveniles), and a penile process with a hairy tip in adult lobsters (Kizhakudan and Patel 2010). The female lobster is characterized by a bigger swimmerets (Ikhwanuddin et al. 2014) and the presence of an ovigerous setae (Kizhakudan and Patel 2010). The male and female ratio of the *P. polyphagus* population in the estuarine waters of Tarakan City was then calculated by dividing the number of males by the number of females.

Testing the normality of sex ratio data using Chi-Square by comparing the normal curve of the collected data (B) with standard normal curve data (A). Normal distribution data if the B value is not significantly different from the A value (Sugiono 2017).

The data normality test method with Chi Square ($\chi^2$) is as follows:

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i}$$

Whereas:

$\chi^2$ = chi-square distribution
O$_i$ = observation value $i$
E$_i$ = expected value $i$

The data is stated to be normally distributed if the calculated Chi Square value < the Chi Square table value, while the data is stated to be abnormally distributed if the calculated Chi Square value > the Chi Square table value (Sugiono 2017).

2.2.2. Length Weight Relationship

The length of the lobster samples was measured from the tip of the posterior margin of the orbit to the tip of the telson to the nearest 0.1 cm following (Indarjo et al. 2023) using the vernier caliper. The total body weight was measured using a digital balance to the nearest 0.1 g. Then, the length-weight relationship of male and female *P. polyphagus* was estimated following the model suggested by Effendie (1979) as follows:

$$Y = a + X^b$$

Whereas:

Y = total weight of *P. polyphagus* (g)
X = total length of *P. polyphagus* (mm)
a+b = constant (intercept)

2.2.3. Condition Index

Condition indexes of the *P. polyphagus* were grouped into five categories i.e., very flatfish/
flatcrustacea (0.01-0.50), flatfish/flatcrustacea (0.51-0.99), proportional/ideal fish or crustacea (1.00), fat fish (1.01-1.50), and the obese fish or crustacea (>1.50) (Firdaus et al. 2020; Indarjo et al. 2021, 2023; Salim et al. 2021, 2022). Meanwhile, the allometric growth and the isometric growth were analyzed based on the methods Field Weatherley (1972) and Field Lagler (1949) suggested Lagler (1949), respectively. The condition factors of the isometric and allometric of lobster were then calculated following Lagler (1949) and Weatherley (1972), respectively.

The condition factor with isometric growth characteristic was calculated using the following equation:

\[ K_{\text{(TI)}} = 10^5 \times \frac{W}{L^5} \]

Whereas:
- \( W \) = total weight of \( P. \) polyphagus (g)
- \( L \) = total length of \( P. \) polyphagus (mm)
- \( 10^5 \) = the equation was taken, so \( K_{\text{(TI)}} \) value is close to 1

The condition factor of lobster with allometric growth characteristic was calculated using the following equation:

\[ K = \frac{\bar{W}}{W} \]

Whereas:
- \( W \) = total weight of \( P. \) polyphagus (g)
- \( \bar{W} \) = average of the total weight of \( P. \) polyphagus (g)
- \( W \) = a \( L^b \) obtained using the regression equation of length-weight correlation

Condition factors can describe the body shape of an aquatic species (Salim et al. 2020; Indarjo et al. 2020, 2021). The classification of the condition factor in this study followed Salim et al. (2020) as follows: very thin (0.01-0.49), thin (0.5-0.99), proportional (1.00), fat (1.01-1.50), and very fat (>1.50).

### 2.2.4. Absolute Growth

The absolute growth of the \( P. \) polyphagus was estimated using von Bertalanffy’s growth model (Sparre and Venema 1999) as follow:

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

Whereas:
- \( L_t \) = length of \( P. \) polyphagus at age \( t \) (unit of time)
- \( L_\infty \) = the theoretical maximum length of \( P. \) polyphagus
- \( K \) = \( P. \) polyphagus growth coefficient (per unit time)
- \( t_0 \) = the theoretical age of \( P. \) polyphagus when the length is zero

### 2.2.5. Age Structure

The age structure of the \( P. \) polyphagus was analyzed using the mode class shift method associated with the von Bertalanffy’s growth model (Sparre and Venema 1999):

\[ \frac{\Delta L}{\Delta t} = \frac{L_2 - L_1}{t_2 - t_1} \]
\[ L_{(j)} = \left( \frac{L_2 + L_1}{2} \right) \]

Whereas:
- \( \Delta L/\Delta t \) = relative growth of \( P. \) polyphagus
- \( L \) = length \( P. \) polyphagus
- \( t \) = difference in sampling time \( P. \) polyphagus
- \( L_{(j)} \) = average length of mode by plotting the values of \( L_{(j)} \) and \( (\Delta L/\Delta t) \), a linear equation can be derived as follows

\[ Y = a + bx \]

Whereas:
- \( a = (\Sigma y/n) - (b (\Sigma x/n)) \)
- \( b = (n\Sigma(xy) - (\Sigma x)(\Sigma y))/(n\Sigma x^2 - (\Sigma x)^2) \)

This linear regression equation was then used to estimate the asymptotic length \( (L_\infty) \) and the growth coefficient \( (K) \) of \( P. \) polyphagus. The theoretical age of the \( P. \) polyphagus, when the length is equal to zero, can be estimated separately using an empirical equation suggested by Pauly (1984) as follows:

\[ \log (-t_0) = 0.3922 - 0.275 \log (L_\infty) + 0.138 \log K \]

Where:
- \( L_\infty \) = asymptotic length (cm)
- \( K \) = growth coefficient
- \( t_0 \) = hypothetical age at length equals to zero (years)

### 2.2.6. Mortality

The natural mortality (\( M \)) of the \( P. \) polyphagus was estimated using the empirical formula of Pauly (1984), as follows:

\[ \log (-t_0) = 0.3922 - 0.275 \log (L_\infty) + 0.138 \log K \]

Where:
- \( L_\infty \) = asymptotic length (cm)
- \( K \) = growth coefficient
- \( t_0 \) = hypothetical age at length equals to zero (years)
Log $M = 0.0066 \times 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T$

The total mortality ($Z$) of the $P. polyphagus$ was estimated using the Beverton and Holt formula (Sparre and Venema 1999) as follows:

$$Z = K \cdot \left[ \frac{L_\infty - L}{L - L'} \right]$$

The fishing mortality ($F$) of the $P. polyphagus$ was estimated according to the following equation:

$$F = Z - M$$

Finally, the exploitation rate ($E$) of the $P. polyphagus$ in sampling sites was estimated following Pauly (1984) as follows:

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

### 3. Results

#### 3.1. Water Parameters

The water depth where the lobsters were caught varied from 18-30 meters. The pH ranged from 7.05 to 7.33, whereas the salinity ranged from 15-18 ppt. The water brightness ranged from 1.9-2.12 m and the temperature ranged from 26-29°C.

#### 3.2. Sex Ratio

The total number of mud-spiny lobster ($P. polyphagus$) obtained during the study was 83 individuals, which included 55 males (66.3%) and 28 females (33.7%) (Table 1). The sex ratio male and female of the mud-spiny in the estuarine waters of Tarakan city was estimated at 1.96:1. Based on the Chi-Square test, the Chi Square value is 1.94 and the Chi Critical Value is 12.59 with a probability value of 0.96 (Table 2).

#### 3.3. Length Weight Relationship

The male mud-spiny lobster population recorded a total length that ranged from 8.7 to 30 cm and the total weight ranged from 91 to 831 g. Meanwhile, the female lobster population recorded a total length that ranged from 12.5 to 28.6 cm and the total weight ranged from 143 to 703 g.

The length-weight relationship of male $P. polyphagus$ was recorded at 0.2951, the value of $b$ was 1.6006 where the $R^2$ value was 0.554 with a correlation value of 0.774. While the female lobster $P. polyphagus$ recorded length-weight relationship of 0.6281, $b$ of 1.4027, and $R^2$ value of 0.5288 with a correlation value of 0.727 (Figure 3).

#### 3.4. Condition Index

The results revealed that the male population of mud-spiny lobster in the estuarine waters of Tarakan city can be grouped into 4 categories including the thin body shape (0.5-0.99) with a percentage of 53%; proportional body shape (1.00) with a percentage of 2%; fat body shape (1.01-1.50) with a percentage of 38% and very fat body shape (> 1.50) by 7% (Figure 4).

Meanwhile, the female population of the mud-spiny lobster can be grouped into 3 categories, namely thin body shape with a percentage of 50%; fat body shape with a percentage of 43%, and very fat body shape with a percentage of 7%.

#### 3.5. Structure Age and Absolute Growth

The size structure of the male mud-spiny lobster ranged from 18.3-20.6 cm (16 samples) which is estimated to be 39-48 days old. The female lobster was found to range from 45-53 cm (8 samples) with estimated age that ranged from 49 to 56 days old.

The absolute growth of male and female lobsters

<table>
<thead>
<tr>
<th>Test</th>
<th>Chi square</th>
<th>Chi-critical value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>1.94</td>
<td>12.59</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Table 1. Observed and expected sex ratio of $Panulirus polyphagus$ in the estuarine waters of Tarakan City

<table>
<thead>
<tr>
<th>Observed</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
<th>Expected</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st week</td>
<td>16</td>
<td>7</td>
<td>23</td>
<td>1st week</td>
<td>15.2</td>
<td>7.8</td>
</tr>
<tr>
<td>2nd week</td>
<td>7</td>
<td>4</td>
<td>11</td>
<td>2nd week</td>
<td>7.3</td>
<td>3.7</td>
</tr>
<tr>
<td>3rd week</td>
<td>7</td>
<td>3</td>
<td>10</td>
<td>3rd week</td>
<td>6.6</td>
<td>3.4</td>
</tr>
<tr>
<td>4th week</td>
<td>18</td>
<td>8</td>
<td>26</td>
<td>4th week</td>
<td>17.2</td>
<td>8.8</td>
</tr>
<tr>
<td>5th week</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>5th week</td>
<td>3.3</td>
<td>1.7</td>
</tr>
<tr>
<td>6th week</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>6th week</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>7th week</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>7th week</td>
<td>3.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Total sample</td>
<td>55</td>
<td>28</td>
<td>83</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
can be estimated by the following equations: 

- Male: $y = -0.0214x + 0.6745$ with a correlation value of 0.95
- Female: $y = -0.0211x + 0.662$ with a correlation value of 0.90 (Figure 5). The growth model of male lobster based on the von Bertalanffy can be estimated by the following equation: $y = -4E-14x^6 + 7E11x^5 - 6E-08x^4 + 2E-05x^3 - 0.01x^2 + 0.60x + 1.32$ with a correlation value of 0.99. The growth model for female lobster can be estimated using the following equation: $y = -7E-14x^6 + 1E10x^5 - 8E08x^4 + 3E-05x^3 - 0.01x^2 + 0.61x + 1.19$ with a correlation value of 0.99 (Figure 6). Using the von Bertalanffy growth model, the length of male and female lobsters at the age of zero days was estimated to be 1.14 cm and 1.20 cm, respectively. The smallest male and female specimens caught during the sampling were 8.7 cm and 12.5 cm which are estimated to be 14 days and 20 days old, respectively.

While the largest specimens were 30 cm and 28.6 cm which are estimated to be 140 days and 114 days old, respectively. The growth rate of male and female lobsters was estimated at 0.02 cm/year and 0.02 cm/year, respectively.

3.6. Mortality

Based on the Beverton and Holt formula, the total mortality ($Z$) of the male and female mud-spiny lobster population in the estuarine waters of Tarakan city was estimated to be at 1.10 and 1.12. The fishing ($F$) or catch mortality ($M$) for male and female lobsters was estimated at 0.11 and 0.25, respectively. The natural mortality for males and females was estimated at 0.99 and 0.89, respectively. The exploitation rate for males and females was recorded at 0.09 and 0.23, respectively (Figure 7).
4. Discussion

This study observed that the sex of the mud-spiny lobster population in the estuarine waters of Tarakan city is dominated by male individuals. Based on the Chi Square Test in Table 1 and 2, it explains that there is no difference in the proportion sex ratio between males and females where the data is normally distributed (Sugiono 2017). This is not a surprise because several studies also recorded similar findings, such as in the waters of Johor Malaysia, got sex ratio of male and female *P. polyphagus* 3.34:1.
out of 300 individuals (Ikhwanuddin 2014; Waiho et al. 2021). However, there is study in other waters in North Kalimantan, namely Sebatik Island waters, that shown different sex ratio of male and female *P. polyphagus*, namely 1:1.15 out of 921 individuals (Chodrijah et al. 2018).

The difference in the dominance of lobster catches can be influenced by environmental conditions such as salinity, fishing pressure (Little and Watson 2005; Pranata et al. 2017), pH, temperature (Anguil-Arberola and MesquitaJoanes 2014), and water depth. Meanwhile, factors that affect the abundance of lobsters include light intensity, water current, dissolved oxygen, and temperature (Nugroho 2007). The sex ratio of the mud-spiny lobster (Ann and Zakariam 2018) in the estuarine waters of Tarakan city is close to balance which indicates good population health (Yusuf et al. 2019). According to Widianti et al. (2021), mud-spiny lobsters are normally found at the depth of lesser than 16 meters. They also prefer muddy and sandy bottom areas. Different ecological (temperature and salinity) and biological (sex ratio) factors could affect the growth pattern of lobsters (Froose 2006; Damora et al. 2018).

Based on the length-weight relationships, it was found that the male and female *P. polyphagus* in the estuarine waters of Tarakan city exhibited b value of less than 3.0. This shows that the growth pattern of the mud-spiny lobster population in the area is characterized by negative allometric (Effendi 2002; Muttaqin et al. 2016; Salim et al. 2020; Indarjo et al. 2021). This deviated from the finding of Waiho et al. (2021) who reported that the female *P. polyphagus* was characterized by negative allometric, but the male lobster was growing in a positive allometric. However, Ikhwanuddin (2014) found the male and female *P. polyphagus* populations in the water of Johore, Malaysia was growing in a negative allometric. The finding of the present study is also in agreement with the finding of Chodrijah et al. (2018) who also found that the male and female *P. polyphagus* population in Sebatik Island, North Kalimantan exhibited negative allometric growth. According to Fazhan et al. (2021), the negative allometric growth could be contributed to the health condition (Hossain et al. 1987; Steinback et al. 2008; Datta et al. 2013), environmental factors (Nahdi et al. 2016) and to certain extent, sample size (Fazhan et al. 2021).

The condition factor, K, is widely used in fisheries and fish biology studies as a measure of the degree of robustness of fish. Condition index values (K) are widely used in the fish biology study literature and can be used on crustaceans as a measure of the degree of fish sturdiness (Indarjo et al. 2021) and fish body shape (Indarjo et al. 2020; Salim et al. 2020).

While the research results of female *P. polyphagus* lobsters obtained 3 categories, namely thin body shape with a percentage of 50%, fat body shape with a percentage of 43% and very fat body shape with a percentage of 7%. The results of the K value on the body shape of crustaceans in the cultivation scale were obtained in the range between 0.97-1.17 (Kunda et al. 2018) and body shape in the range between 0.79-1.00 was the body shape in nursery conditions and the range was 1.14 based on the parent village (Lalrinsanga et al. 2012).

Based on the size structure, males were found at most 18.3–20.6 cm and females were found at 20.5–22.2 cm. In the regression equation, the von Bertalanffy model is obtained where the maximum length growth in male lobsters is obtained at a size of 31.519 cm with an estimated age of 560 days. While the maximum length growth in female lobsters was found at a size of 31.374 cm with an estimated age of 495 days. This maximum length growth of *P. polyphagus* in estuarine waters of the Tarakan city was higher than in Sebatik Island waters, North Kalimantan, Indonesia with 12.41 cm (Chodrijah et al. 2018), and also in Veraval waters, India, with 13.5 cm for male and 12.47 cm for female (Kizhakudan et al. 2013).

The value of male mortality is higher than females in natural mortality, but in total mortality, fishing mortality and exploitation rate, female values are higher than males. This indicates that female lobsters have a fairly high mortality compared to female lobsters, but the highest mortality is caused by natural mortality and not fishing mortality and exploitation rates are in the rational and sustainable category so that sustainable management of Pakistani lobster is needed in the Tarakan city by domestication of spiny lobster *P. polyphagus*. Biological growth and mortality information can be used in the management of fisheries resources for sustainable development and rational exploitation.

However, from lobster research found in Sebatik waters (North Kalimantan, Indonesia) different
results were obtained, where the E value from the results of Chodrijah et al. (2018) research was 0.61 (61%)/year this caused the condition of lobsters in the waters. Sebatik in the category of normal threshold/high exploitation rate (over exploitation) According to Yudiati et al. (2020) explained that the rate of overexploitation is caused by high market demand and attractive price values.

The natural mortality of male *P. polyphagus* was recorded as higher than females. This is particularly worrisome as it will become a threat to the sustainability of the mud-spiny lobster fishery in the estuarine waters of Tarakan city. Unlike the lobster population in Sebatik Island waters, the low exploitation level (E<0.5) of the mud-spiny lobster in the estuarine waters of Tarakan city implies that the fishing activity has not yet been considered a major threat to the sustainability of the lobster population in the area (Pauly 1983; indarjo et al. 2020, 2021). However, good management practices should be developed to avoid the exploitation level becoming higher in the future.

In conclusion, the mud-spiny lobster *Panulirus polyphagus* population in the estuarine waters of Tarakan city was dominated by males. Both male and female mud-spiny lobsters exhibited negative allometric growth. The natural mortality (M) of the male population is higher than the female population. Nevertheless, the lobster population in estuarine waters of The Tarakan City is still under or less exploitation. However, the high natural mortality among male lobsters is a concern that warrants further investigation.

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**References**


