Biological and Fisheries Aspects of Black Tiger Shrimp (*Penaeus monodon* Fabricius, 1798) in East Aceh Waters, Indonesia

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Abstract

The black tiger shrimp (*Penaeus monodon*) belongs to the Penaeidae family and is known for its economic importance. This species was caught using a trammel net in the East Aceh waters, where it is commonly found. This research aimed to discover the biological and fisheries aspects of the black tiger shrimp to provide foundational knowledge for its management. Data were collected monthly from September 2019 to November 2021 and biological data on carapace length (CL), weight, sex, and maturity stages were recorded. Fisheries data on landing catch and effort were also obtained. Common methods in fisheries science were performed to analyse the biological and fisheries data. The average carapace length and weight of females were greater than males, about 10 % and 24 %, respectively. The size at catches fluctuated month by month but tended to be greater from August to September, both in females and males. The sex ratio was unequal, and the growth pattern was negative allometric. The spawning season peaks between November and December. The black tiger shrimp was caught before it reached maturity size ($L_c < L_m$). In addition, there was a 40 % decrease in the abundance index between 2019 and 2021, and November marks the peak of the fishing landings. To promote sustainability, we recommend implementing a seasonal fishing closure during peak spawning in December.

Keywords: abundance, fisheries management, life-histories, penaeid, shrimp

Introduction

The black tiger shrimp (*Penaeus monodon*) belongs to the Penaeidae family, which has the largest, high economic value, and high protein. Black tiger shrimp is widely distributed across the Indo-West Pacific, including regions such as South Africa, Tanzania, Kenya, Somalia, Madagascar, Saudi Arabia, Oman, Pakistan, India, Bangladesh, Sri Lanka, Thailand, Malaysia, Singapore, Philippines, Hongkong, Taiwan, Korea, Japan, Australia, Papua New Guinea as well as Indonesia (Motoh, 1984). In Indonesia, *P. monodon* is found in East Aceh, the Java Sea, eastern and western Kalimantan, Cenderawasih Bay, Aru and the Arafura Sea (Kembaren and Nurdin, 2013; Suman et al., 2017; Suryandari et al., 2018; Tirtadanu and Chodrijah, 2019).

The east Aceh waters, located in the southeast of Nanggroe Aceh Darussalam Province, are a part of the Andaman Sea and the Malacca Strait. The coastal waters of east Aceh are characterised by the presence of estuaries that are dominated by mangroves and freshwater flow from rivers of modest size (Suryandari et al., 2018). This habitat is conducive to the growth of tiger shrimps, particularly in the juvenile stage. The East Aceh waters are renowned for producing high-quality black tiger shrimp broodstock with high genetic variation, rapid growth, virus resistance, and good reproductive performance, especially for males (Sugama et al., 2002; Haryanti et al., 2009; Lante et al., 2014). As a result, black tiger shrimps are exploited for consumption as well as for providing the broodstock for hatcheries in Indonesia.

The fishery for black tiger shrimps uses mainly trammel nets with an inner mesh size of 2.5 inches and an outer mesh size of 8 inches in waters 20–30 m depth. According to Hedianto et al. (2016), the high exploitation rate of black tiger shrimps in east Aceh waters resulted in about 10–13 % decline in capture from 11.9 tonnes in 2012 to 10.7 tonnes in 2015. The availability of the supply of *P. monodon* for markets and providing broodstock for aquaculture may be threatened by this decline. Previous studies of black tiger shrimps in this area have focused on their biological characteristics and nursery grounds (Suryandari et al., 2018) as well as the conservation effort based on the abundance of larvae and juveniles, as well as the habitat degradation (Tjahjo et al., 2019). However, there has been no research that considers the biological and fishery aspects of black tiger shrimp in this area which provides important information for the management of the stock.

This study aims to provide a comprehensive understanding of the biological and fishery aspects of the black tiger shrimp, focusing on key parameters such as size structure, length-weight relationship, sex ratio, maturity proportion, index of abundance, and determining the seasonal pattern of fishing for this species. These aspects were analysed based on monthly catch data recorded from landings in the East Aceh Regency. We hypothesised that black tiger shrimps exhibit seasonal fluctuations in abundance, potentially influenced by environmental factors and fishing intensity, and there is an indication of growth overfishing due to the current levels of exploitation. By investigating these dynamics, this study seeks to fill critical knowledge gaps regarding the species' population structure and exploitation patterns. The results are expected to serve as a basis for developing science-based effective and sustainable fisheries management strategies, including the formulation of appropriate harvest controls, closed seasons, or gear restrictions. Ultimately, the findings will contribute to preserving the long-term viability of the black tiger shrimp fishery.

Materials and Methods

Ethical approval

No live animals were used in this study. This study used shrimp sourced from local fishermen.

Data collection

Biological and fishery data were collected from September 2019 to November 2021. The average number of samples per month was 500 shrimps. Shrimp samples were collected from fishermen who landed black tiger shrimps using trammel nets in East Aceh Regency, Nanggroe Aceh Darussalam (Fig. 1). The biological sampling was conducted randomly from the catch landed before sorting from the represented fishing ground. The black tiger shrimp sample's biological characteristics included body weight, sex, maturity, and carapace length. To examine the abundance index, the number of black tiger shrimps caught per effort (vessel) was calculated. Data were gathered by a qualified officer using semi-regular monitoring.

Data analyses

The length frequencies were constructed at 3 mm

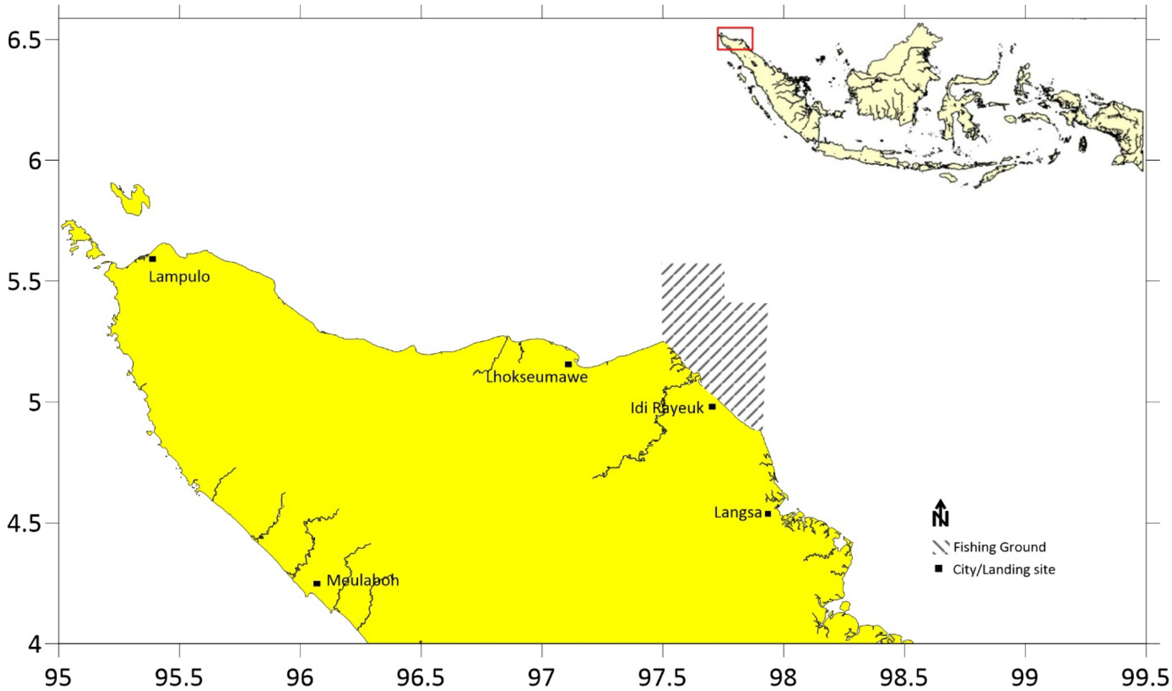

Fig. 1. Fishing ground and landing base of black tiger shrimp *Penaeus monodon* in east Aceh waters, Indonesia.

carapace length class interval. The relationship of length and weight was calculated according to Cren (1951) and Effendie (2002):

$$W = aL^b \tag{1}$$

where *W* is the weight of the shrimp in g, *L* is carapace length (CL) in mm, *a* is the intercept, and *b* is the slope. To determine the growth characteristic, a t-test was carried out to assess whether the value of *b* differed significantly from allometric growth i.e. *b* = 3. Prior to performing the t-test, we analysed the normality and the homogeneity of variance and if necessary, data were transformed using the log transformation.

The number of males and females was used to determine the X^2 value (Fowler et al., 1998):

$$X^2 = \sum \frac{(o_i - e_i)^2}{e_i} \tag{2}$$

where o_i is the observed number of males and females, e_i is the predicted number of males and females. A Chi-square (X^2) goodness of fit test was conducted to verify the difference in sex ratio distribution from 1.

The maturity stage of the black tiger shrimp was staged morphologically according to the criteria developed by Naamin (1984): stage 1 - quiescent/undeveloped; stage 2 - developed; stage 3 - early mature; stage 4 - ripe; and stage 5 - spent. The maturity stages were grouped into two maturity categories: immature (stages 1 and 2); and mature (stages 3 and 4).

Size at first capture (L_c) was calculated using the logistic function (Sparre and Venema, 1998) as:

$$S_{Lc} = \frac{1}{1+e^{(a-b\times L)}} \tag{3}$$

where S_L is the gear selectivity of gillnet, *a* and *b* are constants, L is carapace length, and L_c is derived from *a*/*b*. Size at maturity (L_m) was measured based on the logistic equation developed by (King, 2007) by harmonising the fraction of the mature category (stages 3 and 4) toward the carapace length (CL):

$$P = \frac{1}{1+ e^{[-r(L-L_m)]}} \tag{4}$$

Furthermore, this formula can be written in linear structure as:

$$ln\left[\frac{1-P}{P}\right] = rL_m - rL \tag{5}$$

where *P* is a proportion of carapace length at mature stages compared to immature and mature stages, rL_m is the intercept, *and r* is the slope. Finally, the length, which refers to a proportion of 50 % in reproductive shape (L_m), equals the intercept divided by the slope.

The average percentage approach was used to analyse the seasonal variability of black tiger shrimps (Spiegel, 1961). The main variable that could be changed in this estimation was catch per unit of effort (CPUE) which was derived from monthly data collection from September 2019 to November 2021. The abundance of black tiger shrimps in the unit of kg per trip was measured in this study using landing per unit effort. One-day fishing excursions are used by the fishermen in East Aceh to catch shrimps. The following describes the steps involved in analysing fishing season indices:

Step 1. Calculating the monthly CPUE (U_i) and its average CPUE in a year ($\bar{U}$).

$$\bar{U} = \frac{1}{m}\sum_{i=1}^{m} Ui \tag{6}$$

where $\bar{U}$ is the average monthly CPUE in a year (kg/trip); U_i is the monthly CPUE (kg.trip^{-1}); *m* is the number of months in a year (12).

Step 2. Calculating the *Up*, which is the ratio of *Ui* towards *U* (in percent):

$$U_p = \frac{Ui}{U} x\ 100\% \tag{7}$$

Step 3. Calculating the fishing season indices (*FS*):

$$FSi = \frac{1}{y}\sum_{i=1}^{y} Up \tag{8}$$

where FSi is the indices at a certain season (*i*); *y* is the years calculated.

Step 4. If the sum of *FSi* in a year does not equal 1200 %, the calibration should be made using the following formula:

$$AFSi = \frac{1200}{\sum_{i=1}^{y} FSi} x\ FSi \tag{9}$$

where *AFSi* is adjusted fishing season indices.

Step 5. If there is any extreme value of *Up*, it would not be included in the calculation of FS. Instead, the FS's median value (*Md*) would be used. If the total sum of the median value does not equal 1200 %, another adjustment should be made as follows:

$$AMSi = \frac{1200}{\sum_{i=1}^{y} Mdi} x\ Md \tag{10}$$

where *AMFSi* is adjusted median fishing season indices.

Results

Size structure

In this study, the carapace lengths (CL) of black tiger shrimps ranged from 24 to 92 mm (mean ± SD = 54.6 ± 8.3) for female black tiger shrimps and between 24 to 78 mm (mean = 49.5 ± 6.0) for males. Males ranged in weight from 16.7 to 226.3 g (mean = 81.8 ± 22.8), while females ranged from 16.3 to 274.9 g (mean = 101.1 ± 31.7). The mean size of female black tiger shrimps was larger than males, weighing 24 % more and 10 % longer. The examination of the frequency distribution of carapace length also revealed that female shrimps predominated in sizes larger than 51 mm CL. On the other hand, male shrimps predominated in sizes ≤51 mm CL (Fig. 2).

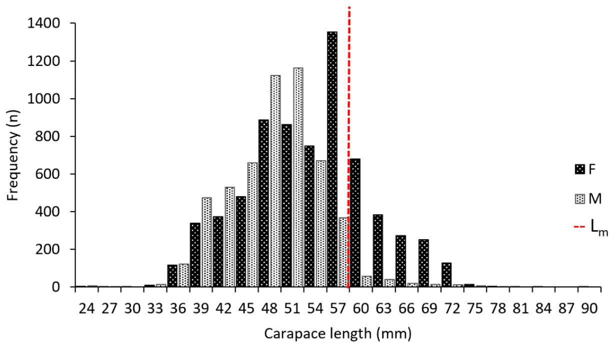

Fig. 2. The distribution of carapace length frequency of black tiger shrimp overlaid with length at maturity (L_m) in east Aceh waters, Indonesia. The red vertical dashed line shows the size at maturity for females (L_m).

Additionally, the frequency distribution of carapace length showed that male had one mode, and females had two. On female, the first mode was observed at 48 mm, and the second at 57 mm.

Figure 3 present the temporal size structure distribution of carapace length and weight of female and male black tiger shrimps. However, the largest mean size of males was recorded in November 2019, and the largest mean size of female was recorded in July 2020. In September 2019, the male and female mean size were the smallest. Additionally, both male and female black tiger shrimp tend to grow larger between August and September.

Length-weight relationship

The relationship between length and weight was based on a large number of tiger shrimps with over 5,000 shrimps measured for each sex (Table 1). Length accounted for >87 % of the total variation in weight for each of the three length-weight relationships (Table 1). The *b* coefficient for males was 2.156, greater than the value of 2.068 calculated for females (Table 1). The growth pattern of this species was shown to be negative allometric (i.e. b < 3), with the length increment faster than the weight increment, based on the t-test analysis of the growth coefficient (b value) for females, males and both sexes combined (Table 1).

Sex ratio and maturity

Over the duration of this study i.e. September 2019 to November 2021, the male to female ratio was 0.8:1, and there was a statistically significant difference in the sex composition ($P < 0.05$). These findings indicate that there is an unequal distribution of males and females, with more females than males present in the measured population. The monthly sex ratios of males to females show that males were only dominant significantly from September 2019 to April 2020, was close to 1 in May and June, while females dominated from July to November (Fig. 4a).

Mature females (gonad maturity stages 3 and 4) were found throughout the year (Fig. 4b). However, the

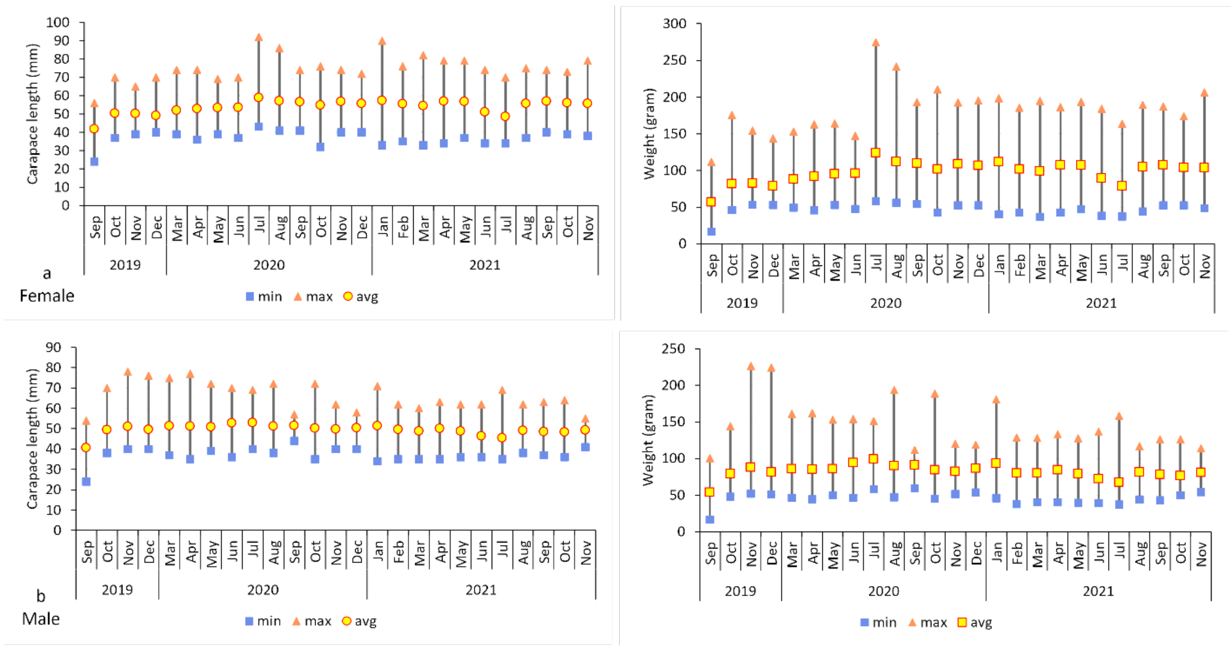

Fig. 3. Temporal variation in mean size and size range (carapace length and weight) distribution of black tiger shrimp in east Aceh waters, Indonesia a. female and b. male.

Table 1. The length-weight relationship parameters of black tiger shrimp *Penaeus monodon* in East Aceh waters, Indonesia.

Sex	n	a	b	R^2	Growth pattern
Female	6994	0.0251	2.0681	0.9160	Negative allometric
Male	5380	0.0178	2.1559	0.8793	Negative allometric
Combined	12374	0.0189	2.1403	0.9013	Negative allometric

n = number of samples.
a = constant (intercept).
b = exponent of the length-weight relationship (slope).
R^2 = correlation.

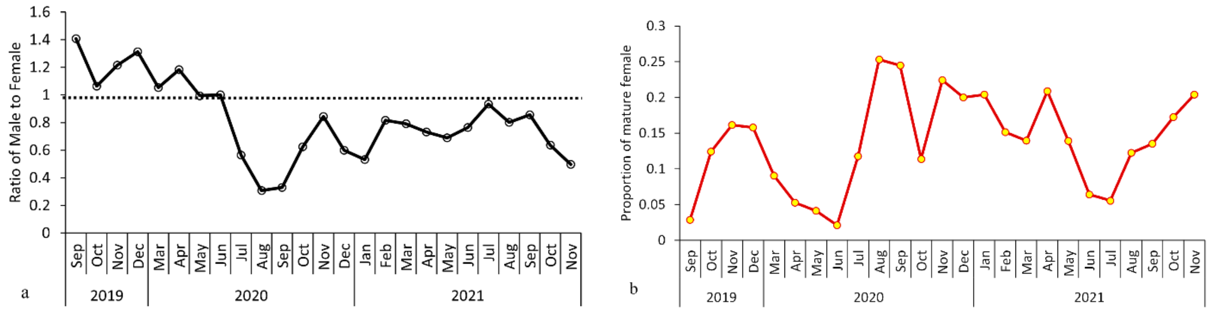

Fig. 4. a. Temporal distribution of sex ratio. b. proportion of mature female of black tiger shrimp *Penaeus monodon* in east Aceh waters, Indonesia.

largest percentage of mature females was found in the time from November–December. In a certain year, for example 2019, the peak of the spawning season is also indicated in August–September. In contrast, June has the lowest percentage of mature females (Fig. 4b).

Size at capture (L_c) and size at maturity (L_m)

The estimated size at capture (L_c) varied from year to year; the lowest L_c was found in 2019 (45.7 mm CL) and the highest in 2020 (53.1 mm CL), the L_c of this species in 2021 was at 50.5 mm CL (Fig. 5). The estimated size maturity was 59 mm CL, which indicates that, on average, *P. monodon* are caught before reaching maturity i.e. $L_c < L_m$ by ~6 to 14 mm (~10–25 %) which is a concern for the sustainability of the black tiger shrimp fishery and the collection of broodstock from the population.

Index of abundance and fishing season

Between September 2019 and November 2021, the black tiger shrimp CPUE decreased from ~0.55 kg per trip to 0.22 kg per trip (an average decrease of 40 %) (Fig. 6a). Additionally, the landing per unit effort decreased with increasing effort. Black tiger shrimp fishing was at its peak in November and at its lowest in January (Fig. 6a). Based on the fishing season analysis, we found that the fishing season of black tiger shrimp in this study area occurred from August to November, with a large peak in November (Fig. 6b).

Discussion

The black tiger shrimp (*Penaeus monodon*) is a member of the penaeid species that is dominantly caught from Indonesian waters, particularly east Aceh waters, where its landing compose 27 % of total penaeid landing in this region (Kembaren et al., 2020). Due to its high exploitation rate, the black tiger shrimp should be managed based on its biological and fishery characteristics. The study of biological aspects is needed to supply basic information on the fisheries management of black tiger shrimps. Understanding the size structure of the fish (shrimp) population is an important parameter that could be used to monitor the size of capture or selectivity of fishing gear (Hicks and McClanahan, 2012).

The size of the black tiger shrimp (*Penaeus monodon*) in this study was notably larger than those previously reported from Tarakan and Sebatik waters (Kembaren and Nurdin, 2013; Tirtadanu and Chodrijah, 2019). This phenomenon is believed to be a consequence of elevated fishing pressure in Tarakan dan Sebatik waters, a phenomenon attributable to the employment of trawl fishing techniques. Remarkably, the specimens observed even surpassed the maximum weight ever reported for the species, which was 261 g (Naser Uddin et al., 2016). This significant finding highlights the potential of the study area as a highly favourable habitat for the growth of black tiger shrimps, possibly due to optimal environmental conditions such as food availability, water quality, and minimal anthropogenic stress. As such, this study contributes important new data to the existing body of knowledge and effectively documents the largest black tiger shrimp ever measured, which could have implications for both ecological studies and aquaculture development.

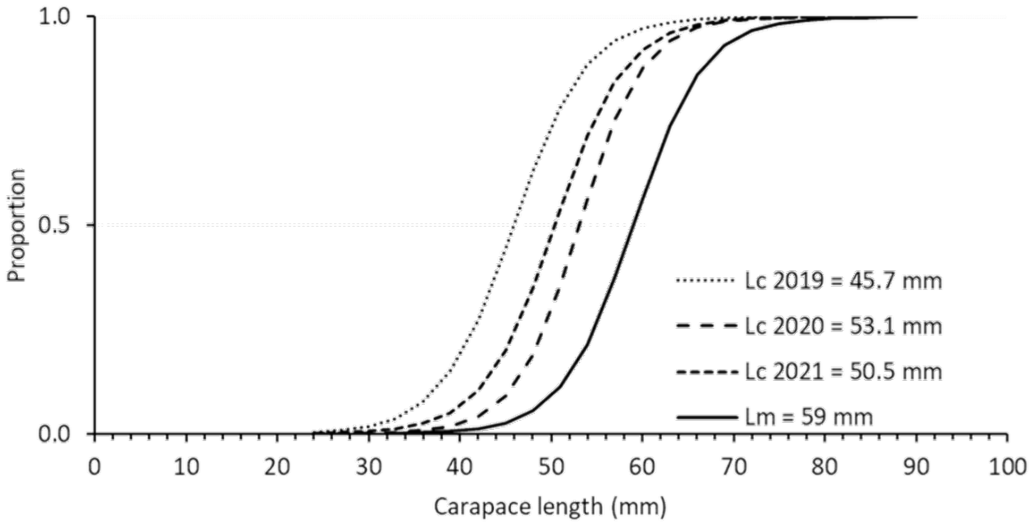

Fig. 5. Estimated size at capture (L_c) and size at maturity (L_m) of black tiger shrimp *Penaeus monodon* in east Aceh waters, Indonesia.

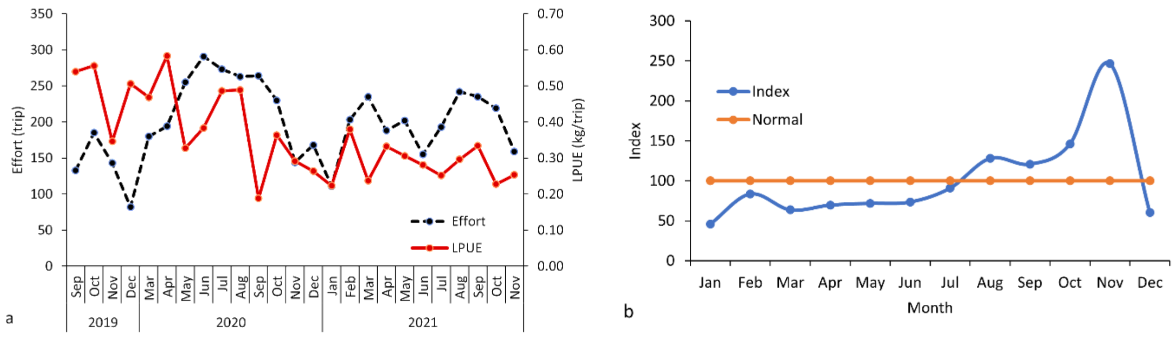

Fig. 6. Landings per unit effort and effort (a) and seasonal fishing index (b) of black tiger shrimp *Penaeus monodon* in east Aceh waters, Indonesia.

Moreover, the growth pattern of the black tiger shrimp in this study was determined to be negatively allometric, indicating that weight increases at a slower rate than length as the shrimp grows. This finding is consistent with earlier research that reported similar negative allometric trends in Bengal waters (Naser Uddin et al., 2016) and Sebatik waters (Tirtadanu and Chodrijah, 2019). The consistency of this growth pattern across different geographic regions suggests a species-specific trait that may be influenced by environment. In fisheries research, the relationship between length and weight is crucial because the value of its parameters can be used to estimate weight based on length observations, estimate fish condition, calculate population growth, biomass, and production, estimate the spawning potential ratio, and compare fish growth across regions (Stergiou and Moutopoulos, 2001; Sinovcic et al., 2004; Froese, 2006; Velamela et al., 2018).

This study revealed an unequal sex ratio in black tiger shrimps, with females predominating in the catch composition. A comparable finding was reported by Naser Uddin et al. (2016) on the Digha coast, West Bengal, India, indicating that females of *P. monodon* predominated in the catch sex composition. The sex ratio information is basic initial knowledge of bio-reproduction (Holden and Raitt, 1974) and may be varied within species. The variation of sex proportion in the population could be affected by differences in sexual behaviour, environmental conditions, and fishing grounds (Effendie, 2002).

In the waters of east Aceh, the black tiger shrimp spawning season peaks in November and December. This study confirmed the previous study conducted in Sebatik waters (Tirtadanu and Chodrijah, 2019), which similarly found that November was the peak spawning season. The study conducted by (Kannan et al., 2014) in Tamil Nadu, South-east Coast of India, revealed that the peak of the spawning season of black tiger shrimp occurs during the pre-monsoon and post-monsoon season.

Estimating the length at maturity was only done for females, and this population parameter was considered as an indicator when the shrimps reached their maturity (Pinheiro and Lins-Oliveira, 2006). In this study we found that black tiger shrimps reach their maturity at 59 mm carapace length which is higher than study by Motoh (1984), at 47 mm carapace length. Moreover, this study found that the size at first capture of the black tiger shrimp was smaller than the size at maturity ($L_c < L_m$), which indicates that the black tiger shrimp in east Aceh waters was threatened since they had been caught before reproducing at least once. Catching a shrimp with a size below maturity will lead to stock depletion because of the disturbance of the recruitment process (Pinheiro and Lins-Oliveira, 2006). The index of abundance analysis showed declining trends where this condition was suspected due to the high exploitation rate, as revealed by the previous study on this water (Hedianto et al., 2016). The extensive exploitation rate should be controlled through some management measures, such as a closure system to sustain these resources. The fishing season, estimated from data on landing per unit effort of black tiger shrimp, starts in August and reaches its peak in November. Similar fishing season for tiger shrimp was also found in northern shrimp fishery of Australia (AFMA 2024).

There are several shrimp fishery management measures that can be taken as outlined by Suman et al. (2022), such as areal and seasonal closures, minimum size restrictions, and effort restrictions. Areal and seasonal closures aim to protect juvenile shrimp and increase the length at first capture, which in turn will increase production. Fishing areal closures can be implemented in areas identified as spawning areas while fishing season closures can be implemented at the peak of the spawning season. The goal of restricting the size of the smallest shrimp that can be captured is to protect shrimps and let them spawn at least once before being captured as well as ensuring the population renewal and stock sustainability. The size-at-maturity is typically used to determine the minimum catch size. Furthermore, limiting fishing effort is related to reducing the number of vessels operating and this is generally very difficult to do.

The spawning and fishing seasons coincide at this study site. Therefore, seasonal closures should be employed as a management strategy to ensure the sustainability of this species as well as increased egg production, as has been applied in the Australian Northern Shrimp Fishery. In addition, spatial limitations and effort to protect nursery habitat and sustain population growth rates are possible management strategies that could support productive and sustainable fishery exploitation (de Barros et al., 2021). Due to the limitations of our study, further research will be needed to complement our study and improve our understanding of this stock, particularly on identifying spawning and nursey ground as well as the environmental conditions that influence the population dynamics of *P. monodon*.

Conclusion

The findings of this study highlight several important biological and fishery characteristics of the black tiger shrimp in East Aceh Regency. Female shrimps exhibited larger average carapace lengths and weights compared to males, and while catch sizes fluctuated monthly, larger individuals were generally observed from August to September. An unequal sex ratio, with a dominance of females was noted, along with a negative allometric growth pattern across all groups. Mature and maturing females were found throughout the year, peaking in November–December. However, the catch was largely composed of individuals below the length at first maturity ($L_c < L_m$), suggesting that many shrimps were harvested before reaching reproductive age. Additionally, the abundance index showed a declining trend despite a seasonal increase in fishing activity during November.

These findings indicate that current fishing practices may be contributing to overexploitation and pose a risk to the sustainability of the black tiger shrimp population. Based on this evidence, we recommend the implementation of a closed season policy, particularly during December for four weeks, to protect spawning individuals and support stock recovery. Such a management measure would help ensure the long-term sustainability of the fishery.

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Conflict of interest: The authors declare that they have no conflict of interest.

Author contributions: Duranta Diandria Kembaren: Conceptualisation, formal analysis, original draft preparation, review, editing, project administration. Hufiadi: Original draft preparation, formal analysis, review, editing. Mahiswara: Original draft preparation, review, editing.

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