



Biological Parameters and Stock Status of *Scylla serrata* in the Kakuluk Mesak Mangrove Area, Belu Regency, East Nusa Tenggara, Indonesia

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ABSTRACT

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Scylla serrata, negative allometric, condition factor, growth, mortality, exploitation rate

This study examined the size structure, growth patterns, condition factors, mortality, and exploitation levels of mud crab (*Scylla serrata*) in the Kakuluk Mesak waters from August to October 2025. Data analysis included length–weight regression, the von Bertalanffy Growth Function (VBGF) to estimate growth parameters (CW_{∞} , K , t_0), and FiSAT-II for mortality (M , F , Z) and exploitation rate (E). A total of 78 individuals were collected using folding traps, with carapace widths (CW) ranging from 31.00–117.07 mm (males) and 38.12–123.28 mm (females). Both sexes exhibited negative allometric growth ($R^2 = 0.8067$ for males; 0.8916 for females). Growth coefficients were higher in males ($K = 0.62 \text{ year}^{-1}$) than in females (0.50 year^{-1}), although females reached larger asymptotic sizes ($CW_{\infty} = 131.72 \text{ mm}$ vs. 118.00 mm). Condition factor analysis indicated that values exceeded 1, suggesting that both male and female mud crabs were in healthy physiological condition. Mortality estimates showed Z values of 3.20 year^{-1} (males) and 1.58 year^{-1} (females), with F values of 1.04 and 0.79 year^{-1} , respectively. Exploitation rates were 0.32 for males and 0.50 for females, indicating lower fishing pressure on males and near-optimal exploitation for females. These findings highlight sex-specific population dynamics and support adaptive management strategies for sustainable utilization.

1. INTRODUCTION

The mud crab (*Scylla serrata*) is a fishery commodity with high economic value, which plays an important role in coastal fisheries, primarily due to domestic and international demand and high cultivation prospects [1]. This crab is widely distributed in almost all coastal areas of Indonesia, specifically in areas with mangrove, estuarine, and lagoon ecosystems. Geographically, mud crabs are widely distributed across Indonesia, extending from the western to the eastern regions, including the coastal areas of Sumatra, Kalimantan, Java, Bali, Nusa Tenggara, Sulawesi, Maluku, and Papua [2-5]. The mud crab occurrence is closely related to the availability of mangrove habitat.

The mangrove ecosystem in Kakuluk Mesak, Belu Regency, East Nusa Tenggara Province, is spread along the coastal area directly bordering the Sawu Sea and the southern coastal waters of Timor Island. In this area, mangroves generally thrive in small bays, river estuaries, and coastal areas with relatively low wave energy [6]. The extensive mangrove area is important for the survival of mud crabs, serving as a nursery and feeding grounds, and providing protection from predators [7]. In addition to their ecological importance, mud crabs also provide significant economic value for coastal communities

because they are marketed for both local consumption and commercial sale as a high-value seafood commodity. Their relatively high selling price makes them one of the important fishery resources in mangrove-based coastal livelihoods.

In this area, the potential of mud crab resources has not been optimally used by local fishermen. This is due to limited knowledge and mastery of fishing technology, as well as a lack of understanding of mud crab as an economically important fishery commodity, despite relatively high demand. Mud crab fishing in Kakuluk Mesak is generally conducted by small-scale fishers using simple and traditional fishing methods, particularly folding traps, hand capture, and other passive gears operated in mangrove channels and intertidal zones. Although the fishery remains relatively small-scale, increasing market demand and easy access to mangrove habitats may gradually intensify fishing pressure on natural stocks.

Furthermore, mud crab populations in various regions continue to face significant threats due to mangrove ecosystem degradation and increasing anthropogenic pressures in coastal areas [8]. Land conversion, habitat destruction, and coastal development pressures have reduced the quality and availability of important habitats that serve as nurseries and growth areas for mud crab. At the national level, Indonesia regulates mud crab harvest and trade through minimum legal

size requirements. Under the Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia (Permen KP No. 1 of 2015), only individuals with a carapace width (CW) greater than 150 mm may be traded legally. However, information regarding the implementation of such regulations at the local level, including the protection of berried females and restrictions on harvesting immature individuals, is still limited and not yet well documented in Kakuluk Mesak. As a result, mud crab utilization in this area is still largely based on opportunity and local practice rather than stock-based management. This condition, compounded by increasing fishing intensity, has the potential to result in overexploitation and a decline in natural stocks. Therefore, before developing utilization, an evaluation of the stock status and biological parameters of the mud crab population is necessary as a basis for planning sustainable utilization and management.

Population size structure studies are necessary to describe the size composition of captured crab and identify indications of premature harvesting of juveniles and brood stock. Analysis of length-weight relationships and condition factors provides important information about growth patterns and the well-being and health of individuals within a population, reflecting the quality of their habitat and the availability of food resources [9, 10]. Growth parameters, such as asymptotic length and growth rate, play an important role in understanding mud crab growth dynamics and determining optimal harvest sizes. Furthermore, estimates of natural and fishing-induced mortality provide a foundation for assessing the pressure exerted on the population. These estimates are subsequently used to calculate the exploitation rate, which reflects the balance between resource utilization and the population's capacity for natural recovery [11]. The exploitation rates exceeding the optimal level may show

overexploitation, potentially threatening the sustainability of mud crab stocks.

Therefore, this study aimed to: (1) describe the size structure of male and female mud crabs (*Scylla serrata*) in Kakuluk Mesak waters; (2) analyze the CW–body weight relationship and condition factor; (3) estimate growth parameters using the von Bertalanffy Growth Function (VBGF), including asymptotic carapace width (CW_{∞}), growth coefficient (K), and theoretical age at zero size (t_0); (4) estimate natural mortality (M), fishing mortality (F), and total mortality (Z); and (5) assess the exploitation rate (E) of the mud crab population. The results of this study are expected to provide a scientific basis for developing sustainable mud crab management strategies, including regulating catch size, controlling fishing effort, and protecting mangrove habitat as the primary support for the mud crab's life cycle.

2. MATERIALS AND METHODS

2.1 Study area

This study was conducted in the Kakuluk Mesak mangrove area, Belu Regency, East Nusa Tenggara (Figure 1), in a space of three months, from August to October 2025. The main sampling location was situated at coordinates 9.007448° S and 124.849526° E. The study area represents a mangrove-associated coastal habitat used by mud crabs for feeding, shelter, and growth. Sampling stations were established in representative habitats within the mangrove ecosystem, including mangrove edges, tidal creeks, and shallow intertidal channels. The selection of sampling locations was based on habitat characteristics and accessibility in the field.

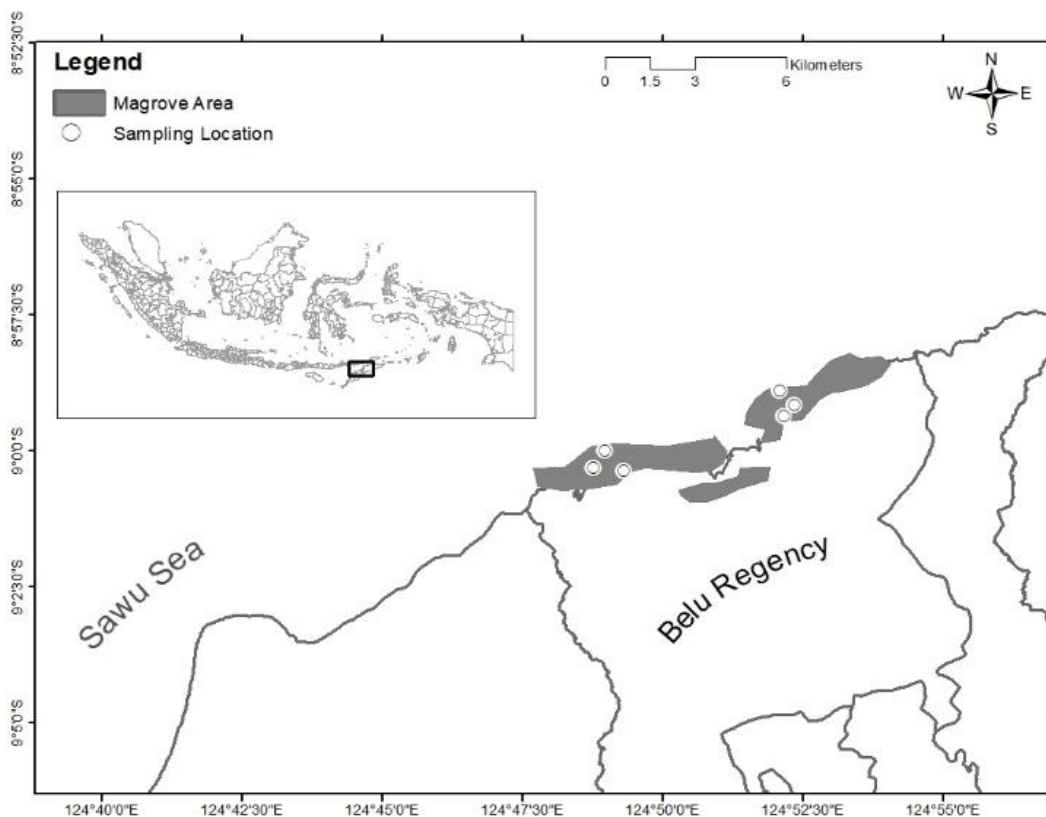


Figure 1. Study location in the Kakuluk Mesak Mangrove area, Belu regency

2.2 Sample collection

In this study, the data used were primary data in the form of biological information on the mud crab (*Scylla serrata*). The data collected included CW (mm), body weight (g), sex, and capture location. Capture was carried out using folding fish traps measuring 20 × 14 × 7 inches, made of a galvanized iron frame with a diameter of 4 mm and covered with polyethylene (PE) netting with a mesh size of 1.25 inches. Each trap was equipped with a funnel-shaped entrance suitable for capturing benthic crustaceans. At each sampling location, 10 traps were deployed per sampling event. Traps were baited with scads and set in the afternoon during the transition from low to high tide, then retrieved the following morning after an approximate soak time of 12–14 h. Sampling was repeated throughout the study period to obtain representative biological data during the observation months. The fish traps were placed randomly in the mangrove area in the afternoon and retrieved in the morning. Water temperature was measured using a thermometer, and the reported value represents the mean of all recorded measurements during the study period.

A total of 78 mud crabs were collected during the study period and separated by sex for biological analysis, consisting of 42 males and 36 females. Although the sample size was relatively limited for population-level inference, the collected data were considered sufficient to provide preliminary information on the size structure, growth pattern, and exploitation status of mud crabs in the study area.

2.3 Data analysis

2.3.1 Size structure

Mud crab catch data from the study sites were analyzed to examine the size structure. The size structure of both sexes was analyzed using CW frequency distributions, with males and females analyzed separately. CW data were grouped into 14 mm class intervals to describe the observed size composition of the catch. Given the relatively limited sample size, this analysis was used primarily to describe the observed size distribution rather than to infer the full population structure. Tabulated data on fishing effort and catch were used to estimate total catch production at the study sites.

2.3.2 Length-weight relationship

The length-weight relationship of fish was analyzed using the equation:

$$W = aL^b \quad (1)$$

W is weight (g), L is length (mm), and a and b are regression constants. In this study, CW was used in place of total length, so the equation was applied as $W = aCW^b$. The b value was tested using a 95% confidence interval and a t-test at a significance level of 0.05 to determine the growth pattern, namely isometric ($b = 3$) or allometric ($b \neq 3$) [9, 10]. Separate regression analyses were performed for males and females.

2.3.3 Condition factors

Condition factors of mud crabs were calculated using the Fulton condition factor (K), allometric condition factor (Ka), and relative condition factor (Kn). The K and ka values show the physical condition of the fish, while the Kn value is used to assess relative condition, with $Kn > 1$ showing good condition [12-14]. Condition factor analysis was conducted

separately for males and females to account for sex-related differences in morphology and growth.

2.3.4 Growth parameters

Crab growth was analyzed using the von Bertalanffy equation [11], which is formulated as:

$$CW_t = CW_\infty (1 - e^{-K(t-t_0)}) \quad (2)$$

where, CW_t is the crab carapace width at age t , CW_∞ is the asymptotic CW, K is the growth coefficient, and t_0 is the theoretical age of the crab when the CW is zero. Growth parameters were estimated separately for males and females based on CW frequency data using ELEFAN I implemented in FiSAT II. The analysis was conducted using the VBGF with a non-seasonal growth assumption. Seasonal growth oscillation parameters were set to $C = 0$ and $ts = 0$, indicating no seasonal variation in growth, consistent with the default settings in FiSAT II. The initial parameter search ranges for CW_∞ and growth coefficient (K) were determined through response surface analysis, and the best fit was selected based on the highest goodness-of-fit index (Rn). The analysis followed standard ELEFAN I procedures, including restructuring of length-frequency data using a moving average smoothing technique. The t_0 value was calculated separately using Pauly's empirical equation:

$$\log(-t_0) = 0.3922 - 0.2752(\log CW_\infty) - 1.038(\log K) \quad (3)$$

Thereby allowing for a more accurate determination of crab growth parameters in each width class. Because the available sample size was relatively limited ($n = 78$), the estimated growth parameters should be interpreted as preliminary approximations of growth dynamics in the study area.

2.3.5 Mortality rate

The total mortality value (Z) was calculated using the length-converted catch curve (LCCC) method in FiSAT II, based on CW frequency data. Prior to analysis, CW data were grouped into 14 mm size class intervals. The descending right arm of the catch curve, representing fully recruited individuals, was selected for linear regression following the standard FiSAT II procedure. Only the descending portion considered biologically representative was used to estimate total mortality (Z). The natural mortality rate (M) was estimated using Pauly's empirical equation:

$$\log M = 0.0066 - 0.79 \log CW_\infty + 0.6543 \log K + 0.4634 \log T \quad (4)$$

where, T is the mean annual water temperature (°C) in the study area. In this study, the average water temperature used in the analysis ($T = 31.5$ °C) was obtained from in situ measurements during gear setting and hauling operations throughout the sampling period. Mortality due to fishing (F) was determined based on the relationship between total mortality and natural mortality, where the F value was obtained from:

$$Z = F + M \quad (5)$$

Thus,

$$F = Z - M \quad (6)$$

Natural mortality (M) was estimated using Pauly's empirical equation, which incorporates growth parameters (CW_{∞} and K) and the mean environmental temperature (T). In this study, no specific assumption of "optimal" temperature conditions was applied; instead, the actual average in situ water temperature measured during the sampling period ($T = 31.5\text{ }^{\circ}\text{C}$) was directly used in the calculation. This approach ensures that the estimated natural mortality reflects the real environmental conditions experienced by the population during the study period. Pauly's formula was selected because it integrates both biological and environmental variables, making it suitable for tropical aquatic species such as the mud crab.

2.3.6 Exploitation rate

The exploitation rate (E) is determined based on the comparison between the fishing mortality rate (F) and the total mortality rate (Z). Referring to Pauly [11], the exploitation rate is calculated using the equation:

$$E = \frac{F}{F + M} \quad (7)$$

or equivalent:

$$E = \frac{F}{Z} \quad (8)$$

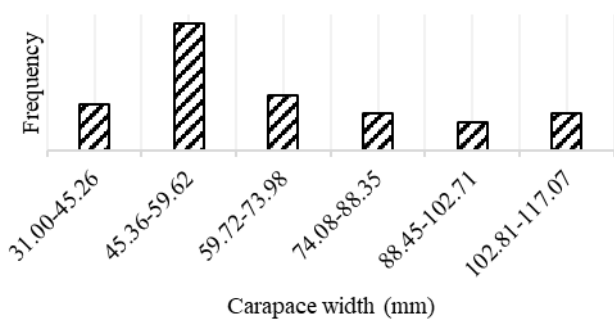
where, F is fishing mortality, M is natural mortality, and Z is total mortality. The exploitation rate (E) reflects the intensity of mud crab resource utilization, where $E < 0.50$ indicates under-exploitation, $E \approx 0.50$ represents the optimal level of exploitation, and $E > 0.50$ indicates overexploitation of the stock.

3. RESULTS

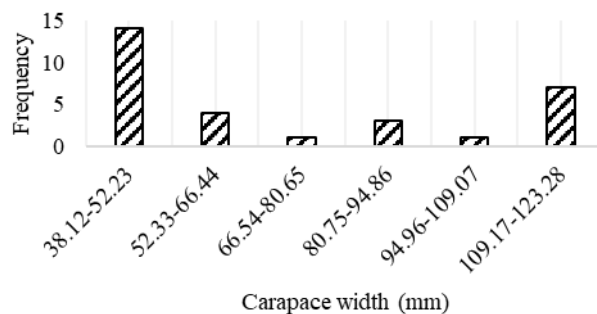
3.1 Size structure

A total of 78 mud crabs (*Scylla serrata*) were collected during the study period from August to October 2025 in Kakuluk Mesak waters. The sample consisted of 42 males (53.85%) and 36 females (46.15%). CW ranged from 31.00 to 117.07 mm in males (Figure 2(a)) and 38.12 to 123.28 mm in females (Figure 2(b)).

The mean carapace width ($CW \pm SD$) was 68.10 ± 25.74 mm for males and 73.73 ± 31.59 mm for females, with an overall mean of 70.70 ± 28.53 mm (Table 1). These results indicate that female mud crabs tended to have a slightly larger average body size and greater size variability than males.



(a) Male



(b) Female

Figure 2. Size structure of mud crabs

Table 1. Sample composition of *Scylla serrata* collected in Kakuluk Mesak waters

Parameter	Male	Female	Total
Number of individuals (n)	42	36	78
Percentage (%)	53.85	46.15	100
Carapace width range (mm)	31.00–117.07	38.12–123.28	31.00–125.14
Mean CW \pm SD (mm)	68.10 ± 25.74	73.73 ± 31.59	70.70 ± 28.53
Berried females	–	0	–

Sampling was conducted over three months, with varying numbers of individuals collected in each month. A total of 24 individuals were obtained in August, 28 individuals in September, and 26 individuals in October. The monthly sex composition consisted of 13 males and 11 females in August, 15 males and 13 females in September, and 14 males and 12 females in October. No berried females were observed during the sampling period. This indicates that all sampled individuals were non-ovigerous at the time of capture. A summary of the sample composition is presented in Table 2.

Table 2. Monthly sample composition of *Scylla serrata*

Month	Male	Female	Total
August 2025	13	11	24
September 2025	15	13	28
October 2025	14	12	26
Total	42	36	78

3.2 Length-weight relation

The growth pattern of the mud crab (*Scylla serrata*) was analyzed using a regression method by examining the relationship between CW and body weight. The results of the analysis showed that the coefficient of determination (R^2) for male mud crab was 80.67% and for females, 89.16%. This coefficient shows the extent to which the independent variable (CW) is able to explain the dependent variable (body weight), thereby allowing prediction of individual weight based on carapace size. The high R^2 values for both sexes show that the body weight of mud crabs in the Kakuluk Mesak mangrove area can be estimated quite accurately from their CW. The obtained length-weight relationship equations are $W = 0.0139 \times CW^{2.0674}$ for male crabs and $W = 0.0024 \times CW^{2.4148}$ for female crabs, which are visualized in the length-weight relationship graph in Figure 3.

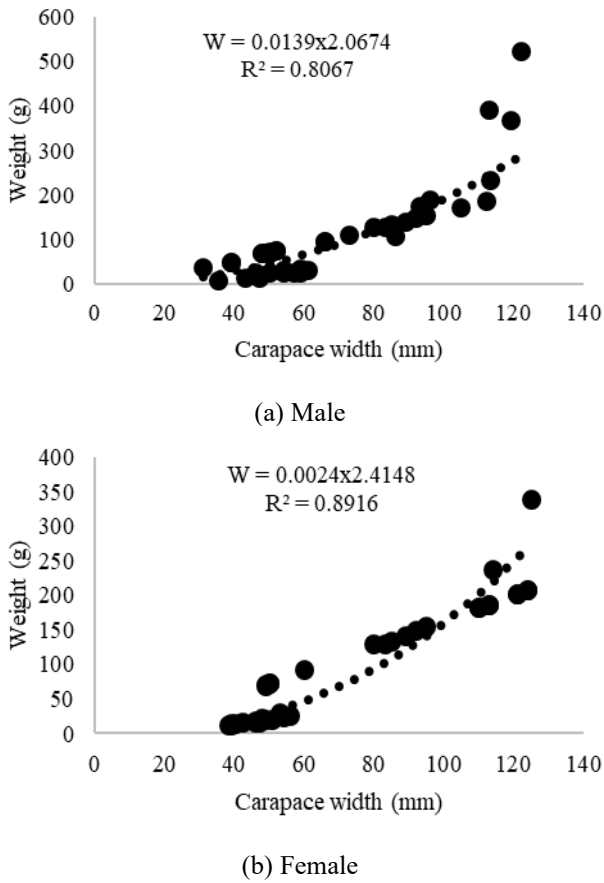


Figure 3. Mud crab growth pattern

The results of the t-test on the relationship between CW and body weight of mud crabs (*Scylla serrata*) in both males and females showed that the calculated t-value (t_{cal}) was greater than the critical t-table (t_{crit}). This shows that the relationship between CW and body weight is not isometric. Furthermore, the growth exponent (b) was less than 3 in both sexes, showing negative allometric growth. This means that the growth of the mud crab's body weight is slower than the growth of the CW.

3.3 Condition factors

The results of the condition factor analysis showed that both male and female mud crabs were in good physiological condition (Table 3). Male mud crabs exhibited a relative condition factor (K_c) of 2.06 ± 0.91 and an absolute condition factor (K_a) of 1.96 ± 0.87 , reflecting favourable body condition and growth performance. This result is further supported by a relative weight condition factor (K_n) of 1.06 ± 0.47 , which was above one. Meanwhile, female mud crabs showed a K_c value of 1.50 ± 0.70 and a K_a value of 1.51 ± 0.40 , which were relatively lower than those of males, but a K_n value of 1.10 ± 0.56 still showed good body condition. Overall, K_n values greater than one in both sexes showed that the mud crab population was in a healthy condition and the aquatic environment was still able to support its growth and survival.

Table 3. Condition factors of mud crabs in the Kakuluk Mesak mangrove areas

Sex	K_c	K_a	K_n	Status
Male	2.06 ± 0.91	1.96 ± 0.87	1.06 ± 0.47	Healthy
Female	1.50 ± 0.70	1.51 ± 0.40	1.10 ± 0.56	Healthy

3.4 Growth parameters and von Bertalanffy Growth Function analysis

The growth of *Scylla serrata* in Kakuluk Mesak waters was analyzed using the VBGF. The estimated growth parameters showed clear differences between sexes. For males, the CW_{∞} was 118.00 mm, with a growth coefficient (K) of 0.62 year^{-1} and a theoretical age at zero size (t_0) of -0.18. For females, CW_{∞} was higher at 131.72 mm, with a lower growth coefficient (K) of 0.50 year^{-1} and a t_0 value of -0.22 (Table 4).

Table 4. Growth parameters of mud crabs in the Kakuluk Mesak mangrove areas

Sex	CW_{max} (mm)	CW_{∞} (mm)	K (yr^{-1})	t_0 (yr)
Male	122.12	118.00	0.62	-0.18
Female	125.14	131.72	0.50	-0.22

The VBGF curves (Figure 4) show that male mud crabs exhibit a faster growth rate at early ages, as reflected by the higher K value, enabling them to attain intermediate sizes more quickly. However, their growth gradually levels off at a smaller asymptotic size. In contrast, female mud crabs display a slower initial growth rate but continue growing over a longer period, eventually surpassing males in size and reaching a larger asymptotic CW. This pattern is evident in the curve where males are slightly larger at younger ages, while females dominate in size at later ages.

The separation between male and female growth trajectories becomes more evident with increasing age, indicating sex-specific growth strategies. This pattern suggests that males prioritize rapid early growth, while females allocate energy toward prolonged growth and larger body size, which may be related to reproductive capacity.

The inclusion of smaller size classes in the frequency distribution supports the reliability of the growth parameter estimation, as early growth stages were represented in the dataset. Nevertheless, given the relatively limited sample size, the estimated parameters should be interpreted as preliminary approximations of population growth dynamics in the study area.

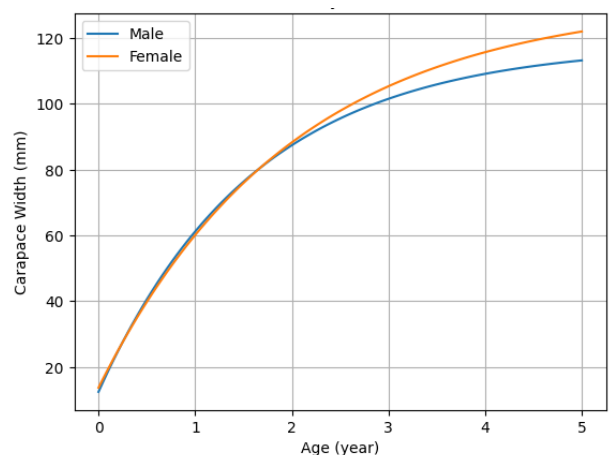


Figure 4. Von Bertalanffy Growth Function (VBGF) curves of male and female *Scylla serrata* in Kakuluk Mesak waters based on estimated growth parameters

3.5 Mortality rate

The results of the mortality analysis showed that the

contribution of each factor causing mortality differed between male and female mud crabs. In male mud crabs, the mortality rate due to fishing (F) of 1.04 per year contributed approximately 32.5% to the total mortality (Z) of 3.20 per year, while natural mortality (M) of 2.16 per year contributed approximately 67.5%. This shows that most of the mortality of male mud crabs was more influenced by natural factors than by fishing pressure. In contrast, in female mud crabs, the mortality rate due to fishing (F) of ± 0.79 per year and natural mortality (M) of ± 0.79 per year each contributed approximately 50% to the total mortality (Z) of ± 1.58 per year. This condition shows that in female mud crabs, fishing factors and natural factors have a relatively balanced influence on the mortality rate.

3.6 Exploitation rate

The results of the exploitation level analysis show that the level of mud crab utilization differs between males and females. Male mud crabs have an exploitation level (E) value of 0.32, showing that fishing pressure on males is still relatively low and has not yet become a major factor causing mortality in the population. This value shows that the exploitation of male mud crabs remains below the optimal level, and the male is generally considered to be in a relatively safe condition. In contrast, female mud crabs exhibit a higher exploitation rate, approximately 0.5, suggesting that fishing pressure on females is approaching the optimal threshold. This condition shows that the proportion of fishing mortality in female mud crabs is almost proportional to the total mortality they experience, thereby increasing fishing effort has the potential to encourage excessive pressure.

4. DISCUSSION

The CW distribution of mud crabs (*Scylla serrata*) in Kakuluk Mesak waters, dominated by small to medium-sized individuals, is consistent with patterns reported in several mangrove waters in Indonesia, including Takalar, Sebatik, and Subang, although the maximum size at these locations is slightly larger [2, 5, 15]. Other studies in Indonesia have shown a dominance of subadult individuals, reflecting interactions between growth dynamics, fishing pressure, and similar mangrove habitat conditions [15]. *S. serrata* populations in the Cochin estuary, India, as well as several other Indo-Pacific regions, show a wider range of size and growth variation influenced by ecological and anthropogenic factors [8].

However, it is important to note that the present study was based on a relatively limited sample size ($n = 78$), which may constrain the representativeness of the observed size structure. Although the data provide useful preliminary insights into the population, a larger sample size would be required to more accurately characterize the full population structure and size variability of *S. serrata* in the study area.

Growth patterns in Kakuluk Mesak showed a negative allometric relationship between CW and body weight, showing that body weight increases at a slower rate than CW. This pattern is consistent with results reported from other locations in Indonesia and across the Indo-Pacific regions [16-20]. The condition factor analysis confirmed that both sexes were in healthy physiological condition, showing sufficient body capacity to support growth and survival, and showing

that the mangrove ecosystem remains adequate for mud crab populations [8, 21-23]. This comparison shows that, despite the relatively smaller maximum size observed in Kakuluk Mesak, healthy size distributions, negative allometric growth patterns, and favourable condition factors represent common biological characteristics of *S. serrata* in tropical mangrove ecosystems.

Nevertheless, the sampling period of this study was limited to three months (August–October 2025), which does not fully capture the complete growth cycle or seasonal variability of the mud crab population. Seasonal factors such as recruitment pulses, spawning cycles, and environmental fluctuations may influence growth and size distribution, and these dynamics could not be fully addressed within the short sampling duration. Therefore, the results should be interpreted as representing a partial temporal snapshot rather than long-term population dynamics.

The results of this study show differences in growth characteristics, mortality, and exploitation rates between male and female mud crabs. Male mud crabs tend to grow faster but reach smaller maximum sizes, while females grow more slowly but have the potential to reach larger sizes. This difference is caused by different energy allocation strategies between the sexes, and this is because males allocate energy to rapid growth and mobility to defend territorial areas and compete for mates, while females allocate energy to longer body growth to support reproductive capacity and egg production [24-27]. This pattern is in line with the results of Fitriyani et al. [3], who reported that female *Scylla* spp. have slower growth with larger carapace sizes. Studies in India also showed a similar trend, where females reach larger maximum sizes despite slower long-term growth [28].

The estimated growth coefficients ($K = 0.62 \text{ year}^{-1}$ for males and 0.50 year^{-1} for females) fall within the general range reported for tropical crustaceans, indicating relatively rapid growth under favorable environmental conditions. The higher K value in males reflects faster growth rates, whereas the lower K value in females indicates slower but prolonged growth. These values are considered biologically reasonable and consistent with patterns observed in other studies of *S. serrata* in tropical mangrove ecosystems. However, variations in K may also be influenced by sampling design, environmental conditions, and the size composition of the sampled population.

Mortality analysis showed differences in the influence of natural factors and fishing pressure between males and females. Male crabs experienced higher total mortality, particularly among crustaceans, due to natural factors such as predation, disease, and intraspecific competition [29-32], while fishing pressure was relatively lower [33]. Conversely, in females, mortality due to natural factors and fishing pressure was relatively balanced, showing that fishing pressure significantly contributed to mortality rates. This difference may be attributed to the behavioural patterns of females, which tend to occupy shallow waters or reproductive habitats for extended periods, thereby increasing their vulnerability to capture by fishers [34].

It is also important to consider that the estimation of CW_{∞} may be influenced by the size composition of the sample. Although smaller size classes were present, the limited number of individuals in the smallest size groups may introduce bias in growth parameter estimation, particularly in length-frequency-based models such as VBGF. Underrepresentation of early size classes can lead to overestimation or

underestimation of CW_{∞} , and therefore, the reported values should be interpreted with caution.

The results from the exploitation rates reinforce differences in population dynamics. Males exhibit low exploitation rates, thereby keeping the population relatively safe from overfishing pressure. In contrast, females exhibit higher exploitation rates, suggesting that female catch is nearly proportional to their contribution to total mortality. This situation results from fishing practices that selectively target larger individuals, predominantly females, as well as market preferences that favour larger female crabs [25, 35]. These results are in line with the harvesting of mud crabs in the Philippines, which emphasizes that overfishing of females has the potential to reduce the reproductive capacity of populations [36].

In general, differences in growth, mortality, and exploitation rates show distinct life strategies between males and females, and are influenced by both biological factors (behavior, energy allocation, reproductive capacity) and external factors (predation, habitat, fishing pressure). Males grow rapidly and have smaller maximum sizes, while females grow slowly but have the potential to reach larger sizes under higher fishing pressure. Given the limitations in sample size and sampling duration, future studies with longer observation periods and larger sample sizes are recommended to improve the robustness of population parameter estimates.

These findings have important implications for fisheries management, particularly when viewed in the context of national regulations in Indonesia. According to the Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia (Permen KP No. 1 of 2015), only mud crabs with a CW greater than 150 mm are legally permitted for trade. However, the size distribution observed in this study indicates that the majority of sampled individuals were below this threshold, suggesting that a significant proportion of the catch may consist of undersized individuals.

Importantly, this finding appears inconsistent with the estimated $CW_{\infty} = 131.72$ mm for females and 118.00 mm for males, both of which are below the legal size limit of 150 mm. This discrepancy suggests two possible explanations: (1) the local population may not naturally attain the legal size threshold under prevailing environmental and ecological conditions, or (2) the sampled population may be truncated, with larger individuals either not captured by the fishing gear or underrepresented due to the limited sample size and short sampling period. Consequently, the absence or low representation of larger size classes in the dataset may bias growth parameter estimates and affect the interpretation of size structure.

This condition raises concerns regarding the sustainability of mud crab exploitation in Kakuluk Mesak waters, as the capture of individuals below the legal size limit may reduce reproductive potential and hinder population recovery. The relatively high exploitation rate observed in females further reinforces this concern, given their role in reproduction and stock replenishment.

Furthermore, the mismatch between the biological growth potential (CW_{∞}) and the regulatory size limit indicates that the application of a uniform minimum legal size (150 mm) may not fully reflect local population characteristics, potentially complicating management implementation. Therefore, further studies with broader temporal coverage, larger sample sizes, and improved sampling strategies are necessary to determine whether the observed size limitation reflects true biological

constraints or sampling bias, and to support more adaptive and site-specific management measures.

Therefore, the implementation and enforcement of size-based regulations, particularly the minimum legal size ($CW > 150$ mm), are essential to ensure sustainable utilization. In addition, complementary management measures such as the protection of large reproductive females, seasonal fishing closures, and habitat conservation should be considered to maintain the ecological balance and long-term productivity of mud crab populations.

5. CONCLUSIONS

This study provides insights into the population dynamics of mud crab (*Scylla serrata*) in Kakuluk Mesak waters based on size structure, growth, mortality, and exploitation analyses. The estimated growth parameters showed that males had a higher growth coefficient ($K = 0.62 \text{ year}^{-1}$) but a smaller $CW_{\infty} = 118.00$ mm, whereas females exhibited slower growth ($K = 0.50 \text{ year}^{-1}$) but a larger asymptotic size ($CW_{\infty} = 131.72$ mm). Condition factor analysis indicated that the population was in a generally healthy physiological state.

Mortality analysis indicated that fishing mortality (F) was 1.04 year^{-1} for males and 0.79 year^{-1} for females, while exploitation rates (E) were 0.32 and 0.50, respectively; these results indicate that males experience relatively low fishing pressure (underexploited), whereas females are at a near-optimal exploitation level ($E \approx 0.50$), which represents the commonly accepted optimal threshold rather than excessive exploitation.

Overall, these findings highlight sex-specific differences in growth and exploitation patterns. Given that most sampled individuals were below the minimum legal size ($CW > 150$ mm), the current exploitation pattern may pose a risk to population sustainability. Therefore, management strategies should consider sex-based approaches, including regulating catch size, protecting larger reproductive females, and strengthening the enforcement of minimum size regulations to ensure sustainable utilization of mud crab resources.

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