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ORIGINAL ARTICLE

Population dynamics of mud crab, *Scylla olivacea* (Herbst, 1796) from the Sundarbans of Bangladesh

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Assessment of Mud Crab Resources in Bangladesh

Abstract

The Sundarbans mangrove regions are the home of the mud crab (*Scylla olivacea*) business, as forest areas are potential places for random crab harvesting, trading, and exporting overseas seafood markets. Since the mud crab was being captured on a large-scale in the wild for various purposes, estimation of population parameters were immediately done in terms of body weight and length-frequency data collected from different locations in the forest of southwestern Bangladesh to understand the status of the stock. Recruitment pattern, growth parameters, mortality rates, and exploitation levels (*E*) were estimated to understand the population dynamics of *S. olivacea*. Asymptotic carapace widths (CW_{∞}) were 14.70 and 14.18 cm, and growth co-efficients (*K*) were 0.47 and 0.50 year^{-1} for male and female *S. olivacea*, respectively. The fishing mortalities were 2.32 and 1.13 year^{-1} and natural mortalities were 1.39 and 1.46 year^{-1} for males and females, respectively. Year-round recruitment of this species takes place in the wild with a peak between June and November. The *E* for *S. olivacea* was found to be 0.63 for the male and 0.44 for the female. In summery, the stock of *S. olivacea* is found to be overexploited in the Sundarbans of Bangladesh. Therefore, mud crab resources should be taken into consideration under suitable fisheries management policies to conserve this national treasure in this delta. It is supposed that the findings will draw the attention of the scientists in the fields of aquatic biology, ecology, and management of the Sundarbans in restoring the mud crab population.

KEYWORDS
assessment, coastal management, exploitation, fisheries stock, growth, mortality

1 | INTRODUCTION

The red mud crab (*Scylla olivacea* Herbst, 1796) is pretty common and abounds in adjacent wetlands of the world's largest mangrove forest, the Sundarbans (Khatun et al., 2009). As a potential aquaculture species, it is also well known as the orange mud crab and has high nutritional value with good market acceptability (Muhd-Farouk et al., 2019). Naturally, four distinct mud crab species have been identified in the wild, namely, *S. olivacea*, *S. serrata*, *S. paramamosain*, and *S. transquebarica* on the basis of morphological and molecular data (Keenan et al., 1998). In Bangladesh, *S. olivacea* belongs to a bigger mud crab community than that of *S. serrata* (Asaduzzaman et al., 2021).

Generally, the intertidal zones of mangrove forests and estuaries are the main shelters of mud crabs for feeding and breeding to introduce their next generations with a view to accelerating recruitment in the Indo-Pacific region (Waiho et al., 2015). Crab farming and fattening are spreading rapidly in this delta as it has high demand in the international market (Ali et al., 2020). Nowadays, commercial and medicinal uses of mud crabs are quite common in different countries around the world due to their high nutritional quality and availability of antioxidant properties (Yusof et al., 2019). In addition, the importance of *S. olivacea* has increased as a potential export earning aquatic resource, just after the shrimp (*Penaeus monodon*), and thus ranked the second highest in earning foreign currency for Bangladesh (DoF, 2016). However, till now, the wild catch of juvenile and brood crabs has remained a regular practice for coastal farming and trading in the national and international markets (Ferdoushi & Xiang-Guo, 2013; Rahman et al., 2020).

Through a comprehensive extension program on crab farming, climate-stressed coastal communities have begun to become self-sufficient by building capacity and improving economic conditions (Huq et al., 2015). However, the scarcity of commercial crab hatcheries causes inconvenience due to the insufficient supply of seeds to farmers for crab culture (Rahman, 2016). On the other hand, earthen ponds have been used for the fattening of mud crabs since 1993 in the mangrove regions of coastal Bangladesh (Zafar & Ahsan, 2006). Soft-shell, a new concept in mud crab farming, was started in Shyamnagor upazila of Satkhira district in Bangladesh (Rahman et al., 2017). During crab farming, the adjacent rivers of the Sundarbans were the prime source of juvenile crabs for hardening and fattening (Chandra, 2012). It seems that the majority of crabs are being harvested from wild habitats in the coastal regions to meet the market demand. Crab harvesting may put additional strain on their community, reducing genetic diversity and pushing them to become endangered (de Mitcheson et al., 2020; Zhang et al., 2021).

Sustainable fisheries management relies on the proper understanding about the fish population dynamics of a particular species (Gebremedhin et al., 2021). Study on causes and processes of fluctuations in fish populations is known as fish population dynamics (Quinn, 1990). In particular, three factors such as recruitment, growth, and mortality rates primarily affect fish population dynamics (Kilduf et al., 2009). Continuous recruitment of mud crab was observed throughout the year without any seasonal fluctuation in Ranong mangrove of Thailand (Moser, 2005). At the same place, the natural mortality rates of males and females were revealed as 0.90 and 0.49 month^{-1}, respectively. In contrast, yearlong recruitment of *S. olivacea* was observed in the Aru Islands, Indonesia. Moreover, 19.15 cm was determined to be the asymptotic carapace width. Their natural mortality (0.77 year^{-1}) was higher than their fishing mortality (0.74 year^{-1}). Thus, their exploitation rate (*E*) 0.49 indicates that they were being caught moderately (Pane et al., 2020). Likewise, baby crabs were also recruited year-round in the Pichavaram mangroves of India (Viswanathan et al., 2018). In this forest, the male and female *S. olivacea* showed positive and negative allometric growth, respectively. The males asymptotic carapace width was 14.80 cm, while that of the females was 13.88 cm. The natural mortality rates of male and female were 0.21 and 0.37 year^{-1}, respectively. The exploitation rates were 0.78 and 0.66 for male and female *S. olivacea* (Viswanathan et al., 2018). Year-round recruitment, heaviness of male crabs, and high exploitation rate were identified in the mud crab population from Pichavaram forest. Overall, fishing pressure has increased dramatically, which has led to the overexploitation of *S. olivacea* in India, a neighbouring country of Bangladesh.

Stock management is an effective strategy to get back the abundance of threatened species in the wild. Input and output controls are very popular in fisheries management to maintain a healthy stock of a species (Lee et al., 2020). Prior to handling a stock, it seeks some preliminary information on the age, growth, recruitment pattern, mortality, and exploitation rate of a species. Nonetheless, previous research on mud crab stocks in the Sundarbans mangrove areas is limited despite the fact that this crustacean has the potential to establish a lucrative sector for earning foreign currency. Considering these backdrops, this study aims to assess the main population parameters such as carapace width (CW)–body weight (BW) relationship, asymptotic carapace width (CW_∞), growth co-efficient (*K*), recruitment, mortality (*Z*, *M*, and *F*), exploitation level (*E*), and virtual population analysis (VPA) of *S. olivacea*.

2 | MATERIALS AND METHODS

2.1 | Sampling

The Sundarbans mangrove forest and its adjacent areas were emphasized for conducting the study. The sampling stations were chosen based on the abundance of desired mud crab species in three districts in the south-western regions of Bangladesh: Khulna, Bagerhat, and Satkhira. Thereafter, Koyra, Rampal, Mongla, Sharankhola, and Shyamnagar were considered as the sampling stations from the study area (Figure 1). A yearlong sampling was carried out by using hooks and lines to harvest crabs from the wild between February 2016 and January 2017. At each station, baited hooks with chopped fishes mainly tilapia (*Oreochromis mossambicus*) and cuchia (*Monopterus cuchia*) were set during the ebb and flood tides. Besides, a few basket traps were also located in shallow water with samilar baits at a distance of 20–25 m for around 6 h.

2.2 | Data collection

The total number of *S. olivacea* specimens was 1848 consisted of 983 males and 865 females. On the basis of morphological features of the crabs, a standard method was used to identify the species and sex (Keenan et al., 1998). Crab BW was taken using an electronic balance with an accuracy of 0.01 g, and CW was measured by a slide calipers with an accuracy of 0.05 mm.

2.3 | Data analysis

The relationship between CW and BW provides a summary of some attributes and the nature of the growth of a species. The CW-BW

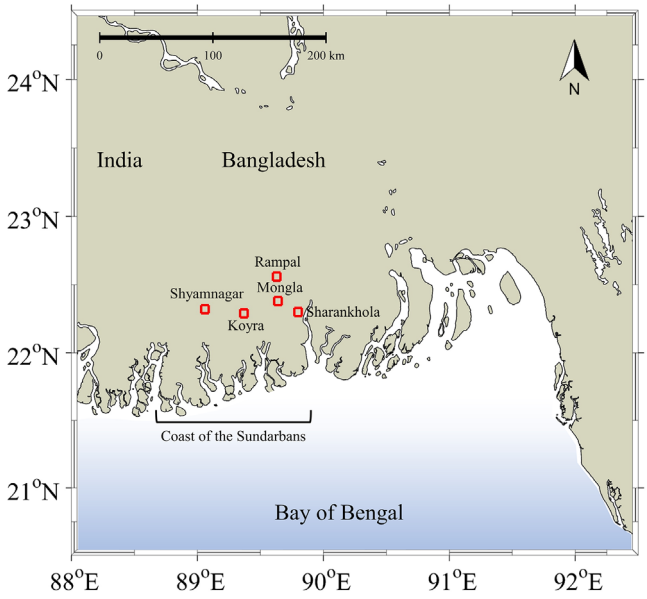

FIGURE 1 Mapping of sampling sites along with the Sundarbans mangrove areas in Bangladesh

relationship of the mud crab was established in terms of both genders by using the following equation:

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

where *W* is BW in gram, *L* is CW in centimetre, *a* and *b* are constants. The log-transformed values of BW and CW were computed for linear regression analysis (log BW = log *a* + *b* × log CW). The student's t-test was chosen to estimate the significance of coefficient b at a 5% significance level. A Pearson's correlation was used to examine the relationship between CW and BW.

The FiSAT-II (FAO-ICLARM Stock Assessment Tools) computer program was used to calculate the asymptotic carapace width (CW_∞) and *K* of the von Bertalanffy equation for growth considering the CW of a crab individual. Incorporated ELEFAN-I (Electronic Length Frequency Analysis) in the FiSAT program was assigned to estimate the value of CW_∞ and *K* by using the following formula:

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

where *t* indicates the age of the mud crab (year), *CW* is the mean carapace width at age *t* (cm), t_0 is the hypothetical age when *CW* is zero, and *K* represents a growth coefficient (year^{-1}). From *K* and CW_∞ the growth performance index (ϕ') of *S. olivacea* derived according to Pauly and Munro (1984), is as follows:

$$\phi' = \log K + 2\log CW_\infty, \quad (3)$$

The length converted catch curve method of Beverton (1956) was applied to determine total mortality (*Z*) by considering the habitat temperature of 30.8°C in 2016 as mentioned by Azad et al. (2020). According to Pauly (1980), an empirical relationship was employed to predict natural mortality (*M*); by subtracting natural mortality (*M*) from total mortality (*Z*), fishing mortality (*F*) was measured in year^{-1}. According to Gulland (1971), *E* was estimated to reveal the portion of total mortality due to fishing by the following formula:

$$E = F/Z, \quad (4)$$

The FiSAT-II length-weight data management software was applied to estimate the recruitment pattern by considering a backward projection method on the CW axis of a set of CW-frequency data. The 'probability of capture' routine was used to measure the possibility of mud crab capture, and the FiSAT-II analyzer was used to determine the approximate CW structured virtual population.

TABLE 1 Carapace width–body weight (CW-BW) association of sampled *Scylla olivacea* from the Sundarbans of Bangladesh

Sex	Size (N)	*a*	*b*	*r*	R^2	Allometry	p-Value
Male	983	0.2274	3.05	0.99	0.99	Positive	0.00
Female	865	0.4296	2.61	0.99	0.98	Negative	0.00

3 | RESULTS

3.1 | CW-BW relationship

The relationship between CW and BW of *S. olivacea* for both sexes is displayed in Table 1. The logarithmic form of the equation (BW = $a \times CW^b$) was considered to establish the CW-BW relationship. All values of carapace widths were plotted against the values of respective BWs to complete the scatter diagram for getting a curvilinear relationship (Figure 2). Parabolic curves were made by plotting the calculated value of the BW against the carapace width of the male and female *S. olivacea*. In contrast, the values of log total CW against their log calculated BW were plotted to get linear lines. The estimated *b* values were 3.05 and 2.61 for the male and female, respectively. The male showed positive growth allometry, whereas the female showed negative growth allometry. The Pearson correlation co-efficient (*r*) value was 0.99 for both sexes of *S. olivacea*. It indicates highly significant relationships between CW and BW of this species.

3.2 | Growth parameters

The von Bertalanffy asymptotic lengths (CW_∞) were 14.70 and 14.18 cm and the *K* was 0.47 and 0.50 year^{-1} for males and females *S. olivacea*, respectively. These two parameters were used to produce growth curves with the length frequency distribution (Figure 3). The estimated growth performance index (ϕ') for males and females was observed to be 2.006 and 2.002, respectively (Table 2). For both sexes, the best estimated value of growth coefficient (*K*) and growth performance index (ϕ') is presented in Figure 4.

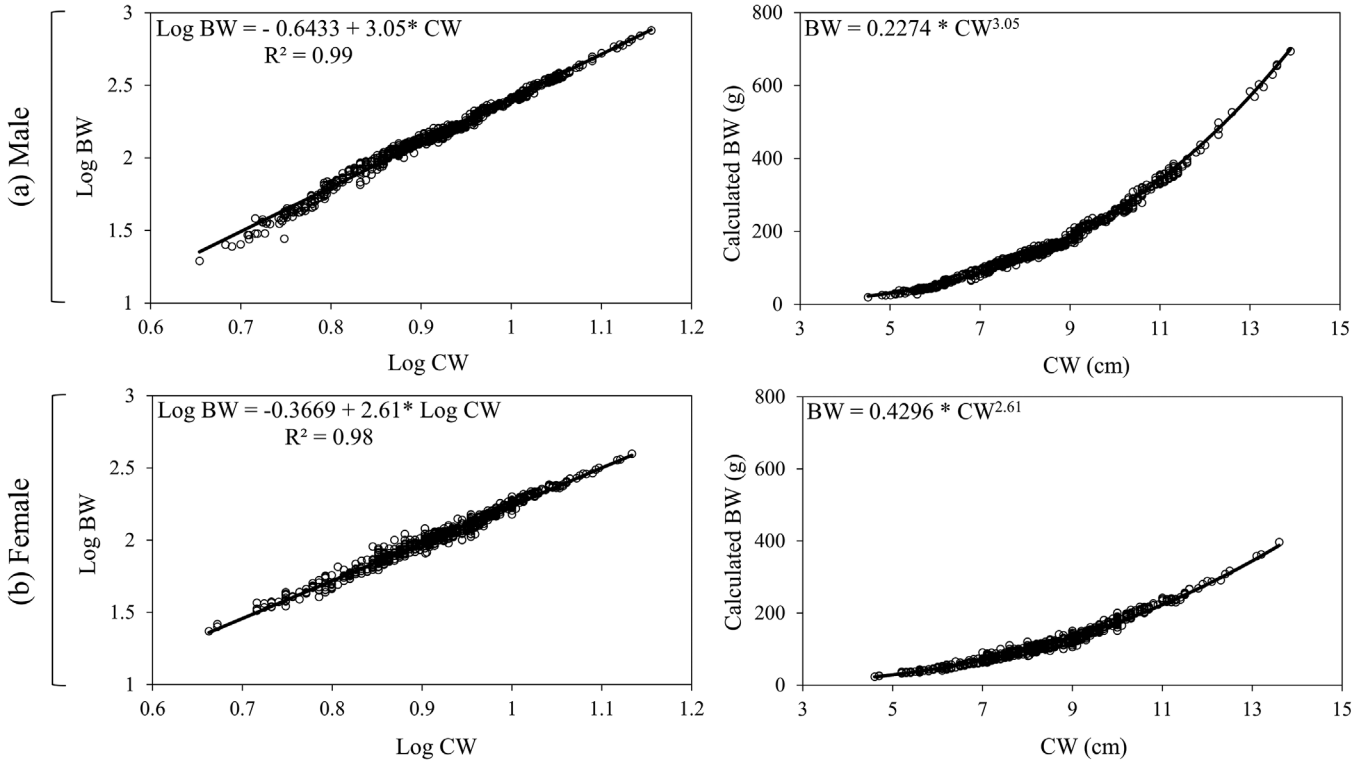

FIGURE 2 The relationship between body weight (BW) and carapace width (CW) of (a) male and (b) female *Scylla olivacea* in the Sundarbans mangrove forest of Bangladesh

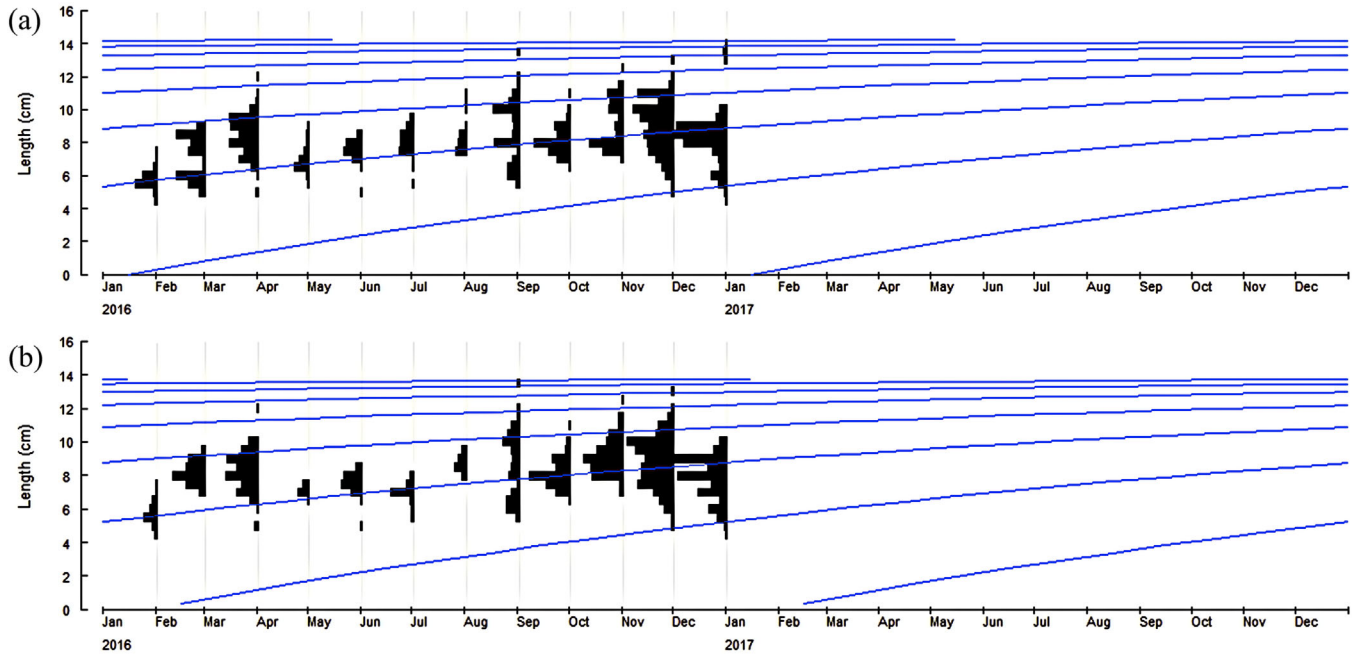

FIGURE 3 von Bertalanffy growth curves of (a) male and (b) female *Scylla olivacea* drown over their restructured length distribution

TABLE 2 Population parameters of *Scylla olivacea* at the Sundarbans in Bangladesh

	Parameters								
Sex	CW_{∞} (cm)	K(year^{-1})	ϕ'	M (year^{-1})	F (year^{-1})	Z (year^{-1})	E	E_{max}	Status
Male	14.70	0.47	2.006	1.39	2.32	3.71	0.63	0.50	$E > E_{max}$
Female	14.18	0.50	2.002	1.46	1.13	2.59	0.44	0.50	$E < E_{max}$

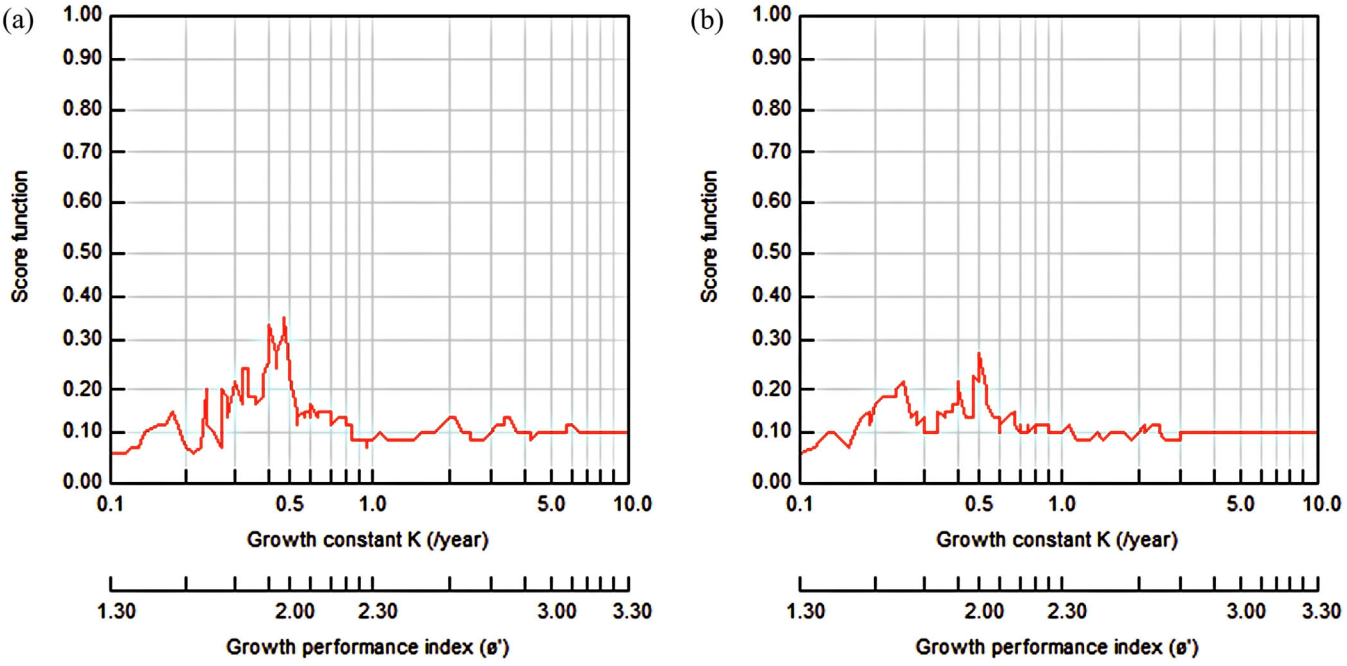

FIGURE 4 Estimation of *K* for (a) male and (b) female *Scylla olivacea* in the Sundarbans of Bangladesh

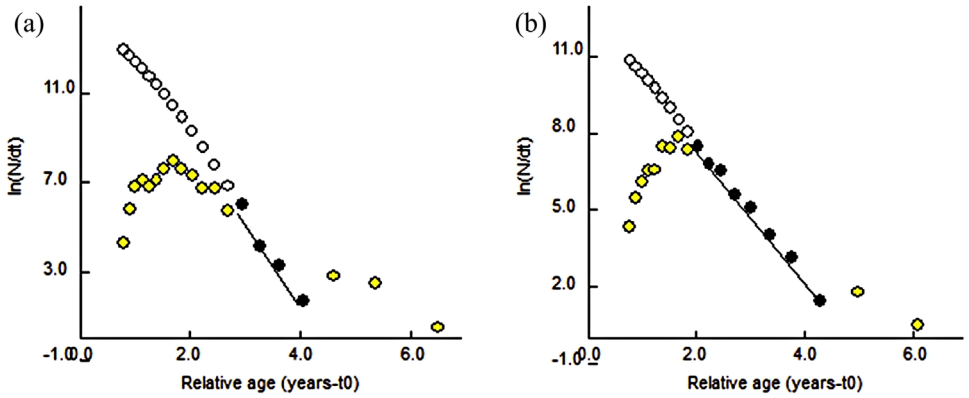

FIGURE 5 Length converted catch curve of (a) male and (b) female *Scylla olivacea* in the Sundarbans mangrove regions of Bangladesh

3.3 | Mortalities

The total mortality (*Z*) for male and female *S. olivacea* was estimated at 3.71 and 2.59 year^{-1}, respectively, using length converted catch curve analysis (Figure 5). Natural mortalities (*M*) were 1.39 year^{-1} for males and 1.46 year^{-1} for females, and fishing mortalities (*F*) were 2.32 year^{-1} for males and 1.13 year^{-1} for females (Table 2). Male and female natural mortality rates ranged from 1.39 to 1.46 year^{-1}, but fishing mortality rates between the females and males were in the range of 1.13–2.32 year^{-1}.

3.4 | Exploitation levels (*E*)

E for male and female *S. olivacea* were 0.63 and 0.44, respectively (Table 2). The maximum permissible limit of exploitation (E_{max}) value is 0.50 for both sexes of *S. olivacea*. Apparently, it was found that exploitation value (*E*) for females was very close to the E_{max} value. On the other hand, *E* of males were exceeded the maximum permissible limit of expoitation (E_{max}).

3.5 | Recruitment pattern

Overall, recruitment was observed all year long for both sexes of mud crab. However, the recruitment pattern for the male *S. olivacea* in the study area suggested continuous recruitment with only one yearly major peak from July to October. Likewise, recruitment of female *S. olivacea* was also continuous with a major peak between June and September (Figure 6).

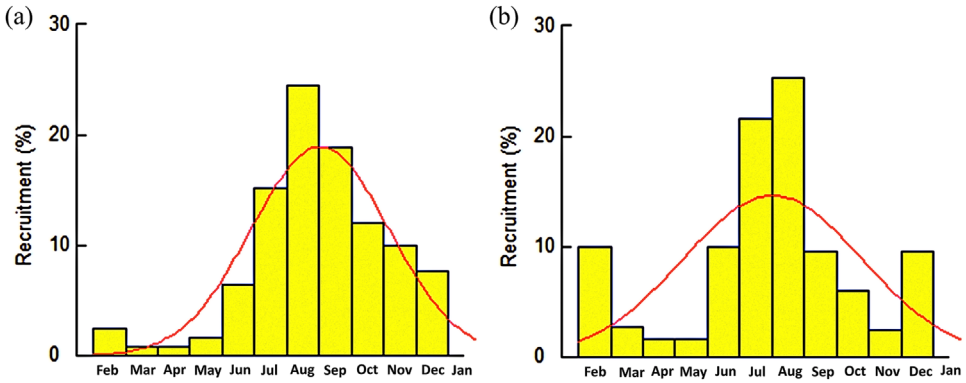

FIGURE 6 Annual recruitment pattern of (a) male and (b) female *Scylla olivacea* in the Sundarbans of Bangladesh

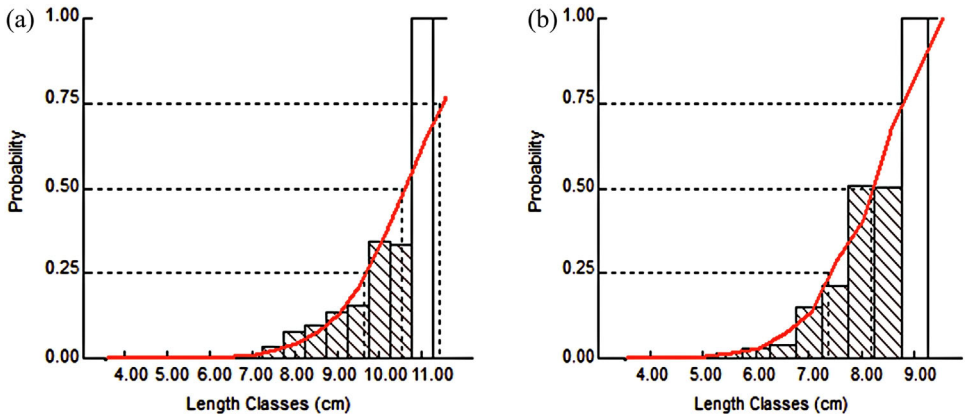

FIGURE 7 Possibilities of capture on the basis of the length (carapace width; CW) groups of (a) male and (b) female *Scylla olivacea* in the Sundarbans of Bangladesh

3.6 | Probability of capture

Probability of capture is one of the very useful drivers in stock assessment of fisheries science. It shows the vulnerability of different sizes of finfishes and shellfishes to different gears in a given location at a given time (Figure 7). The probabilities of capture analysis for males depicted that 25% of 9.63 cm CW, 50% of 10.53 cm CW, and 75% of 11.43 cm CW were vulnerable to the gears, whereas in females it was 7.51 cm CW (25%), 8.16 cm CW (50%), and 8.18 cm CW (75%). Therefore, it can be assumed that more than half of the harvested crabs remained between the carapace length of 7.51 and 11.43 cm.

3.7 | Virtual population analysis

The results of length-based VPA analysis are depicted in Figure 8. The figure shows the fishing mortality in relation to mean length. The VPA results indicate that a maximum number of male crabs were caught between carapace length of 8.50 and 11.0 cm. Similarly, the highest peaks of *F* for females occurred within some length groups, ranging from 8 to 10 cm, with vales of *F* between 0.60 and 1.37 year^{-1}.

4 | DISCUSSION

Stock assessment programs for *S. olivacea* are rarely implemented in the regions of the Sundarbans. A very few studies of *S. olivacea* were carried out by emphasizing a small geographical territory of the entire mangrove area. In contrast, in the present study, three south-western districts where the Sundarbans spread inside the Bangladesh boundary were considered. Thus, *S. olivacea* was sampled from the Sundarbans mangrove areas to determine important population parameters on the basis of their CW-frequency data.

The coefficient of determination (R^2) for both sexes of *S. olivacea* was very close to 1 in the regression analysis (Table 1). Thus, the nature of the relationship between CW and BW can be expressed as highly positive. The value of exponent (*b*) is a very important indicator for judging the growth pattern of a species. However, ecological factors (i.e., food availability, water quality parameters, sample size, and length range) can cause variation in slope (*b*) in the case of any species (Mommsen, 1998; Ighwela et al., 2011). When *b* is equal to 3, a species grows in all dimensions, such as length, width, and weight. Females showed negative allometric growth ($b < 3$). Negative allometric growth is characterized as having an elongated body shape of a species in their

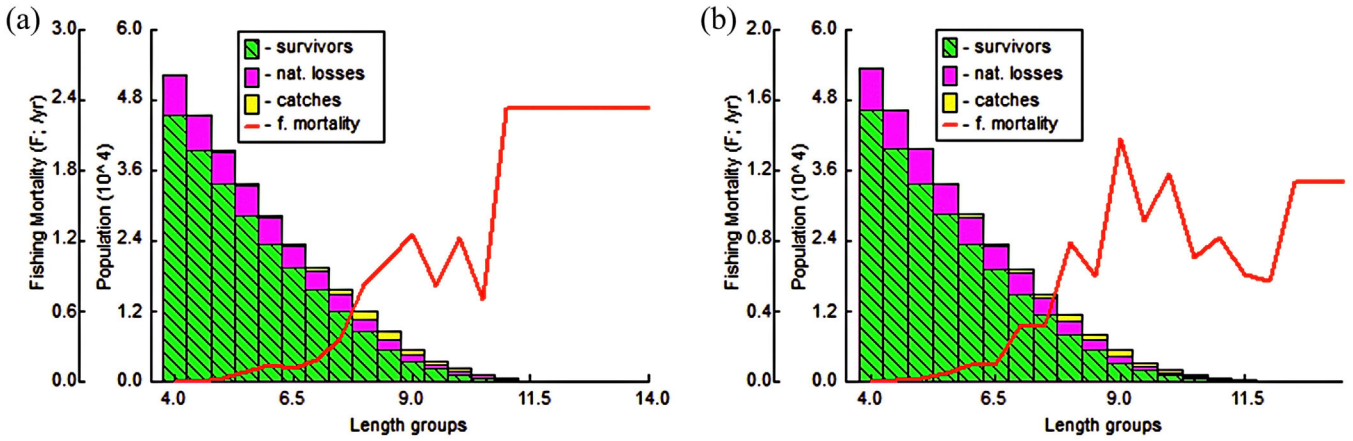

FIGURE 8 Length structured virtual population analysis (VPA) of male (a) and female (b) of *Scylla olivacea* in the Sundarbans of Bangladesh

adulthood than in their juvenile period (Froese, 2006). In contrast, males exhibited positive allometric growth ($b > 3$). Positive allometric growth influences increasing body width to become heavier in weight (Bolger & Connolly, 1989).

The majority of the peaks were on or close to the line for the male and female *S. olivacea* as the growth curves were drawn directly from the length-frequency samples (Figure 3). The CW_{∞} were estimated at 14.70 and 14.18 cm, and K were 0.47 and 0.50 year^{-1} for male and female *S. olivacea*, respectively (Table 2). The highest CW of males and females were 13.4 and 12.7 cm, respectively in Malaysia (Waiho et al., 2016). In India, the largest CW of males and females were 14.8 and 13.8 cm, respectively (Viswanathan et al., 2019). However, the CW_{∞} of *Scylla* sp. in Australia were 15.25 and 18.54 cm for males and females, respectively (Sara et al., 2017). Generally, if the K value is greater than 1, it indicates higher growth of a species. Slower growth rates were observed in this study as the K values were less than 1 for both sexes of *S. olivacea* (Sparre et al., 1998).

Higher fishing mortalities (2.32 year^{-1}) were observed than natural mortalities (1.39 year^{-1}) for the male *S. olivacea*, whereas lower fishing mortalities (1.13 year^{-1}) were estimated than natural mortalities (1.46 year^{-1}) for the female *S. olivacea* (Table 2). It depicts the non-equilibrium stock status of the mud crab. When, $F = M$, the yield was generally optimized (Gulland 1971). The value of E (0.63) indicated overfishing during the study period for male *S. olivacea*. However, the lower value of E (0.44) indicated underfishing conditions during the study period for female *S. olivacea*. Theoretically, when E is 0.50, the stock of any aquatic species is at its optimum level. According to Gulland (1971), the yield was optimized when $F = M$; thus, when E is greater than 0.50, the stock is predicted to be over fished. Therefore, there is a huge chance of being overfished in the case of the female mud crab population in the near future, as the estimated E value of the female is very close to the optimum value of exploitation rate. From the present study, it could be assumed that male *S. olivacea* was in overfishing condition and more exploitation may have led to the population collapse. As mentioned, the exploitation rate of female mud crabs was 0.44, which was close enough to 0.50 (Table 2). Generally, female mud crabs also have a high demand in the local market as an input for crab fattening, soft-shell farming, and direct export to foreign markets (Hoq, 2007; Rivera et al., 2017; Suman et al., 2018; Wu et al., 2020). Crab harvesters are quite choosy about colleting immature female crabs from the mangrove regions. Therefore, there is a possibility of harvesting female mud crabs excessively in coming days.

Male *S. olivacea* in the study revealed a year-round recruitment with a major peak between the months of July and November. Likewise, recruitment of female *S. olivacea* was also found throughout the year, with a noticeable pick between June and October. Kathirvel & Srinivasagam (1991) reported that the breeding of *Scylla* sp. occurred throughout the year. Typically, the recruitment of *S. olivacea* has happened all year long in previous studies (Viswanathan et al., 2018; Rouf et al., 2021). Gears for both sexes of *S. olivacea* made a very small group with CW ranging from 7.51 to 11.43 cm (Figure 7). According to VPA, the fishing mortality was found to be high for a mud crab group having a CW between 8 and 11 cm (Figure 8).

5 | CONCLUSION

In Bangladesh, the mud crab business is a heritage in the southern part of the country for daily livelihood. As a result, people collect crablets directly from nature in order to meet demand at various farms that produce specific crab products for local and international markets. Thus, there is a possibility of a collapse of the *S. olivacea* fishery soon. Thus, a mud crab stock assessment was carried out to address the issue of determining the status of the population in the mangrove regions. To estimate population parameters of male and female *S. olivacea*, length-frequency data were collected from various areas of the Sundarban mangrove forest to evaluate growth parameters, mortality rates, recruitment pattern, and exploitation levels. In terms of weight, the male *S. olivacea* grew faster than the female. Overall, growth rates of *S. olivacea* were observed to be quite slow for both sexes. The *S. olivacea* population was facing high fishing pressure. Therefore, a low harvest was recommended. Both male and female mud crabs were recruited all year long. The exploitation level of male *S. olivacea* was higher than the female in the mangrove regions. In summary,

the population of *S. olivacea* was overexploited in the Sundarbans of Bangladesh.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHICS STATEMENT

The authors were aware of animal ethics clearance from the concerned authorities. However, the protocol of the experiment was approved by Bangladesh Fisheries Research Institute (BFRI), and the research was conducted by considering the guidelines of the 'Animal Welfare Act 2019' approved by the National Parliament of Bangladesh.

AUTHOR CONTRIBUTIONS

Conceptualization, data curation, formal analysis, investigation, methodology, resources, software, validation, visualization, writing-original draft, and writing-reviewing & editing: Md. Hashmi Sakib. *Data curation, formal analysis, investigation, software, and validation*: Shawon Ahmmed. *Investigation, resources, and visualization*: Mizanur Rahman Washim. *Conceptualization, data curation, funding acquisition, investigation, methodology, project administration, resources, supervision, and writing—review & editing*: Md. Latiful Islam. *Data curation*: Parvez Chowdhury.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1002/aff2.42.

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