



Research article

Stock assessment of Hooghly Croaker *Panna heterolepis* in the Bay of Bengal (Southern Bangladesh): implications for sustainable managementWasim Sabbir^{a,b}, Md. Ashekur Rahman^a, Md. Yeamin Hossain^{a,*}, Md. Rabiul Hasan^a, Zannatul Mawa^a, Obaidur Rahman^a, Sumaya Tanjin^a, Most. Shakila Sarmin^a^a Department of Fisheries, Faculty of Agriculture, University of Rajshahi, Rajshahi 6205, Bangladesh^b Fisheries and Marine Resource Technology Discipline, Khulna University, Khulna 9208, Bangladesh

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ABSTRACT

The study describes growth pattern, growth parameter, mortality, recruitment pattern, exploitation rate (E) and maximum sustainable yield (MSY) to *Panna heterolepis* from the Bay of Bengal (Bangladesh). About 1223 specimens were collected from commercial fishermen for 12 consecutive months from January to December, 2019. Length–frequency data were analyzed with FAO-ICLARM Stock Assessment Tool. Moreover, our study recorded different water quality and environmental parameters including pH, rainfall, temperature and DO (dissolved oxygen) from the Bay of Bengal. The findings of the study revealed that the allometric co-efficient (b) value indicated negative allometric growth (<3.00) for *P. heterolepis* population. Whereas, the population dynamic parameters showed growth coefficient (K) 0.13 year^{-1} , life-span (t_{max}) 3.85 year and growth performance index (ϕ') 2.30. Along with this, *P. heterolepis* was found to grow rapidly with an asymptotic length (L_{∞}) of 39.08 cm. We found that the natural mortality ($M = 0.44 \text{ year}^{-1}$) rate was almost similar with fishing mortality ($F = 0.42 \text{ year}^{-1}$). Consequently, the standing stock was not quite sustainable with the existing fishing strategy. Furthermore, the maximum allowable exploitation rate ($E_{max} = 0.471$) was lower than the recorded exploitation rate ($E = 0.490$). Subsequently, overfishing is the most focal threat to the wild stock. The recruitment pattern was almost continuous throughout sampling period. Finally, the MSY was assessed at 10234.47 metric tons. Additionally, the environmental parameters denoted that the ecosystem was in a balanced condition for the wild population. The findings would be very useful to introduce appropriate fishing regulations in the Bay of Bengal and nearby ecosystem.

1. Introduction

Fish and their products are the most significant protein source for global population (Roy et al., 2020). The increasing demand for products creates massive fishing pressure on natural stock, especially in the open-water ecosystem (Panhwar et al., 2013). Fish are now considered as limited renewable resources (Gulland, 1982). Therefore, it is essential to assess the life-history traits i.e. growth, reproductive characteristics, recruitment pattern and mortality to ensure sustainable management for conserving the wild stock (Foster and Vincent, 2004). Besides, the lack of information about such traits on marine fisheries resources is a barrier to implementing suitable fishing strategies in the marine ecosystem (Dinh et al., 2018) and this demands quick investigation.

Length-frequency distribution (LFD) is an important biometric index to assess the dynamic rates of recruitment, growth, mortality, yields and

stock biomass in a particular ecosystem (Neuman and Allen, 2001) through dynamic mathematical models (Beverton and Holt, 1979). Likewise, growth pattern is essential to detect the temporal variation of fish growth (Hossain and Ohtomi, 2010). Growth of fish and other aquatic organisms largely depend on sex, maturity status and environmental factors (Dall et al., 1990). Fast growth rate of fish is advantageous in many ways. Rapid growth rate of fish not only gives the fish immunity from predators but also allows carrying large numbers of eggs with higher chances of larval survival (Hossain et al., 2017). In addition, growth and recruitment have remarkable effects on the maintenance of maximum sustainable yield of a wild stock (Ahmed et al., 2012).

Presently environmental issues are vibrant threats to marine fish populations accompanied by other hazards like overfishing, pollution in addition to habitat deterioration (Rose, 2005). Environmental changes are considered the latest warning that causes rapid declining of marine

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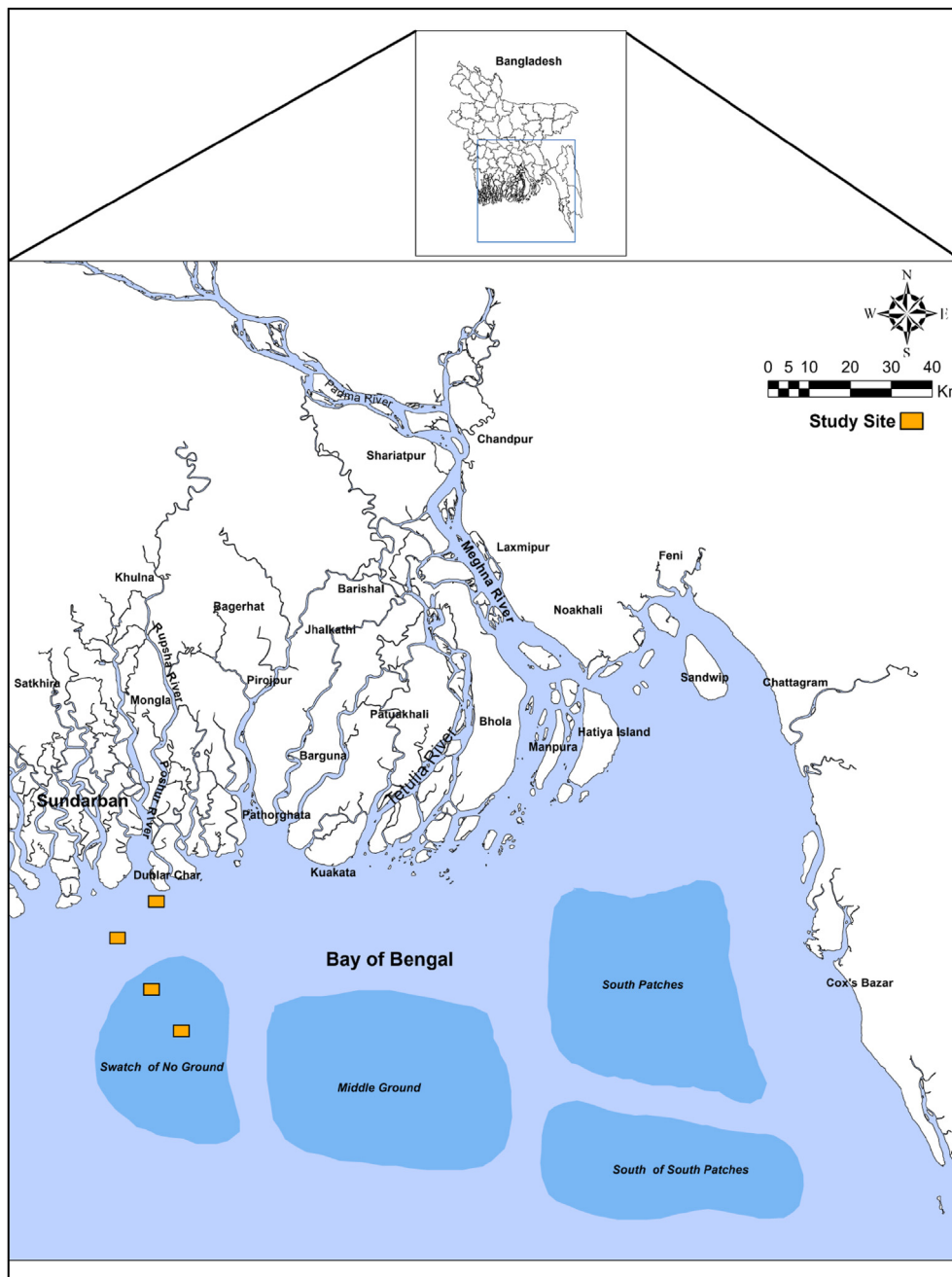


Figure 1. The study site in the Bay of Bengal, Bangladesh (Rectangle shapes indicate the sampling sites).

fish stocks worldwide (Cochrane et al., 2009). Consequently, this has a catastrophic impact on the livelihoods of many poor fishers, especially in developing countries like Bangladesh (Allison et al., 2009). Already marine fisher folks are facing deviations in the diversity and abundance of target fish species in the marine and coastal ecosystem (Johnson and Welch, 2009). Therefore, evaluating fisheries vulnerability in relation to environmental factors is obligatory for safeguarding the sustainability of the marine fisheries resources.

Hooghly Croaker *Panna heterolepis* is found profusely in the Bay of Bengal ecosystem (Sasaki, 1995). Talwar and Jhingran (1991) stated that *P. heterolepis* belongs to the family Sciaenidae inhabits marine and brackish-water ecosystems. According to Froese and Pauly (2020), *P. heterolepis* is very famous among the three representative species under the genus *Panna* in the Bay of Bengal existing with *P. perarmatus* and *P. microdon*. In Bangladesh, *P. heterolepis* is locally

called Poa. Besides, it is commercially very important as a widespread food fish item because of outstanding flesh quality. However, total demand of this species is met through the capture from wild stock due to absence of culture practice (Hossen et al., 2019; Sabbir et al., 2020a). Besides, the species is considered as the least concern worldwide (IUCN, 2020).

A good number of studies with morphology (Sasaki, 1995), condition factor (Sabbir et al., 2020a) and reproductive biology (Sabbir et al., 2021) were done on *P. heterolepis*. Therefore, our aim is to describe the growth pattern, growth parameters, recruitment pattern, mortality, exploitation rate and maximum sustainable yield of *P. heterolepis* through evaluating the monthly length data collected from the commercial fishers' catch for consecutive 12 months as well as to suggest sustainable management approach considering the effects of environmental factors.

Table 1. Descriptive statistics on the total length (cm) and body weight (g) measurements of *Panna heterolepis* Trewavas, 1977 in the Bay of Bengal, Bangladesh.

| Month | n | Total length (cm) | | | | Body weight (g) | | | |
|-------|-----|-------------------|------|------------------|----------------|-----------------|--------|-------------------|----------------|
| | | Min | Max | Mean \pm SD | 95 % CL | Min | Max | Mean \pm SD | 95 % CL |
| Jan | 107 | 12.0 | 25.9 | 17.23 \pm 1.79 | 16.88 to 17.57 | 12.39 | 134.28 | 39.72 \pm 14.75 | 36.89 to 42.55 |
| Feb | 104 | 11.0 | 34.5 | 18.70 \pm 4.39 | 17.85 to 19.56 | 9.02 | 342.26 | 58.74 \pm 51.08 | 48.80 to 68.67 |
| Mar | 104 | 11.1 | 25.7 | 17.66 \pm 2.89 | 17.09 to 18.22 | 11.98 | 133.35 | 46.06 \pm 24.17 | 41.36 to 50.76 |
| Apr | 84 | 10.5 | 28.7 | 16.80 \pm 4.67 | 15.78 to 17.81 | 10.02 | 175.60 | 46.79 \pm 40.32 | 38.04 to 55.54 |
| May | 101 | 11.9 | 27.0 | 16.89 \pm 2.74 | 16.34 to 17.43 | 11.42 | 144.30 | 41.26 \pm 22.36 | 36.85 to 45.68 |
| Jun | 99 | 11.5 | 28.5 | 19.79 \pm 3.78 | 19.04 to 20.55 | 14.20 | 174.60 | 63.72 \pm 33.53 | 57.03 to 70.41 |
| Jul | 103 | 10.5 | 29.5 | 17.64 \pm 3.55 | 16.94 to 18.33 | 11.20 | 187.53 | 45.13 \pm 29.14 | 39.43 to 50.82 |
| Aug | 106 | 13.0 | 31.4 | 18.22 \pm 3.59 | 17.53 to 18.91 | 17.90 | 203.89 | 47.48 \pm 33.86 | 40.96 to 54.00 |
| Sep | 102 | 15.0 | 30.9 | 19.30 \pm 2.36 | 18.83 to 19.76 | 24.19 | 165.15 | 51.05 \pm 19.63 | 47.19 to 54.91 |
| Oct | 104 | 12.5 | 27.2 | 17.86 \pm 2.73 | 17.33 to 18.39 | 13.89 | 140.58 | 43.71 \pm 21.48 | 39.53 to 47.89 |
| Nov | 105 | 13.1 | 26.4 | 17.96 \pm 2.47 | 17.48 to 18.43 | 18.05 | 120.22 | 42.16 \pm 17.49 | 38.78 to 45.55 |
| Dec | 104 | 14.7 | 25.2 | 18.02 \pm 1.97 | 17.64 to 18.41 | 24.44 | 117.38 | 43.25 \pm 15.28 | 40.28 to 46.22 |

Notes: n, sample size; TL, total length; W, body weight; min, minimum; max, maximum; SD, standard deviation; CL, confidence limit.

2. Materials and methods

2.1. Sampling site and sampling

In total, 1223 individuals of *P. heterolepis* were harvested during January to December 2019 by using different local gears from the Bay of Bengal (21.7728°N; 89.5592°E), southern Bangladesh (Figure 1) on a monthly basis.

2.2. Fish measurement

Total length (TL) and body weight (BW) of each specimen were assessed with 0.1 cm and 0.01 g accuracy.

2.3. Growth pattern

Growth pattern was calculated by LWRs involving the calculation: $W = a \times L^b$. The regression coefficient a and b were assessed using the formula: $\ln(W) = \ln(a) + b \ln(L)$. A t-test was executed to approve whether the b value was statistically dissimilar from isometric value ($b = 3$).

2.4. Estimation of growth parameters

Length-frequency data were analyzed with FISAT software version 1.1 (Gayaniilo and Pauly, 1997). The von Bertalanffy Growth Function (VBGF) was employed to obtain the asymptotic length (L_∞) and growth constant

(K) (Gayaniilo et al., 2002). The life-span (t_{max}) was determined using the formula of $\log(t_{max}) = 0.5496 + 0.957 \times \log(t_m)$ (Froese and Binohlan, 2005), where t_m indicates the age of first sexual maturity. Age at zero length (t_0) was determined with the calculation of $\log(-t_0) = -0.3922 - 0.2752 \log L_\infty - 1.038 \log K$ (Pauly, 1980) and growth performance index was calculated as $\phi' = \log_{10}K + 2\log_{10}L_\infty$ (Pauly and Munro, 1984).

2.5. Estimation of mortality and exploitation

Total mortality (Z) was calculated by the length-converted catch curve method (Gayaniilo et al., 2002). Natural mortality (M) was assessed as $\log_{10}M = -0.0066 - 0.279\log_{10}L_\infty + 0.6543\log_{10}K + 0.0463\log_{10}T$; where T is the average temperature of the ecosystem (28.5 °C). The fishing mortality (F) was estimated as $Z - M$. Besides, exploitation rate (E) was determined as: $E = F/Z = F/(F + M)$ (Gulland, 1983). Consequently, exploitation rate producing maximum yield (E_{max}), exploitation rate at which the secondary increase of relative yield-per-recruit (Y'/R) is 10% its virgin biomass ($E_{0.1}$) and the exploitation rate under which the stock is reduced to half its virgin biomass ($E_{0.5}$) were calculated following knife-edge selection (Beverton and Holt, 1979).

2.6. Recruitment pattern

Recruitment pattern of *P. heterolepis* was assessed from the analysis of the total time series of LFDs and growth parameters using VBGF models.

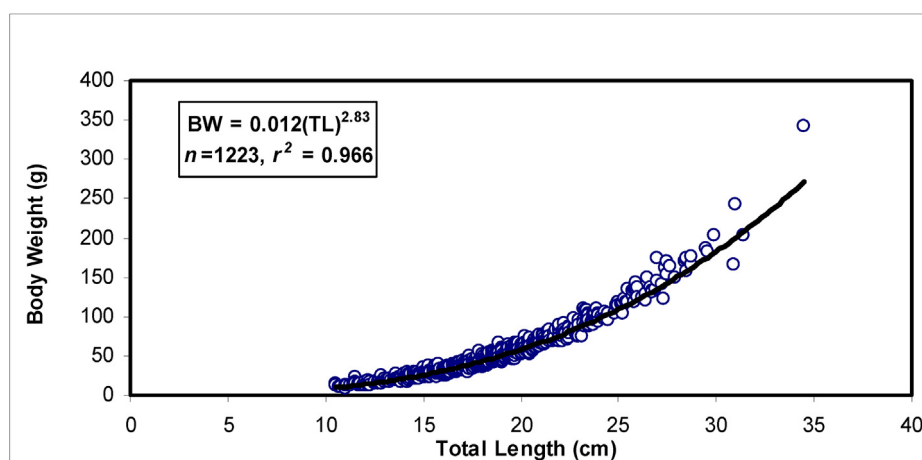


Figure 2. Growth pattern of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

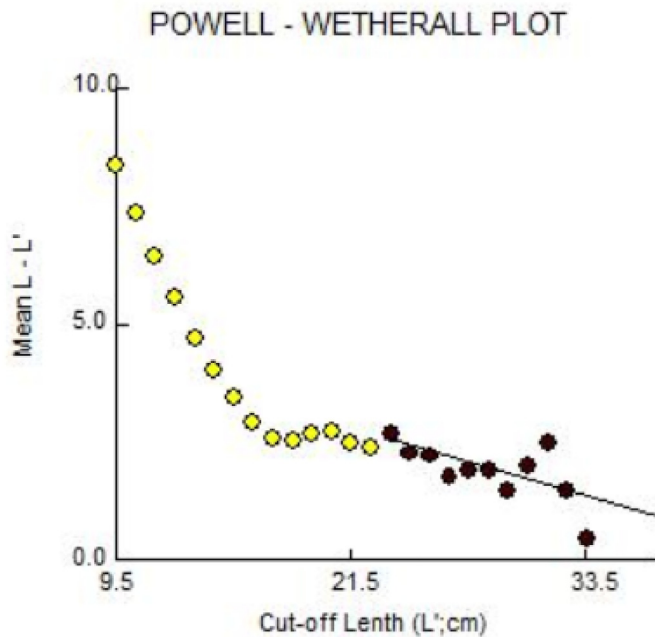


Figure 3. Powell-Werherall Plot for the length frequency data of *Panna heterolepis* from the Bay of Bengal, Bangladesh suggests that values of $(L - L')$ plotted against a series of cut-off points, L' as a straight line. Black dots are exploited samples. The regression equation is $Y = 1.03 - 0.255X$, $r = 0.862$. Estimated $L_{\infty} = 39.08$ cm and $Z/K = 5.118$.

2.7. Relative yield-per-recruit (Y'/R), steady state biomass (SSB) and maximum sustainable yield (MSY)

The **Beverton and Holt (1979)** model was applied to assess the Y'/R of *P. heterolepis*. The recommended length at first capture (L_c) was predicted at $E_{0.5}$ level. The SSB was calculated using the length-structured virtual population analysis (VPA) routine in FiSAT II. Consequently, MSY of *P. heterolepis* was calculated as $MSY = 0.5 * SSB * Z$ (**Gulland, 1983**).

2.8. Environmental factors

In order to assess the status of water quality of the Bay of Bengal, different parameters i.e. temperature ($^{\circ}C$), pH and DO (mg/l) were recorded monthly basis following **APHA (2005)** procedure. Besides, monthly rainfall data were collected from the meteorological station of Khulna, Bangladesh.

3. Results

3.1. Growth pattern

LFD revealed that the TL varied from 10.5 to 34.5 cm and BW ranged from 9.02 to 342.26 g (**Table 1**). The regression coefficients a and b for *P. heterolepis* were assessed from the length and weight data and calculated as $W = 0.012TL^{2.83}$ ($p < 0.001$; $r^2 = 0.966$; **Figure 2**).

3.2. Growth parameters

The study revealed the L_{∞} of 39.08 cm TL. Further, the value of K was recorded as 0.13 year^{-1} for the unique data set (**Table 2** and **Figures 3** and **4**). The length-frequency histograms and the von Bertalanffy Growth curve were shown in **Figure 5**. The ϕ' , t_{max} and t_0 were found 2.30, 3.85 year and 0.108 year, respectively (**Table 2**).

3.3. Mortality

Total mortality (Z) was recorded 0.86 year^{-1} (**Figure 6**). Further, natural mortality (M) and fishing mortality (F) were calculated 0.44 and 0.42 year^{-1} , respectively (**Table 2**).

Table 2. Growth parameters (L_{∞} and K), mortality (Z , M , F) and Fishery parameters (E , L_c and MSY) of *Panna heterolepis* Trewavas, 1977 in the Bay of Bengal, Bangladesh.

| Description of Parameters | Values |
|---|--------------------------|
| Growth and reproduction | |
| Asymptotic length (L_{∞}) | 39.08 cm TL |
| Growth coefficient (K) | 0.13 year^{-1} |
| Life-span (t_{max}) | 3.85 year |
| Growth performance indexes (ϕ') | 2.30 |
| Age at zero length (t_0) | 0.108 year |
| Age at first sexual maturity (t_m) | 0.69 years |
| Mortality parameters | |
| Total mortality (Z) | 0.86 year^{-1} |
| Natural mortality (M) | 0.44 year^{-1} |
| Fishing mortality (F) | 0.42 year^{-1} |
| Fishery parameters | |
| Exploitation ratio (E) | 0.490 |
| E_{max} | 0.471 |
| $E_{0.1}$ | 0.364 |
| $E_{0.5}$ | 0.268 |
| Total length at first capture (L_c) | 14.96 cm TL |
| Maximum sustainable yield (MSY) | 10234.47 metric ton |

3.4. Recruitment pattern

The recruitment of *P. heterolepis* population is more or less continuous throughout the sampling period with a major peak in April–May (**Figure 7**).

3.5. Relative yield-per recruits (Y'/R), steady state biomass (SSB) and maximum sustainable yield (MSY)

From Y'/R analysis, the estimated values of E , E_{max} , $E_{0.1}$, and $E_{0.5}$ were 0.490 , 0.471 , 0.364 and 0.268 respectively (**Figure 8**; **Table 2**).

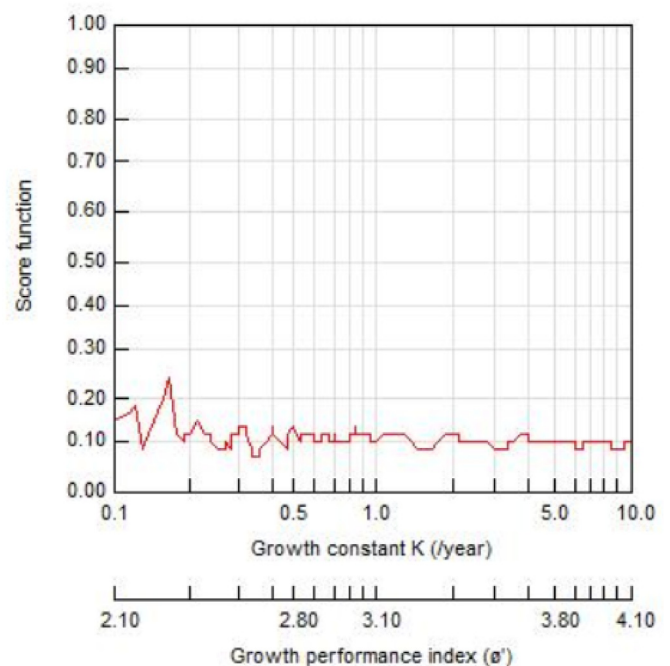


Figure 4. K-scan routine for determining best growth curvature giving best value of asymptotic length with growth performance indices for *Panna heterolepis*.

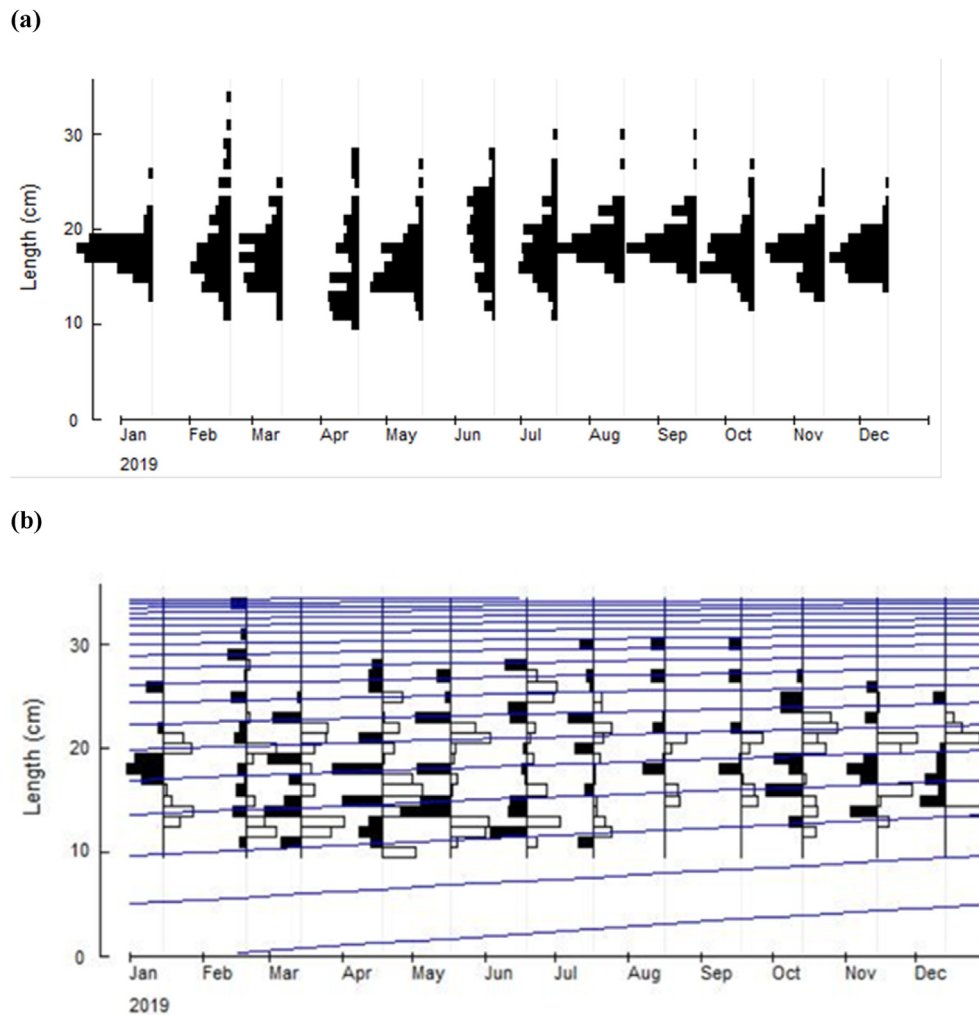


Figure 5. Total length (TL) frequency distribution and growth curve of *Panna heterolepis*. (a) Histogram showing distribution of TL frequency data of collected specimens and (b) von Bertalanffy growth curve (parameters values: $L_{\infty} = 39.08$ cm and $K = 0.13$ year⁻¹) superimposed on the restructured length frequency histogram of the *Panna heterolepis*.

Moreover, the calculated TL of *P. heterolepis* at first capture (L_c) was 14.96 cm (Figure 9). The predicted total SSB was 23801.09 metric tons. Consequently, the MSY of *P. heterolepis* was estimated at 10234.47 metric tons.

3.6. Environmental factors

We observed four environmental factors namely temperature (°C), rainfall (mm), DO (mg/l) and pH. The maximum and minimum water temperature was documented 34.4 °C in May–June and 19.8 °C in January, respectively with an average of 28.5 °C. The peak rainfall was occur in August (370 mm) but no precipitation was recorded in January. Further, the highest DO was found in July (6.15 mg/l) and the lowest DO was recorded in December (5.42 mg/l). However, minimum pH was found in May and September (6.76) and the maximum pH was recorded in the month of July (7.32).

4. Discussion

Stock assessment is essential to obtain the highest benefit from a natural stock without hampering the wild population. Information on stock assessment of *P. heterolepis* is absent in literature from Bangladesh and elsewhere. In our study, a large number of specimens (1223) were

sampled using local gears including gill net for successive twelve months from the Bay of Bengal, Bangladesh. However, absence of individuals smaller than 10.50 cm TL may be attributed to the selectivity of fishing gear (Hossain et al., 2016a, b). The highest length of *P. heterolepis* was recorded 34.50 cm from the sampling site. Our study revealed a length of 28.20 cm in standard length (SL) specifically higher than the report (21.40 cm) of Sasaki (1995). Therefore, this study recorded the maximum length (34.50 cm in TL) for *P. heterolepis* (Sabbir et al., 2020b).

Carlander (1969) stated that b values may range between 2.0 to 4.0 for fishes. On the other hand, Froese (2006) reported that the b values of LWRs should range from 2.5 to 3.5. Our experiment recorded a negative allometric growth pattern ($b = 2.83$) for *P. heterolepis* population, which is comparable to Froese (2006) for teleost fishes. However, b values often differ for same species because of consolidation of various factors i.e. sex, development of gonad, growth variations in different body parts, physiological condition, food availability and preservation methods (Le Cren, 1951; Hossain et al., 2015).

It is crucial to determine the growth parameters for predicting future yields and stock biomass from a particular aquatic ecosystem (Dadzie et al., 2017). We estimated the L_{∞} higher than our largest specimen might be attributed to von Bertalanffy model being insufficient for determining the growth of fish species because fish do not grow linearly

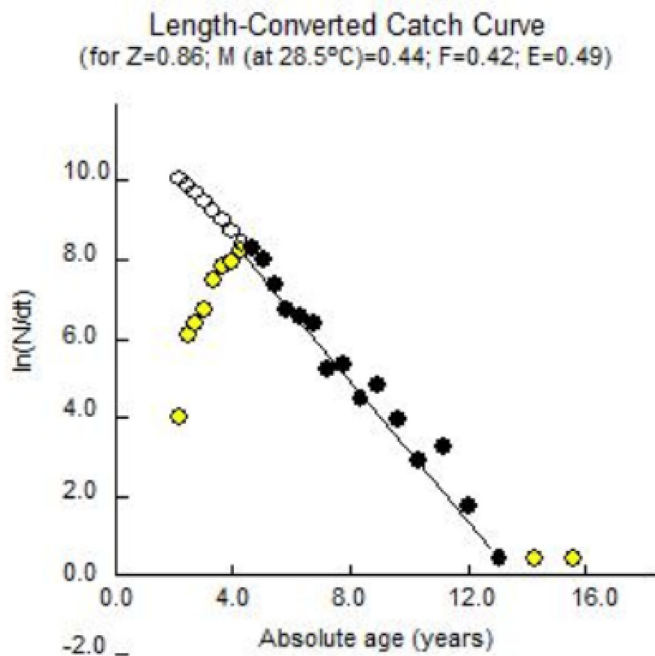


Figure 6. Length-converted catch curve of *Panna heterolepis* in the Bay of Bengal, Bangladesh. Note: only black dots are considered for computation of total mortality.

(Vigliola et al., 1998). Fish grow more rapidly at Juvenile stage and growth rate becomes slower at older stage. Consequently, the growth performance index (ϕ') is a more consistent method for a fish population to compare the growth performance as it considers L_∞ along with K simultaneously (Pauly and Munro, 1984). However, the calculated ϕ' for *P. heterolepis* was 2.30. Further, we observed the maximum age or life span (t_{max}) was 3.85 year and age at zero length (t_0) was 0.108 year. There was no previous data on growth parameter of *P. heterolepis* to compare our findings.

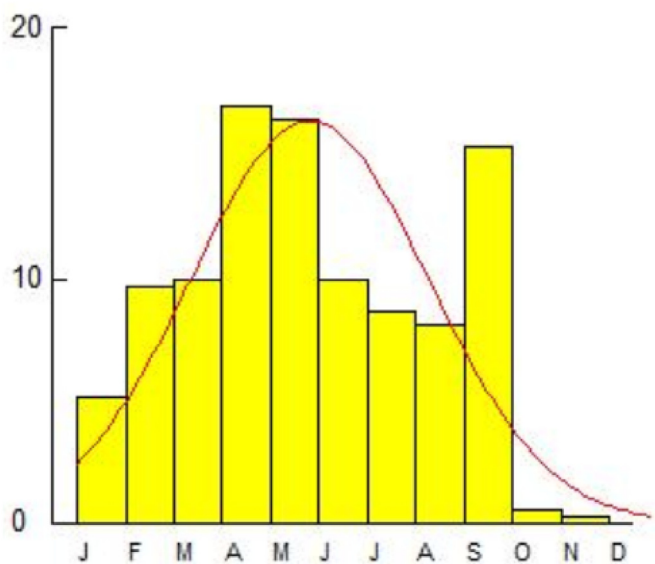


Figure 7. Recruitment of *Panna heterolepis* in the Bay of Bengal, Bangladesh. The histogram shown relative percentage of recruits per month whilst bell-shaped curves show the one recruitment peak.

Assessment of the mortality rate is crucial for evaluating the abundance of a fish stock which helps to set harvest limits to obtain maximum benefit for the stakeholders of the resource. Total mortality (Z) was recorded 0.86 year^{-1} . We found that the natural mortality ($M = 0.44 \text{ year}^{-1}$) rate is almost similar to fishing mortality ($F = 0.42 \text{ year}^{-1}$). Consequently, the standing stock is not quite sustainable with the existing fishing strategy. We found the maximum allowable exploitation rate ($E_{max} = 0.471$) is close to the observed exploitation level ($E = 0.490$). According to Gulland (1983) and Pauly (1983), the exploitation of this species is at optimum level in the Bay of Bengal, Bangladesh. Similarly, we found that the Z/K ratio was 5.118 (Figure 3) which denoted that the exploitation level was very high (Barry and Tegner, 1989). Pauly and Munro (1984) stated that juveniles of a certain species would be higher in the catch composition if the L_c/L_∞ ratio was lower than 0.5. Our study recorded the L_c/L_∞ ratio was 0.38. Consequently, the fishing composition was dominated by smaller sizes of fish.

Recruitment typically refers to a new cohort in the catch due to becoming big or old enough to be vulnerable to the fishery. Peak pawning season was estimated in February (Sabbir et al., 2021). Thus, our study recorded that there were major recruitment peaks in the population during April–May and they overlapped in time to provide a continuous pattern throughout the year. Finally, the MSY of *P. heterolepis* was calculated as 10234.47 metric tons, if the recommended length at first capture ($L_c = 14.96 \text{ cm TL}$) is maintained. Though, the estimated length at first capture was similar to size at first sexual maturity (15.0 cm TL) (Sabbir et al., 2021).

A good number of researches have been documented the distributional changes of marine fisheries stock due to environmental changes (Alheit et al., 2005; Perry et al., 2005). However, in the Bay of Bengal, such studies are absent. Temperature is thought to be the most imperative environmental factor influencing the distribution of larval accumulations of marine and freshwater fish species (Houde and Zastrow, 1993; Jakobsen et al., 2009). Likewise, rainfall is another important factor prompting the hydrological events through runoff and river inflow (Patrick, 2016). During the sampling period, the highest and lowest surface water temperature was documented in June–July ($34.4 \text{ }^\circ\text{C}$) and in January ($19.8 \text{ }^\circ\text{C}$), respectively. The highest rainfall was observed in August and no precipitation was occurred in the month of January. Besides, DO is an important ecological parameter for metabolic activities of fish (Timmons et al., 2001). The minimum DO level requirement should remain 3.5 mg/l for coastal and marine fish stocks for their survival (EPA, 2000). Likewise, pH is a critical ecological parameter for marine and freshwater habitat. Both acidic ($\text{pH} < 4.5$) and alkaline ($\text{pH} > 9.5$) condition hinder the growth and reproduction of fish (Ndubuisi et al., 2015). In the present study, monthly DO level fluctuated from 5.42 to 6.15 mg/l and pH varied from 6.76 to 7.32 indicating a suitable habitat for *P. heterolepis* in the Bay of Bengal, Bangladesh (Sabbir et al., 2020a).

5. Conclusion and recommendations

The study describes the growth pattern, growth parameters, mortality, recruitment, exploitation rate and MSY of *P. heterolepis* from the Bay of Bengal, Bangladesh. Overfishing may be the most focal threat for the wild population of *P. heterolepis* if fishing activity is not maintained with the finding range ($E_{max} = 0.47$). Illegal gear should be banned and mesh size should be increased to limit catching mature smaller individuals to provide them opportunity to spawn as the L_c and L_m are the same in size. If it is not done, future stock will be hampered due to lack of spawner. The temperature of the world environment is increasing every year. So, long term management policy should be taken for sustainable management of wild stock of *P. heterolepis* considering the emerging climate change. However, the findings of our study might be a potential tool for fishery biologists to initiate alternative management approaches to conserve this prominent fish species from possible future collapse.

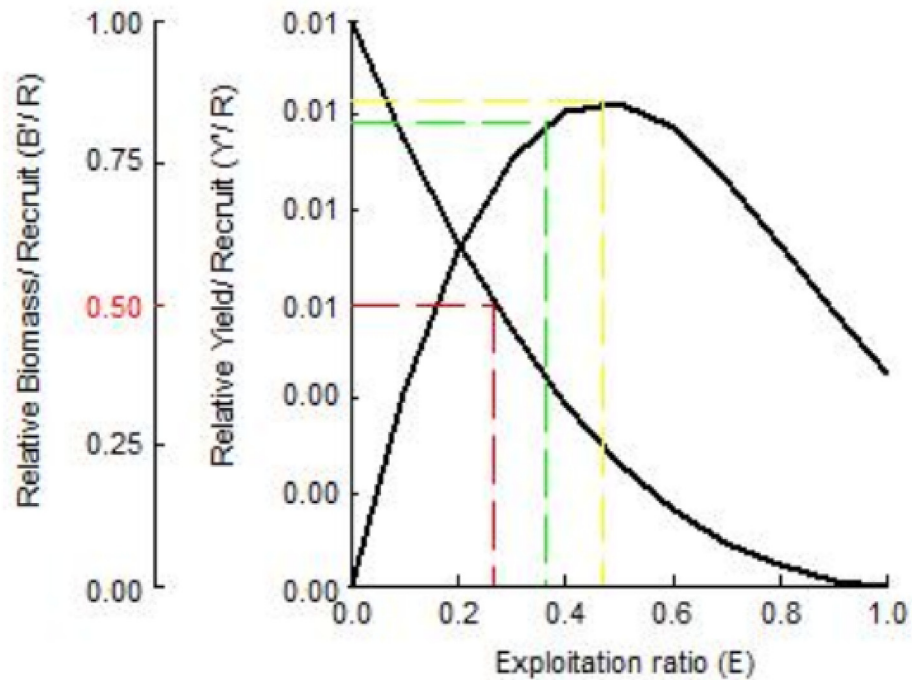


Figure 8. Yield-per-recruit and average biomass per recruit models, showing levels of yield index of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

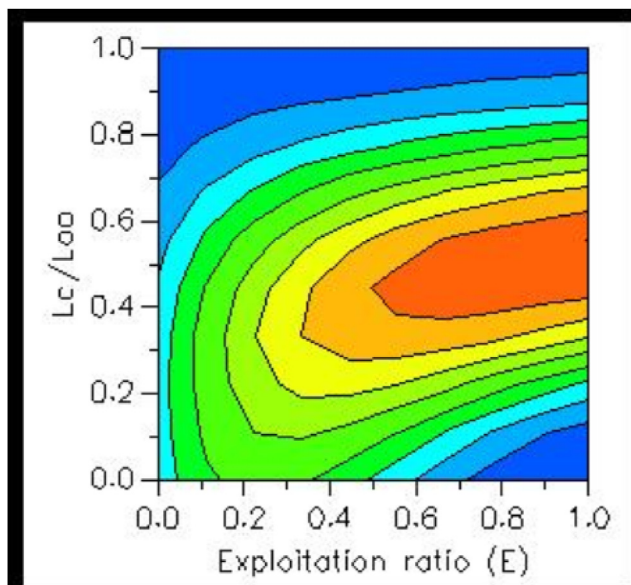


Figure 9. Yield Isopleths, showing optimum fishing activity of *Panna heterolepis* in the Bay of Bengal, Bangladesh.

Declarations

Author contribution statement

Wasim Sabbir; Md. Ashekur Rahman; Md. Yeamin Hossain: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Md. Rabiul Hasan; Zannatul Mawa; Obaidur Rahman; Sumaya Tanjin; Most. Shakila Sarmin: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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