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Research article

Stock assessment of barred spiny eel, *Macrognathus pancalus* (Hamilton, 1822) in a wetland ecosystem, northwestern Bangladesh: A fundamental approach to ensure sustainability and conservation

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ABSTRACT

This research delved into the management approach for *Macrognathus pancalus* within the Gajner Beel of northwestern Bangladesh, employing a comprehensive array of length-based indicators. The study encompassed an investigation into population structure, growth parameters (including asymptotic length (L_∞), asymptotic weight (W_∞), growth coefficient (K), and age at zero length (t_0)), mortality parameters, growth performance indices, recruitment pattern, exploitation rate (E), relative yield per-recruit (Y'/R), optimum catchable length (L_{opt}), longevity, biomass, and maximum sustainable yield (*MSY*). The TL and BW ranged from 5.00 to 16.20 cm and 0.49 g–17.20 g for males, and 7.80–18.80 cm and 1.25–29.75 g for females. The overall b value of LWR indicated positive allometric growth for both males and females. The size at first sexual maturity (L_m) was measured 9.74 cm for males and 11.16 cm for females in TL, while calculated age at first sexual maturity (t_m) (year) was 0.83 for males and 0.84 for females. The L_∞ and W_∞ values were determined as 17.15 cm, 23.20 g for males and 19.86 cm, 41.40 g for females. Growth performance indices for males and females were found to be 2.26 and 2.60, respectively. The longevity of males and females was estimated at 4.84 and 4.76 years, respectively. L_{opt} values were recorded as 9.65 for males and 11.14 cm for females. Calculated M values were 0.95 year^{-1} for males and 0.97 year^{-1} for females, while F was determined as 1.29 year^{-1} and 1.51 year^{-1} for males and females, respectively. Total mortality (Z) was found to be 2.24 year^{-1} and 2.48 year^{-1} for male and female *M. pancalus* populations. The E were calculated at 58% and 61%, while the MSY indicated 46% and 49%, underscoring the need for a 12% reduction in fishing pressure for both males and females to prevent overexploitation. The findings offer valuable insights for the sustainable management of *M. pancalus* in the Gajner Beel and its surrounding habitats, underlining the urgency of conservation efforts.

1. Introduction

One of the frequently studied species of fish belonging to the Mastacembelidae family found in Asia is the barred spiny eel, *Macrognathus pancalus* [1] (also known as the striped spiny eel). This species can be found in India, Pakistan, Bangladesh, and Nepal

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[2]. Freshwater, brackish, and benthopelagic fish make up the majority of *M. pancalus*. It inhabits wetlands, ponds, small rivers, and streams, as well as canals [3]. In Bangladesh it is one of the significant species in the wetland Gajner Beel. A wetland is a piece of land that frequently or seasonally floods with water, either permanently or momentarily [4]. One of Bangladesh's largest wetlands (floodplains), Gajner Beel is situated in Sujanagar Upazilla, Pabna, Northwestern Bangladesh. It is a significant feeding and breeding site for a large number of freshwater indigenous fish species [5].

In Bangladesh and the areas around it, *Macrognathus pancalus* is valuable both for food and decoration. It is crucial in meeting the nutritional requirements of people of Bangladesh. Spiny eels are one of the most important sources of micronutrients and animal protein. An examination of the nutritional value of the spiny eel, *M. pancalus* in laboratory condition, revealed that the moisture percentage was about 77%; ash percentage was about 2%; crude protein percentage was (18%); crude lipid percentage was 3%. Fe content of the fish sample was 0.62 mg/100 g and Ca content was 0.13 mg/100 g of fresh sample [6]. Due to its extensive distribution and minimal indications of threats, *M. pancalus* is classified as a species of least concern, particularly in the context of the high market demand for live specimens in Bangladesh [7].

The goal of fishery management is to strike a balance between the economic and social needs of fishermen and the need for long-term fish stock harvests to be ecologically sustainable [8]. Fisheries conservation strategies improve management techniques that safeguard aquatic ecosystems, stop the extinction of species, and increase the number of fish stocks that are in danger of going extinct [9].

Understanding the fish's population structures, growth patterns, recruitment, exploitation, biomass and mortality is essential for sustainable management since they give a whole picture of a species. The principal factors widely used as management tools in capture and culture-based fisheries conservation practices are length-weight correlations [10]. In an aquatic ecosystem, these correlated factors can be utilized to assess individual growth patterns and classify potential distinctions across several unit stocks of the same fish individuals [11]. Stock assessments is the method of collecting, interpreting, and reporting information on fish populations for evaluating abundance fluctuations of fisheries stocks corresponding to fishing and, to the greatest degree feasible, predict future outlines in stock abundance [12]. Biological reference points are usually a combination of numerous characteristics, such as stock evaluations, growth, recruitment, and mortality. They provide a vital concept regarding the current situation of the fish population because of their meaningful and significant characteristics [13]. All relevant factors, especially those that directly affect one species, should be included when evaluating a fish population. To assess the state of fish stocks and determine how suggested measures would affect them, decisions about fisheries policy are made based on those variable aspects. For instance, fishing regulation measures like temporal and spatial closures in fishing, no-fishing zones, restrictions on the growth of fishing fleets, limitations on the size and number of fishing gears and crafts, catch quotas, etc. may be strengthened if the results of stock assessment studies show that fish populations are declining. The goal of stock assessment is to predict changes in stock size and catch trend as functions of both fishery dependent parameters (fishing effort, intensity of fishing effort, gear specifications, etc.) and fishery independent parameters (changes in distributions of fish populations over time, surveys in relation to non-harvesting activities, etc.), in order to determine the best limits of effort and total catch.

No prior research has previously focused on stock assessments of *M. pancalus* within the study site; however, limited evidence exists regarding various aspects of *M. pancalus* from diverse water bodies worldwide, as outlined in Table 1. Therefore, the present research was conducted in the Gajner Beel to comprehensively examine the population structure, growth characteristics, mortality rates, recruitment patterns, exploitation rates (E), biomass, maximum sustainable yield (MSY), and relative yield per-recruit (Y'/R) of *M. pancalus*. This investigation utilized data collected over one-year duration, with the aim of encompassing a broad spectrum of size

Table 1
Available works on *Macrognathus pancalus* species from worldwide water bodies.

Aspects	Study site
Growth	
Length- weight, length- length relationships	Ganges and Brahmaputra River, India [14]
Length-weight relationship and condition factor	Atrai and Brahmaputra rivers, Bangladesh [15]
Length- weight, length- length relationships	Mathabhanga River, Bangladesh [16]
Life history traits	Gajner Beel, Bangladesh [17]
Size at sexual maturity	Gajner Beel, Bangladesh [18]
Length-weight relationship	Gajner Beel, Bangladesh [19]
Reproduction and feeding habits	
Biology and fishery	Ganga River basin, India [20]
Reproductive biology	River Sessa, Assam, India [21]
Fecundity	Bangladesh [22]
Comparative analysis of reproductive traits	Gangatic Basin, India [23]
Food and feeding habits	India [24]
Hatchery and aquaculture	
Induced breeding, embryonic and larval development	India [25]
Captive breeding	Bangladesh [26]
Induced breeding	India [27]
Proximate Composition	
Nutrient composition	Bangladesh [28]
Proximate analysis	Tripura, India [29]
Nutritional Analysis	Jashore district, Bangladesh [6]

categories within the species.

2. Materials and methods

2.1. Research site and sample collection

The current investigation was conducted in Gajner Beel, NW Bangladesh (Lat. 23° 55 N; Long. 89° 33 E). A total number of 1218 individuals of *M. pancalus* were collected monthly (January to December 2018) from the Gajner Beel through gill nets, cast nets, and square lift nets. The mesh sizes of the fishing nets were varied to allow for the collection of sample of varying sizes, sexes, and maturity levels. The mesh size of a gill net was 1.5–2.5 cm, that of a cast net was 1.0–2.0 cm, and that of a square lift net was 1.0 cm. On-site, collected *M. pancalus* samples were quickly refrigerated on ice before being stored in 10% formalin solution in the research lab.

2.2. Fish measurement and data collection

This assessment was carried out in accordance with the principles of Talwar and Jhingran [2], and data from FishBase was used [30]. Total length (TL) of each specimen was precisely measured against a standardized measuring board, while whole body weight (BW) was accurately determined using a high-precision electric balance with a remarkable 0.01 g level of accuracy. In parallel with these morphometric analyses, vital data affecting to the primary factors contributing to the decline of *M. pancalus* in the Gajner Beel ecosystem were systematically gathered. These insights were gleaned through a combination of structured questionnaire interviews and corroborative cross-check interviews conducted with key informants, thereby ensuring a comprehensive and well-informed assessment.

2.3. Population structures

Length-frequency distributions (LFDs) for *M. pancalus* were constructed using 1.0 cm class intervals of TL. A normal frequency distribution was established to fit the total length frequency distribution of *M. pancalus*, employing the Microsoft Excel add-in Solver, following Hasselblad's maximum-likelihood system [31]. The relationship between length and weight (LWR) was calculated using the expression: $BW = a{*}TL^b$, where BW is the total body weight (g), TL the total length (cm), a and b are the parameters of regression analysis [32]. The regression analysis did not include extreme outliers [33].

2.4. Length-based growth analyses

Appropriate samples with a considerable number of observations for *M. pancalus* were used in this analysis to prevent any bias that could be induced by small size samples. Employing the multiple samples technique, the curves of a single cohort's modes were systematically tracked as they traversed the length axis. This process entailed sequentially organizing the length-frequency distributions (LFDs) from samples collected at various time points in accordance with the respective sampling dates. Subsequently, the ages of the modes, whether pertaining to a single cohort or all cohorts, were determined with reference to the spawning date, as established [34]. The estimation of growth parameters was accomplished using monthly length-frequency data. For each sample, comprehensive total length frequency distributions, differentiated by sex, were established for *M. pancalus*, employing 1 cm intervals. To facilitate the analysis, it became imperative to compile a dataset comprising a time series of length-frequency data, meticulously structured with a fixed class size. Notably, the L_∞ parameters were calculated because the time series of length frequencies did not appear to have undergone any modal shifts, ensuring the reliability and integrity of the analysis.

The Powell-Wetherall plot is used to calculate the values of L_∞ and Z/K independently for direct fitting of length-frequency data [35]. The function of the input parameter L', or the cut-off length, is to identify the least length entirely recruited by the gear graphically.

The mean length (L) signifies the average length of fish specimens that meet or exceed a specific length denoted as L'. Equation $(L-L') = a + b * L'$ provides a series of lower bounds representing the length intervals where fish are entirely susceptible to exploitation. Within the framework of the Wetherall plot, a regression line is meticulously fitted to the dataset, encompassing the fully utilized portion of the sample. This often commences one length-interval to the right of the highest recorded value.

The calculation of the Z/K ratio involves deriving it from the slope (b) of the regression line, as indicated by the formula: $Z/K = -(1+b)/b$ [35]. Additionally, the growth coefficient K is determined employing the Pauly and Munro model [36], where $K = 3/t_{\max}$. Both asymptotic length (L_∞) and growth coefficient (K) values are assessed for both male and female populations, drawing on input data derived from length frequency distributions.

Data input is segregated by sex, enabling the estimation of K and L_∞ values for each gender. This estimation is facilitated through the von Bertalanffy growth equation [37]:

$$L_t = L_\infty\,[1\text{-}\exp\{^{-K(t-\ t0)}\}]$$

Where, L_t represents the total length (TL) in centimeters at age t (in months), L_∞ denotes the asymptotic TL (in centimeters), K represents the growth coefficient (in year^{-1}), and t_0 signifies the hypothetical age when the TL would theoretically be zero. The t_0 value is estimated using the equation presented, $\log(-t_0) = -0.3922 - 0.2752 \log L_\infty - 1.038 \log K$ [38]. L_{opt} was calculated as $\log L_{opt} =$

1.0421*log (L_∞)-0.2742 [39]. Log $t_{\max} = 0.5496 + 0.957$*log ($t_m$) [39] was used to compute the maximum life span ($t_{\max}$), where t_m is age at sexual maturity (year). The age at first maturity (t_m50) was calculated using the age at length equation: t_m50 = -(1/K)*ln (1-L_m50/L_∞) + t_o, where L_m50 is the length at first maturity [40].

2.5. Weight-based growth analyses

The von Bertalanffy equation was fitted to the mean BWs at different ages to simulate the growth patterns of both male and female *M. pancalus*: $W_t \equiv W_\infty(1 - \exp(-k(t - t_0)))^b$ [37]

Where, W_t represents the body weight (BW) in grams at age t (in year), W_∞ denotes the asymptotic BW (in grams), K represents the growth coefficient (in year^{-1}), and t_0 signifies the hypothetical age when the BW would theoretically be zero. The length-weight relationship (LWRs) was used to determine the BWs of both males and females in each age group from the corresponding mean TLs.

2.6. Growth performance indices (Ø) and longevity

The calculated values of L_∞ and K for *M. pancalus* were used to compare growth performance indices (Ø) between sexes using the equation [36]: $Ø = \log_{10} K + 2\log_{10} L_\infty$

The estimation of the potential longevity of *M. pancalus* was conducted through the utilization of the Pauly and Munro [36] formula, which derives this parameter from the values of L_∞ and K found within the von Bertalanffy growth equation.

2.7. Recruitment pattern

The recruitment pattern of *M. pancalus* was calculated by using the von Bertalanffy equation to analyze the entire time series of LFDs and growth parameters. In the analysis, the input parameters L_∞, K, and t_0 were used [41]. The pattern of recruitment was described as a percentage of recruitment against time in months. The Excel-add-in-solver determined that the recruitment pattern had a normal distribution.

2.8. Estimation of mortality and exploitation rate

The estimation of the instantaneous rate of total mortality (Z) for *M. pancalus* was carried out using the length-converted catch curve method [32]. This method involves the expression ln (Nt/Δt) = $a + b$*t, where N represents the number of individuals of relative age (t), and Δt denotes the time required for *M. pancalus* to pass through a particular length class. The estimation of Z is derived from the slope (b) of the curve, with the sign reversed, following the methodology [42].

To ascertain the overall immediate mortality rate (Z), the length-converted catch curve procedure was applied [43]. Conforming to the Pauly's empirical equation, $\log 10\, M = -0.0066 – 0.279 \log 10\, L + 0.6543 \log 10 K + 0.0463 \log 10 \mathrm{T}$ [44], the natural mortality (M) was computed. Here, T signifies the average temperature of the ecosystem, which is assumed to be 27 °C. Subsequently, the fishing mortality (F) was determined by employing formula $F = Z - M$, representing the subtraction of natural mortality (M) from total mortality (Z) [45].

Further insights into the exploitation level were obtained using Gulland's formula [46], which calculates the exploitation rate (E) as $E = F/Z = F/(F + M)$. This parameter is instrumental in assessing the impact of fishing activities on *M. pancalus* populations, offering valuable information for sustainable management practices.

2.9. Maximum sustainable yield

The yield per recruit model described by Beverton and Holt is the most widely used method for estimating yield per recruit [47] which can be expressed as a function of L_c/L_∞, F/K, M/K, and F/M: Maximum sustainable yield estimated:

$$\frac{Y'}{R} = \frac{\frac{F}{M}}{1 + \frac{F}{M}}\left(1 - \frac{Lc}{L\infty}\right)^{M/K}$$

$$\left(1 - \frac{3(1 - L_c - L_\infty)}{1 + \frac{1}{\mathrm{M/K}+F/K}} + \frac{3(1 - L_c - L_\infty)^2}{1 + \frac{2}{\mathrm{M/K+F/K}}} + \frac{3(1 - L_c - L_\infty)^3}{1 + \frac{3}{\mathrm{M/K+F/K}}}\right.$$

2.10. Biomass model

An approach was used to estimate the relative biomass, which corresponds to the total relative weight of a cohort [48]. This estimation was achieved by multiplying the weight of each individual within the cohort by the number of survivors within that cohort. Additionally, the calculation of the number of individuals surviving within the cohort was conducted using the exponential decay equation, expressed as $N_{t+1} = N_t * \exp[-M]$. Here, N_t signifies the number of individuals present at the outset of one year, while N_{t+1} represents the number of individuals present at the outset of the subsequent year, as delineated in the methodology detailed [13].

These techniques collectively facilitate the evaluation of cohort-specific biomass and survivorship dynamics, aiding in the assessment of population characteristics and trends.

2.11. Statistical analysis

The Microsoft® Excel add-in solver DDXL, and the GraphPad Prism 6.5 software were used to conduct data analysis. The Shapiro-Wilk normality test and the Kolmogorov–Smirnov test were used to confirm the data's normality.

3. Results

3.1. Population structures

A total of 1218 individuals (565 male and 653 female) of *Macrognathus pancalus* were collected from Gajner Beel during the study period, which spanned from January 2018 to December 2018. Descriptive statistics for length and weight measurements of *M. pancalus* are presented in Table 2. The length-frequency distributions (LFDs) of *M. pancalus* indicated that the smallest and largest specimens measured 5.00–16.20 cm TL for males and 7.8–18.8 cm TL for females. In the case of males, the size group ranging from 9.00–9.99 cm to 10.00–10.99 cm TL was numerically dominant, constituting 46% of the population (Fig. 1a and b). On the other hand, for females, the 12.00–12.99 cm and 13.00–13.99 cm size groups were numerically dominant, accounting for 41% of the population which are presented in Fig. 1a and b. The LFDs for males and females did not pass the normality (Shapiro-Wilk normality test, $p < 0.0001$). Regarding body weight, males displayed a range of 0.49–17.20 g, while females exhibited a range of 1.25–29.45 g in Gajner Beel.

The sample sizes (n), regression parameters, 95% confidence intervals for a and b in the Length-Weight Relationships (LWRs), coefficients of determination (r^2), and the growth type of *M. pancalus* are presented in Fig. 2a and b) and detailed in Table 3.

For males, the b values in the TL–BW relationships suggest positive allometric growth in most of the 12 months, except for Isometric growth was observed in July, September, and November. In females, the b values for TL–BW relationships also indicate positive allometric growth in most months, except for isometric growth observed in April, September, October, November, and December (Table 3). It's worth noting that all LWRs demonstrated high significance levels ($p < 0.01$), and the coefficient of determination (r^2) values for all relationships exceeded 0.955.

3.2. Length based growth parameters of Macrognathus pancalus

As no continuous cohort could be reliably traced within either the male or female *M. pancalus* populations over the sampling period, growth parameter analyses were conducted using the Excel add-in solver model tool. The Powell-Wetherall method was utilized to do the analysis the length-frequency data collected from male *M. pancalus*, and the results showed an initial L_∞ value of 17.15 cm and a Z/K value of 2.94 (Fig. 3a and b). Subsequently, optimization of the Froese and Binohlan [39] and von Bertalanffy growth curves [37] was carried out, with the initial seed values set at $L_\infty = 16.60$ cm in the K-Scan analysis. The optimized parameters obtained were $L_\infty = 17.15$ cm and $K = 0.62$ year-1. The revised TL distribution was then accompanied by a growth curve generated using these parameters.

The maximum measured TL was 16.2 cm, while the projected maximum TL was 17.15 cm. In contrast, the Powell-Wetherall analysis of the combined length-frequency data for female *M. pancalus* produced an initial TL value of 19.86 cm and a Z/K value of 2.63 (Fig. 3a and b). The K-Scan analysis, initiated with $L_\infty = 17.90$ cm as the seed value, yielded optimal results following the methodology outlined by Froese and Binohlan [47]. The male and female growth curve was superimposed onto the revised total length-frequency histogram (Fig. 4a and b) using the von Bertalanffy growth curve parameters: $L_\infty = 17.90$ cm and $K = 0.62$ per year and $L_\infty = 19.86$ cm and $K = 0.63$ per year. The maximum observed TL for females was 18.80 cm, while the estimated maximum TL was 19.86 cm. Additionally, t_0 was calculated as 0.042 for males and 0.040 for females.

Table 2
Descriptive statistics on the length (cm) and weight (g) measurements of *Macrognathus pancalus* (Hamilton, 1822) in the Gajner Beel, northwestern Bangladesh.

Measurements	Sex	n	Min	Max	Mean ± SD	95% CL
TL	Male	565	5.00	16.20	10.384 ± 1.865	10.230–10.538
SL			4.50	15.10	9.603 ± 1.777	9.457–9.750
BW			0.49	17.20	4.923 ± 2.988	4.676–5.169
TL	Female	653	7.80	18.80	12.714 ± 1.751	12.580–12.849
SL			5.60	17.80	11.834 ± 1.670	11.708–11.969
BW			1.25	29.45	9.503 ± 4.208	9.181–9.827
TL	Combined	1218	5.00	18.80	11.633 ± 2.146	11.513–11.754
SL			4.50	17.80	10.802 ± 2.063	10.686–10.918
BW			0.49	29.45	7.380 ± 4.333	7.136–7.623

TL, total length; FL, fork length; SL, standard length; BW, body weight; n, sample size; Min, minimum; Max, maximum; SD, standard deviation; CL, confidence limit for mean values.

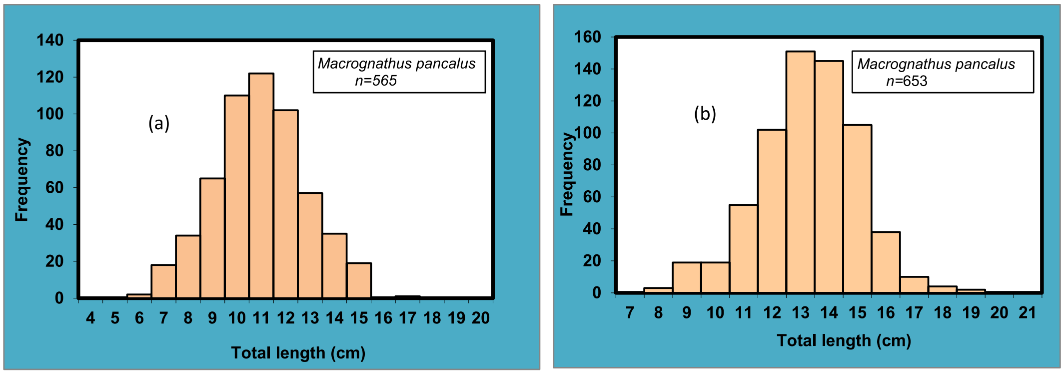

Fig. 1. Length frequency distributions of (a) males and (b) females of *Macrognathus pancalus* from the Gajner Beel, northwestern Bangladesh.

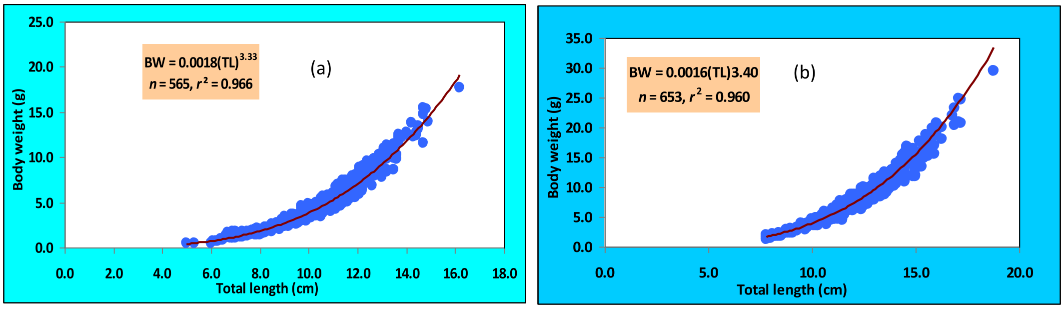

Fig. 2. Length weight relationships of (a) males and (b) females of *Macrognathus pancalus* from the Gajner Beel, northwestern Bangladesh.

3.3. Weight based growth parameters of Macrognathus pancalus

The relationships between total length (TL) and body weight (BW) for both male and female *M. pancalus* are as follows: For males: BW = 0.0018 $(TL)^{3.33}$ ($r^2 = 0.966$). Males reach an asymptotic BW of 23.20 g with a growth coefficient of 0.62 per year. For females: BW = 0.0016 $(TL)^{3.40}$ ($r^2 = 0.960$). Females attain an asymptotic body weight of 41.40 g with a growth coefficient of 0.62 per year (Table 4).

In the case of males, the parameters for the von Bertalanffy growth curve are $W_\infty = 23.20$ g and $K = 0.62$ year^{-1} (Table 4). Fig. 5a illustrates the computed growth curve using these parameters over the restructured BW distribution. For females, the highest observed BW was 17.72 g, while the projected maximum BW was 23.20 g. The von Bertalanffy growth curve was fitted with the following parameters: $W_\infty = 41.40$ g and $K = 0.63$ year^{-1} (Table 4). Fig. 5b depicts the computed growth curve employing these parameters over the restructured BW distribution. The maximum BW observed for females was 29.45 g, whereas the estimated maximum BW was 41.40 g (Table 4).

3.4. Growth performance index (Ø) and life-span (t_{max})

The growth performance index, based on asymptotic length, was determined to be 2.26 for males and 2.60 for females in the case of *M. pancalus*. Moreover, the longevity of this species was estimated to be 4.84 years for males and 4.76 years for females (Table 4).

3.5. Recruitment pattern

Regarding the recruitment pattern of *M. pancalus* in the Gajner Beel, it exhibited a consistent pattern throughout the year, with the primary peak observed at 7.0 cm for both male and female individuals (Fig. 6).

3.6. Stock assessment of Macrognathus pancalus

In Fig. 7, the overall mortality values were depicted, which were calculated based on the slope of the length-converted catch curve for both male and female *M. pancalus*. The instantaneous rate of total mortality, determined through the length-converted catch curve analysis, was found to be $Z = 2.24$ year^{-1} for males and 2.48 year^{-1} for females (Fig. 7a and b).

The average water temperature in the Gajner Beel was estimated at approximately 27 °C. The calculated instantaneous rates of natural mortality were $M = 0.95$ year^{-1} for males and 0.97 year^{-1} for females. Consequently, the fishing mortality (F) was documented

Table 3
Descriptive statistics and estimated parameters of the length-weight relationships (BW = $a \times TL^b$) of *Macrognathus pancalus* (Hamilton, 1822) in the Gajner Beel, northwestern Bangladesh.

Months	Sex	*n*	*a*	*b*	95% CL of *a*	95% CL of *b*	r^2	GT
January	M	53	0.0025	3.14	0.0020–0.0032	3.04–3.24	0.987	+A
	F	47	0.0016	3.33	0.0013–0.0020	3.24–3.42	0.991	+A
	C	100	0.0019	3.25	0.0017–0.0023	3.19–3.32	0.990	+A
February	M	48	0.0024	3.22	0.0016–0.0034	3.07–3.37	0.976	+A
	F	57	0.0021	3.29	0.0017–0.0026	3.20–3.37	0.990	+A
	C	105	0.0019	3.32	0.0016–0.0023	3.25–3.39	0.988	+A
March	M	45	0.0028	3.09	0.0020–0.0040	2.93–3.25	0.971	I
	F	55	0.0023	3.24	0.0015–0.0033	3.08–3.39	0.970	+A
	C	100	0.0017	3.35	0.0013–0.0021	3.25–3.45	0.979	+A
April	M	49	0.0020	3.23	0.0013–0.0030	3.05–3.41	0.965	+A
	F	52	0.0037	3.04	0.0024–0.0057	2.87–3.20	0.964	I
	C	101	0.0013	3.45	0.0010–0.0016	3.34–3.54	0.978	+A
May	M	46	0.0016	3.36	0.0012–0.0021	3.24–3.48	0.986	+A
	F	54	0.0019	3.25	0.0014–0.0025	3.14–3.37	0.984	+A
	C	100	0.0022	3.21	0.0018–0.0026	3.14–3.29	0.987	+A
June	M	48	0.0030	3.08	0.0020–0.0046	2.89–3.26	0.961	+A
	F	52	0.0015	3.42	0.0010–0.0021	3.27–3.56	0.978	+A
	C	100	0.0015	3.40	0.0012–0.0019	3.31–3.49	0.983	+A
July	M	30	0.0045	3.02	0.0023–0.0089	2.74–3.29	0.947	I
	F	65	0.0033	3.14	0.0019–0.0056	2.93–3.35	0.932	+A
	C	95	0.0044	3.02	0.0030–0.0064	2.87–3.17	0.945	I
August	M	51	0.0024	3.22	0.0015–0.0039	3.01–3.43	0.951	+A
	F	52	0.0026	3.23	0.0017–0.0040	3.06–3.40	0.967	+A
	C	103	0.0014	3.47	0.0010–0.0018	3.35–3.60	0.967	+A
September	M	51	0.0035	3.03	0.0023–0.0054	2.84–3.23	0.952	I
	F	50	0.0044	3.00	0.0027–0.0071	2.82–3.19	0.954	I
	C	101	0.0022	3.27	0.0017–0.0028	3.17–3.38	0.973	+A
October	M	48	0.0040	3.04	0.0026–0.0064	2.87–3.22	0.964	+A
	F	60	0.0044	3.03	0.0028–0.0069	2.86–3.21	0.955	I
	C	108	0.0030	3.17	0.0022–0.0041	3.04–3.28	0.963	+A
November	M	45	0.0040	3.03	0.0025–0.0066	2.83–3.24	0.953	I
	F	55	0.0041	3.05	0.0025–0.0068	2.86–3.23	0.953	I
	C	100	0.0027	3.20	0.0022–0.0034	3.12–3.29	0.983	+A
December	M	51	0.0024	3.23	0.0018–0.0033	3.09–3.37	0.978	+A
	F	54	0.0040	3.03	0.0025–0.0064	2.84–3.22	0.952	I
	C	105	0.0025	3.22	0.0021–0.0030	3.13–3.30	0.983	+A
Overall	M	565	0.0018	3.33	0.0016–0.0020	3.28–3.39	0.966	+A
	F	653	0.0016	3.40	0.0014–0.0018	3.35–3.45	0.960	+A
	C	1218	0.0016	3.39	0.0014–0.0017	3.36–3.43	0.974	+A

M, Male; F, Female; C, Combined; +A, Positive allometric; I, Isometric growth; *n*, sample size; CL, confidence limit for mean values.

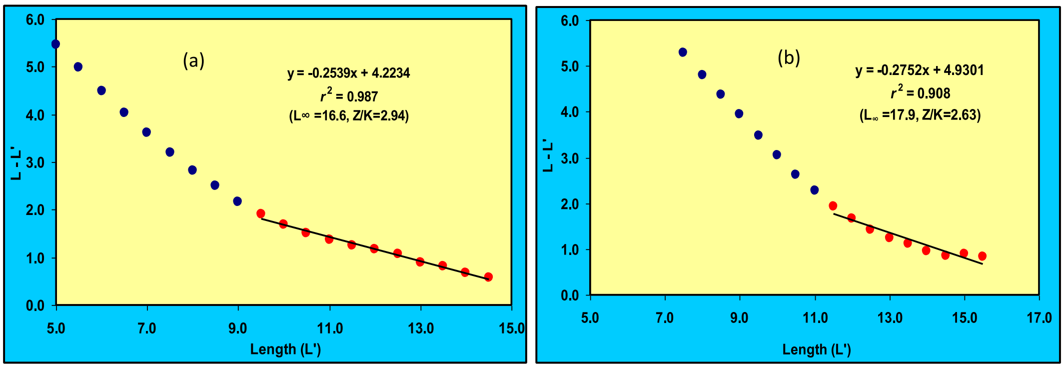

Fig. 3. A Powel-Wetherall plot for the (a) males and (b) females of *Macrognathus pancalus*. Solid red symbols are used in the regression which provides asymptotic TL of 16.6 cm and *Z/K* of 2.94 for male and asymptotic TL of 17.9 cm and *Z/K* of 2.63 for female.

as 1.29 year^{-1} for males and 1.51 year^{-1} for females. The values of estimated natural mortality (*M*), as determined by various techniques, are shown in Table 5. To assess the level of exploitation in the Gajner Beel, we computed the exploitation rate (*E*) using the estimates of instantaneous fishing and total mortalities, yielding $E = 0.58$ for males and $E = 0.61$ for females.

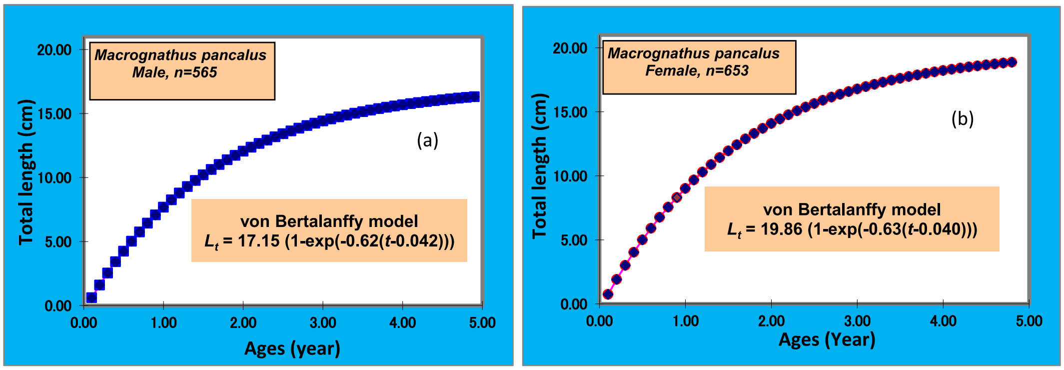

Fig. 4. The von Bertalanffy growth curve of (a) males ($L_\infty = 17.15$ cm, $K = 0.62$ year^{-1}, $t_0 = 0.042$) (b) females ($L_\infty = 19.86$ cm, $K = 0.63$ year^{-1}, $t_0 = 0.040$) based on length *Macrognathus pancalus* from the Gajner Beel, northwestern Bangladesh as superimposed on the restructured total length-frequency histogram.

Table 4
Growth and reproduction parameters (L_∞, t_{max}, $Ø$, t_0, L_m, t_m, and K), mortality (Z, M, and F) and Fishery parameters (E, Lc, and MSY) of *Macrognathus pancalus* (Hamilton, 1822) in the Gajner Beel, northwestern Bangladesh.

Description of Parameters	Male	Female
Growth and reproduction		
Asymptotic length (L_∞)	17.15 cm TL	19.86 cm TL
Asymptotic weight (W_∞)	23.20 gm	41.39 g
Growth coefficient (K)	0.62 year^{-1}	0.63 year^{-1}
Life-span (t_{max})	4.84 year	4.76 year
Growth performance indexes ($Ø'$)	2.26	2.60
Age at zero length (t_0)	0.042 year	0.040 year
Size at first sexual maturity (L_m)	9.74 cm TL	11.16
Age at first sexual maturity (t_m)	0.84 years	0.83 years
Length at maximum yield per recruit (L_{opt})	9.65 cm	11.14 cm
Age at maximum yield per recruit (t_{opt})	1.79 year	1.76 year
Z/K	2.94	2.63
Length at requirement (L_r)	7.00 cm (Both sex)	
Mortality parameters		
Total mortality (Z)	2.24 year^{-1}	2.48 year^{-1}
Natural mortality (M),	0.95 year^{-1}	0.97 year^{-1}
Fishing mortality (F)	1.29 year^{-1}	1.31 year^{-1}
Fishery parameters		
Exploitation rate (E)	0.58	0.61
Maximum yield-per-recruit (Y'/R)	0.46	0.49
Over exploitation	0.12	0.12
Biomass	1603 g (1.6 kg)	2830 g (2.8 kg)

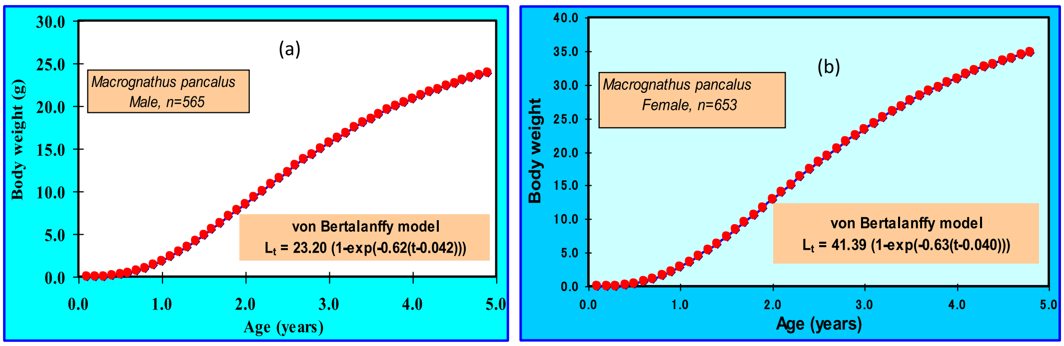

Fig. 5. The von Bertalanffy growth curve of (a) males ($W_\infty = 23.20$ g, $K = 0.62$ year^{-1}, $t_0 = 0.042$) (b) females ($W_\infty = 41.39$ g, $K = 0.63$ year^{-1}, $t_0 = 0.040$) of *Macrognathus pancalus* based on weight from the Gajner Beel, northwestern Bangladesh as superimposed on the restructured total length-frequency histogram.

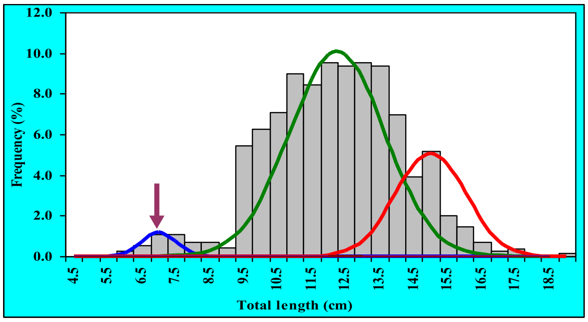

Fig. 6. Length at first recruitment pattern of overall *Macrognathus pancalus* in the Gajner Beel, northwestern through Excel-add-in- solver program.

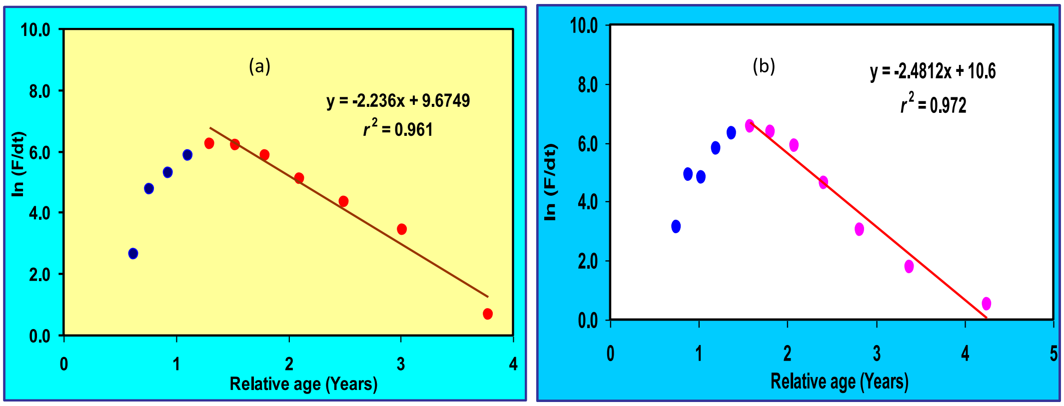

Fig. 7. Length-converted catch curves for (a) males (b) females *Macrognathus pancalus* in the Gajner Beel, northwestern. Data included in the regression are shown as red solid points. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 5
Methods used to calculate natural mortality (*M*) of *Macrognathus pancalus* (Hamilton, 1822) in the Gajner Beel, northwestern Bangladesh.

Sl no	*Method*	Natural mortality (M)
1	Then_nls	1.17
2	Then_lm	1.15
3	Hamel_Amax	1.13
4	ZM_CA_pel	1.34
5	ZM_CA_dem	0.71
6	Then_VBGF	1.09
7	Hamel_k	1.10
8	Jensen_k 1	0.95
9	Jensen_k 2	1.01
10	Pauly_lt	1.48
11	Roff	2.71
12	Jensen_Amat	1.96
13	Ri_Ef_Amat	1.56

*Detail methodologies for the estimation of natural mortality are presented in http://barefootecologist.com.au/shiny_m (Accessed on: September 03, 2020).

3.7. Maximum sustainable yield and biomass

The maximum yield-per-recruit (Y'/R) for male and female *M. pancalus* in the Gajner Beel was 0.46 and 0.49, respectively. These findings signify that both male and female populations of *M. pancalus* are experiencing overexploitation to the extent of 12%. In terms of biomass (in grams), the highest recorded levels were observed when the male population reached an age of 2.1 years, as illustrated in Fig. 8a and b. Likewise, the peak biomass (in grams) was achieved when the female population reached the same age of 2.1 years, as depicted in Fig. 9a and b. Regarding the length at which maximum yield per recruit was attained; it was found to be 9.65 for males and

11.14 for females. Additionally, the age at which maximum yield per recruit occurred was estimated at 1.79 years for males and 1.76 years for females. These findings provide valuable insights into the population dynamics and the extent of exploitation of *M. pancalus* in the Gajner Beel ecosystem.

3.8. Threats identification for threatening of Macrognathus pancalus in the Gajner Beel

The findings suggested that fish biodiversity in the Gajner Beel is reducing owing to a variety of reasons including reduction of water level, over fishing, environmental degradation, use of destructive fishing gear, destruction of fry and fingerlings, reducing water level, destruction of breeding grounds, aquatic pollution, natural disasters, pesticides and spread of diseases outbreaks, uncontrolled exotic fishes introduction, siltation, and diverse ecological modifications in its natural habit. A preliminary survey was conducted among 230 fishermen to find out the principal causes for declining the fish species in the Gajner Beel depending on the respondent (Fig. 10). In the present investigation reduction of water level, over fishing and habitat degradation are key factors for declining of fishes from the Gajner Beel.

4. Discussion

Stock assessments are a crucial part of a dynamic cycle of management aimed at protecting our fisheries resources. Based on the results of stock assessments, effective policy formulation for fisheries resources provides probable future directions for its fishery [49]. Since many stock assessment methods require a lot of data, their use is ultimately constrained to just desirable species and stocks [50]. Until now, other species receive less attention [51].

A significant number of specimens with various body sizes were collected for this study utilizing conventional fishing equipment gear (cast net, gill net and seine net) from the Gajner Beel throughout the year. The total length (TL) of *M. pancalus* was ranged from 5.00 to 16.20 cm TL for male and 7.80–18.80 cm TL for female. However, catching fish smaller than 5.00 cm TL and larger than 18.80 cm TL was not possible due to either inappropriate fishing gear selection or fishermen not going where the smaller size belongs, or rather their absence in the fishing grounds [5]. The maximum size of *M. pancalus* recorded in this study was 18.8 cm TL, which is larger than the FishBase value of 18.0 cm TL [30], and this recorded size, could be used to effectively determine the asymptotic length and growth co-efficient of wild populations. In addition, this study estimated the LWR by using a wide range of body size (TL = 6.0–18.8 cm) than that of previous studies in Mathabhanga river, Bangladesh (TL = 6.20–16.20 cm) [16], in upper Assam, India (TL = 6.00–18.00 cm) [13] and also in Gorgon Beel, Assam, India (TL = 9.10–15.30 cm) [52]. Maximum length is critical for estimating asymptotic length and growth coefficient of fishes, as well as for fisheries resource planning and management [53].

The overall *a* values for males, females, and combined sexes in this study were 0.0018, 0.0016, and 0.0016, respectively. However, the reported a value for *M. pancalus* was 0.0045 in the Mathabhanga River, southwestern Bangladesh [16], whereas the observed a value for combined sexes was 0.0026 in the Gajner Beel floodplain [19], which is compatible with the current research. The discovered a value for combined sexes was 0.006 [15], which is consistent with current research. Contrary to the parameter *b*, which does not vary greatly over the year, the regression parameters, in particular parameter *a*, may vary daily, seasonally, or between habitats [54].

Population parameters play a crucial role in fisheries research as they provide insights into the growth patterns of different fish species. Isometric growth is characterized by a regression parameter "*b*" equal to 3, while significantly different values indicate either positive or negative allometric growth [55]. In the current study, most months exhibited *b*-values falling within the range of 2–4, as reported [56]. The regression parameter "*b*" for both male and female fish in this study ranged from 3.28 to 3.39 and 3.35 to 3.45, respectively, indicating a consistent pattern of positive allometric growth throughout all months. This growth pattern aligns with findings from previous studies [19,52]], where similar *b*-values were reported in different regions. However, it's worth noting that these findings differed from those reported in the Gurgon Beel, India [52], where they observed negative allometric growth with *b*-value of 2.85. Similarly, the growth pattern was negative allometric growth ($b > 3.0$) in the Atrai and Brahmaputra River, Bangladesh [15]. Additionally, this study identified sex-specific differences, with males exhibiting a lower slope than females. Overall, the *b*-value for females was larger than that for males, indicating a faster increase in body weight for female fish. These variations in *b*-values for similar species can be attributed to changes in observed fish length, abiotic factors like water quality parameters, and biotic factors such as microbial and parasite infestations on the host [57].

The von Bertalanffy model has proven to be the most accurate description of the growth of *M. pancalus* in this study. This model is widely recognized as an effective tool for describing fish growth patterns and is frequently used in the field of fishery biology [58]. Maximum length, as highlighted [41], has been widely adopted as a growth parameter for estimation purposes. King's study suggests that maximum length is a more suitable parameter for growth estimation than other length measurements. In the case of male M. pancalus, using an initial value of $L_\infty = 16.6$ cm, we estimated an asymptotic length of $L_\infty = 17.15$ cm. Similarly, for female *M. pancalus*, using an initial value of $L_\infty = 17.90$ cm, we estimated an asymptotic length of $L_\infty = 19.86$ cm. Notably, our estimations indicated that female *M. pancalus* tend to have a larger asymptotic length (19.86 cm TL) compared to males (17.15 cm TL). Furthermore, the parameter t_0, calculated as 0.042 for males and 0.040 for females, provides additional insights into growth patterns. In terms of body weight, males were estimated to attain an asymptotic weight of 23.20 gwith a growth coefficient of 0.62 per year, while females were estimated to reach an asymptotic body weight of 41.40 g with a growth coefficient of 0.63 per year.

Comparing our findings with those of Mustafa and Graff [59], we observed some similarities and differences. In their study conducted in Mara Beel and Ashura Beel, Bangladesh, they reported an L_∞ of 23.00 cm with a growth coefficient of 0.50 per year and 0.80 per year, respectively, which aligns reasonably well with our present findings. However, their findings from Medi Beel and Dikshi Beel, Bangladesh, indicated an L_∞ of 23.00 cm with growth coefficients of 1.3 per year and 1.4 per year, respectively, which differed from

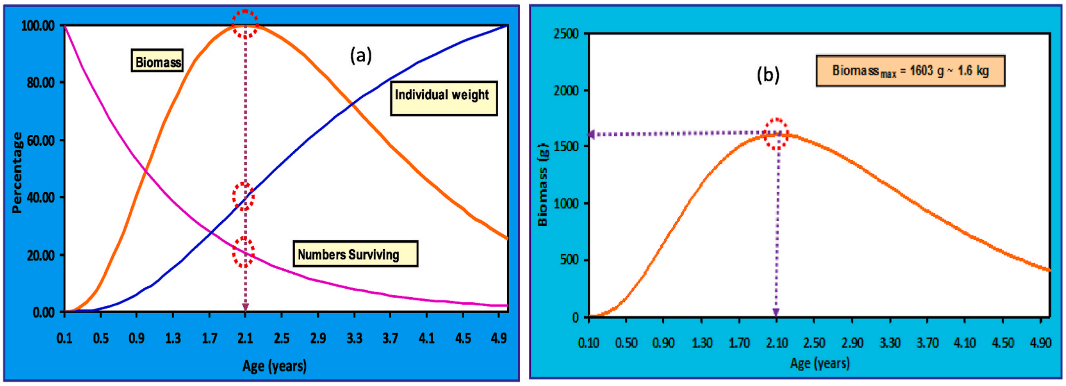

Fig. 8. (a) Percent of biomass, survival rate and individual weight (b) Biomass per recruit for the male *Macrognathus pancalus* in the Gajner Beel, northwestern Bangladesh.

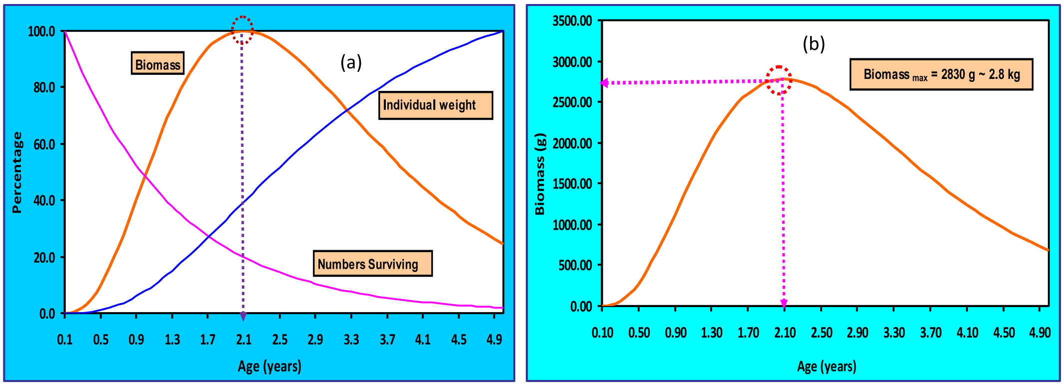

Fig. 9. (a) Percent of biomass, survival rate and individual weight (b) Biomass per recruit for the female *Macrognathus pancalus* in the Gajner Beel, northwestern Bangladesh.

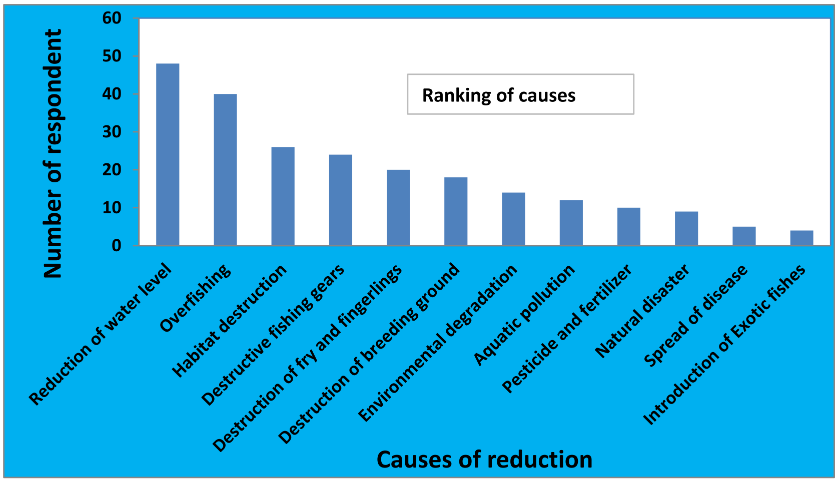

Fig. 10. Causes for reduction of *Macrognathus pancalus* in the Gajner Beel, northwestern Bangladesh.

our results.

The growth performance index (Ø) is an indicator used to assess the well-being of aquatic animals in relation to their environment [60]. Comparing growth rates between sexes and species using Ø is more straightforward than comparing L_∞ and K, which are typically negatively correlated [36]. In a study on *M. pancalus*, Ø was calculated to be 2.26 for males and 2.60 for females based on asymptotic length, indicating that females grew faster than males. The observed disparity in size between the sexes can be explained using the life-history technique, which accounts for differences in the growth performance index between males and females [61]. The study also found that male and female longevity in the Gajner Beel was 3.0 and 2.97 years, respectively. These differences in longevity can be attributed to environmental factors, especially water temperature [62].

The recruitment pattern of *M. pancalus* in the Gajner Beel was continuous throughout the year in this study, with the peak occurring at 7.00 cm for both sexes. The difficulty to compare the current result with other outcomes is caused by the lack of recruitment-related literature in availability.

The observed increase in mortality rates can be attributed to the rising fishing pressure that all fish stocks are currently experiencing compared to a decade ago. Additionally, it's essential to recognize that several of these variables are specific to each stock or location. Even minor changes in growth variables, environmental conditions, and the abundance of predators within a stock can have a substantial impact on expected mortality rates [63]. Natural mortality plays a crucial role in managing and evaluating fisheries stocks. Predation mortality often outweighs natural mortality, further emphasizing the need for effective conservation and management strategies [64]. Estimating natural mortality in tropical environments can be challenging due to practical difficulties in apportioning efforts. The commonly used approach of relating fishing effort to catch (Z versus effort) may not provide a comprehensive estimate of natural mortality (M). In this study, the length-converted catch curve analysis predicted natural mortality rates (M) of 0.95 and 0.97 year^{-1} for males and females, respectively. The instantaneous rates of total mortality (Z) were estimated at 2.24 and 2.48 year^{-1} for males and females, respectively. Fishing mortality (F) for both males and females was calculated as 1.29 year^{-1} and 1.51 year^{-1}, respectively. The exploitation rate (E) in Gajner Beel was found to be 0.58 and 0.61 based on estimates of instantaneous fishing and total mortalities. The Z (year^{-1}), M (year^{-1}), F (year^{-1}), and E were 4.75, 1.65, 3.10, and 0.65 in Ashura Beel; 5.18, 2.32, 2.86, and 0.55 in Dikshi Beel; and 6.41, 1.70, 4.71, and 0.74 in Mara Beel in Bangladesh [59] for combined sexes, which differs from the current findings.

In fisheries management, parameters like $E_{0.1}$ and $E_{\max}$ are frequently employed [13]. The exploitation ratio is a fundamental element used to justify the level of fishery utilization. The maximum sustainable yield (MSY) of *M. pancalus* population of Gajner Beel was estimated by using yield per recruit and biomass model. The maximum yield for males and females can be attained at E of 0.46 (46%) and 0.49 (49%), respectively based on the relative yield per recruit. Furthermore, the current E is around 0.58 (58%) for males and 0.61 (61%) for females, indicating that *M. pancalus* is being overexploited from the Gajner Beel. It was assumed that if 1000 males and 1000 female individual are recruited, then the maximum biomass will be 39.33 g with survival rate around 20% attained at the age of 2.1 years. The relative biomass at the age of 2.1 years for males and females were obtained as 1.6 kg and 2.8 kg, respectively. Even though this species is classified as least concern, it is not widely distributed in the Gajner Beel and is still under threat of extinction; therefore, effective conservation measures should be implemented to protect this species in its natural environment. There had been no previous studies on the aforementioned aspects, and it was not possible to compare with the current findings due to a lack of available literature.

Furthermore, the causes for declining the biodiversity of *M. pancalus* in the Gajner Beel includes reduction of water level, overfishing, environmental degradation, use of destructive fishing gear, destruction of fry and fingerlings, damaging of breeding grounds, illnesses proliferate, mudslides occur, and different ecological changes affect its natural habitat. To address these issues, a thorough and integrated strategy that includes habitat restoration, sustainable fisheries management, community involvement, and ecological research is required. It is essential to recognize the interconnectedness of these issues and to work collaboratively with local communities, governmental agencies, conservation organizations, and researchers to develop and implement strategies that promote the conservation and recovery of *M. pancalus* while also preserving the overall health of the Gajner Beel ecosystem. By taking concerted and coordinated action, it is possible to mitigate the threats facing *M. pancalus* and protect the biodiversity of this vital aquatic ecosystem for future generations.

4.1. Management approach of Macrognathus pancalus

This study aims to contribute to the development of effective management policies and fishing regulations to conserve *M. pancalus* in the wetland ecosystems of Bangladesh. While this research focuses on biological characteristics, it is crucial to consider environmental and socioeconomic aspects as well. If current fishing practices persist, there is a risk of depleting the species. Fisheries management aims to ensure long-term ecological sustainability and maximize benefits to fishers and communities while preserving habitat. Key objectives include establishing a conservation-oriented management program, maintaining a sufficient spawning stock, conducting studies to understand fisheries biology, and promoting public awareness about *M. pancalus.*

In the Gajner Beel, *M. pancalus* is a significant fish stock, but overfishing and habitat degradation are causing depletion. The study identified factors such as reduced water levels, overfishing, habitat degradation, illegal fishing gear, and the destruction of fry and fingerlings as leading causes of *M. pancalus* decline in the Gajner Beel. Collaboration between government and non-government organizations is essential to protect the fish habitat and species in the area. Furthermore, the study suggests the ban on destructive fishing gear and limitations on gear efficiency to aid in conservation. While research on reproductive variables is limited, the findings can inform a management regime to protect and conserve *M. pancalus* and other valuable fish species.

5. Conclusion

This research has the potential to significantly contribute to the effective and sustainable management of wetland ecosystems, particularly in the context of implementing fishing regulations. Recommendations based on the L_m provide valuable insights for proper wetland conservation, such as limiting net mesh sizes and harvesting during breeding times of *M. pancalus*. The long-term protection of the species and the well-being of the communities that surround it are ensured by reducing the exploitation of *M. pancalus* and promoting sustainable fishing methods, habitat preservation, and continuous monitoring.

Ethical approval

This research was conducted in accordance with the approval of Bangladesh Agriculture Research Council (Project ID: 484) ethical committee.

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Data availability statement

Research data of this study will be made available on request.

CRediT authorship contribution statement

Md Ataur Rahman: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mst Afia Sultana:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Md Akhtarul Islam:** Writing – review & editing, Visualization, Data curation. **Md Yeamin Hossain:** Writing – review & editing, Validation, Supervision, Software, Project administration, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e26492.

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