Heliyon 7 (2021) e08046

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Assessing the exploitation status of main catfish *Eutropiichthys vacha* based on length based stock assessment models in the Kaptai Lake from Bangladesh

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ARTICLE INFO

Keywords:
Stock assessments
Exploitation
Eutropiichthys vacha
Kaptai lake
Bangladesh

ABSTRACT

The current study focuses on the detailed data on stock assessments including population structure, growth parameters, mortality, recruitment pattern, exploitation rate (*E*), maximum sustainable yield (MSY) and relative yield per-recruit of *Eutropiichthys vacha* (Hamilton, 1822) based on 2512 specimens through regular monthly sampling using gill net, cast net, and square lift net in the Kaptai Lake, located in the hilly region of Bangladesh during January to December 2017. Total length (TL) and body weight (BW) were measured using digital slide calipers and electronic balance with 0.01 cm and 0.01g accuracy for each individual. The asymptotic length (L_∞) was 44.40 cm and growth coefficient (*K*) was 0.70 year^{-1}. The growth performance index ($Ø'$) was 3.14. The age at zero length (t_0) was 0.027 year and life-span (t_{max}) was 2.73 year. We estimated total mortality (*Z*), natural mortality (*M*) and fishing mortality (*F*) as 4.23, 1.27 and 2.96 year^{-1}, respectively. The recruitment pattern was throughout the year with two pick-events during May and September. Length at first capture (L_c) was 20.65 cm TL. The *E* was 0.70 where the E_{max} (exploitation rate producing maximum yield) was 0.45 which indicates 25% over fishing. The MSY was estimated as 34257 metric ton. In conclusion, the results of this study would be very operative to execute specific management for *E. vacha* in Kaptai Lake, Hilly region of Bangladesh.

1. Introduction

Kaptai Lake is the largest lake in Bangladesh which is positioned in the Kaptai Upazila under Rangamati District of Chittagong Division. These Lake contains a lot of freshwater small fish species that are in decreasing trend and produce 10,578 metric ton fish annually (FRSS, 2020). Schilbid catfishes are one of the important genera in this Lake. In Kaptai Lake, *Eutropiichthys vacha* (Hamilton, 1822) is the mostly dominant catfish. *E. vacha* is commonly known as the Batchwa vacha, which is generally available in tropical, brackish and freshwater bodies. This fish has very high economic value in our country. Due to their flesh quality and low price in market, this fish are mainly used for human consumption (Soomro et al., 2007) and it is also as aquarium fish (Abbas, 2010). Moreover, this fish is an essential source of survival for those fishers who employ various traditional fishing gears (Abbas, 2010; Hossain, 2010; Rahman et al., 2019a,b). Though, *E. vacha* is facing several threats such as habitat loss and increase temperature, this fish is very enduring, habitat-generalist fish which is previously categorized as critically endangered (Khan et al., 2000), nevertheless now it is categorized in Bangladesh (IUCN Bangladesh, 2015) and also worldwide (IUCN, 2015) as least concern.

Growth pattern is regularly applied to detect the year-round difference in growth and condition indices of fish. In addition, growth pattern is vital for the estimation of fish production and biomass. Different dynamic mathematical (Beverton and Holt, 1957, 1966) models are thoroughly employed for prescribing management plans for assessing prospective yields and biomass of stock at various stages of fishing techniques (Dadzie et al., 2017). Knowledge on growth, recruitment, mortality, relative yield per recruit, exploitation and maximum sustainable yield of fish populations are important requirements for the origin of

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https://doi.org/10.1016/j.heliyon.2021.e08046
Received 12 April 2021; Received in revised form 5 July 2021; Accepted 17 September 2021

these models. In most tropical and semi-tropical waters, the different dynamic pool models have been applied for estimating of fish age and defining management strategies in fisheries. Though, the enhancement of the stock assessment methodologies is probable to examine fish population dynamics in temperate water-bodies.

However, stock assessment is important for the fisheries researcher with the statistics that is needed for the guideline of a fish stock and also defines the previous and current stock status of fish. Information on exploitation status and length based stock assessment of *E. vacha* is not available in literature. However, few studies have been carried out on various aspects on this species from Indian Sub-Continent including morphological relationships (Hossain et al., 2009; Hossain, 2010; Soomro et al., 2007; Parvej et al., 2014), morphometric features (Hossain et al., 2013), sexual maturity (Hossain et al., 2012), exploitation, sex ratio, reproduction, food and feeding habits (Tripathi and Gopesh, 2017; Khatun et al., 2019a,b), spatial variation of growth and physiological status (Khatun et al., 2018). Though it has commercial importance as a food fish throughout the different countries but aquaculture technique of this fish has not been established yet. Therefore, capture from wild population is still fulfilling total demand in the local markets. So the appropriate management of capture fisheries of *E. vacha* is very essential. Therefore, the present study was conducted in the Kaptai Lake to assess the stock's status of *E. vacha* for developing the management strategies of this fish so that they can sustain in their natural habitat which are now being subjected to high exploitation.

2. Materials and methods

2.1. Sampling site

From January to December 2017, the author collected 2512 individuals of *E. vacha* from fisher's catch in the Kaptai Lake, Bangladesh. A number of standard fishing nets including cast net (mesh size: 1.0–2.0 cm) and gill net (mesh size: 1.5–2.5 cm), were used to catch fish. At the sampling site, the specimens were chilled and after that stored in laboratory of Bangladesh Fisheries Research institute with 10% alcohol solution.

2.2. Fish measurement

The total length (TL, cm) was measured by digital slide calipers and total body weight (BW, g) were measured by electronic balance with a precision of 0.01 cm and 0.01 g, respectively in the laboratory. However, the TL was considered by the FAO-ICLARM Stock Assessment Tools II (FiSAT II) (Gayanilo and Pauly, 1997) and TropFishR Packages (Mildenberger et al., 2017) for the stock assessment study. Sample collection, slaughtering, measurement and other standard methods were followed throughout this study properly by the approval of Agricultural Research Institute (ARI) ethical committee appointed by Bangladesh Fisheries Research institute (BFRI).

2.3. Growth types

The growth forms were evaluated via the formula: BW $= a$*(TL)^b. Linear regression study was used to measure the parameters a and b and to evaluate natural logarithms: ln (W) $=$ ln (a) $+$ b*ln (L). Based on the Froese (2006), extreme outliers were omitted from regression studies. To check the growth forms, either isometric or allometric ($\pm$), a t-test have been accustomed to test for major difference from the isometric value of b $= 3$ (Sokal and Rohlf, 1987).

2.4. Growth parameters

Using FISAT software (Gayanilo et al., 1994) version 1.1, the monthly length-frequency data (LFD) was investigated. Firstly, the Powell-Wetherall method (Powell, 1979; Wetherall, 1986), as updated by Pauly (1984a) was accustomed to analyze the LFD which involves a rearrangement into a linear regression equation of the Beverton and Holt (1966) length-based Z-equation: L- ′ - $L'a + Lb$ where, L- ′ = cut off length, i.e. the length of the smallest fully recruited fish for each size class, L- ′= $(L + L')/[1+(Z/K)]$ = mean length of all fish $\geq L'$. On the basis of the above equation, the preliminary L_∞ was determined as s/b and Z/K as –$(1 + b)/b$.

With the electronic frequency analysis (ELEFAN I) process, growth parameters was determined (Gayanilo et al., 1994). The effects of the gear selectivity were adjusted using the capture probabilities. For obtaining preliminary growth coefficient (K) and asymptotic length (L_∞) of the von Bertalanffy Growth Function (VBGF), ELEFAN 1 was employed through “TropFishR” package of R program (Mildenberger et al., 2017) upon the length–frequency distribution of *E. vacha*.

Length-converted catch curve was made by these preliminary estimates. The mean selection curve of the fishing gear was calculated through a complete study of the left (ascending) portion of the length-converted catch curve. To precise the length-frequency data for gear selection for small fish, this selection curve was used (Pauly, 1980, 1984b). FISAT software was accustomed to obtain new values of K and L_∞ from the analysis of the corrected LFD (Gayanilo et al., 2002).

The life-span (t_{max}) was assessed by the equation: log $t_{max} = 0.5496 +$ 0.957*log (t_m) (Froese and Binohlan, 2000), where t_m is the life-span. Through the Pauly's equation of Log (-t_0) = -0.3922 - 0.2752 Log L_∞- 1.038 Log K (Pauly 1980), age at zero length (t_0) was assessed and growth performance indexes were calculated as Ø' $= \log_{10}K + 2\log_{10} L_\infty$ (Pauly and Munro, 1984).

2.5. Capture probabilities

According to Sparre (1987), the catch-curve analysis was developed to calculate the probabilities of capture by backward projection of the number (N), which would be predicted if no selectivity had occurred.

2.6. Length at recruitment of *Eutropiichthys vacha*

Growth parameters L_α, K, C and WP were applied as inputs. Plots presenting the seasonal patterns of recruitment into the fishery were acquired by backward projection, beside a trajectory specified by the VBGF, of the frequencies into the time alignment of a collection of samples throughout time. As mentioned by Moreau and Cuende (1991), reconstructed samples were used.

2.7. Stock assessment of *Eutropiichthys vacha*

The length-converted capture curve technique (Gayanilo et al., 2002) was accustomed to estimate the instantaneous total mortality (Z). The Pauly equation was used to obtain an independent natural mortality (M) *via*: log10M = -0.0066 – 0.279log$_{10}$ L_∞ + 0. 6543log$_{10}K$ + 0:0463log$_{10}$T (Pauly, 1980); wherever T indicates the average temperature of the ecosystem, i.e. 27 °C, based on data gathered during the analysis. Fishing mortality (F) was assessed as Z-M. According to Gulland (1965), exploitation rate (E) was assessed via the equation: $E = F/Z = F/(F + M)$. Through the Beverton and Holt (1966) method, E_{max} (exploitation rate generating highest yield), $E_{0.1}$ (exploitation rate upon which the secondary rise of Y'/R is 10 percent of its virgin biomass) and $E_{0.5}$ (the exploitation rate at which half its virgin biomass of stock is reduced) were determined. At $E_{0.5}$ level, the recommended length at first capture (Lc) was calculated. Yield counters were plotted to calculate the effect of deviations in exploitation rate (E) and critical length ratio Lc/L_∞.

2.8. Maximum sustainable yield (MSY) of *Eutropiichthys vacha*

FiSAT II software was accustomed to estimate of the relative yield per recruit (Y'/R) based on the updated model of Pauly and Soriano (1986).

The methods provides a Y'/R vs. $E=(F/Z)$ and also a relative biomass per recruit (B'/R) vs. E.

Through the virtual population analysis (VPA), the steady state biomass (SSB) was calculated (Mildenberger et al., 2017). This provides the current biomass as metric ton SSB for every length class by altering the total quantity of fish to weight in accordance with the length-weight relationships parameters for each length class. The equation suggested by Gulland (1983) and further reformed by Garcia (1985) was used to assess the MSY of *E. vacha*: MSY = 0.5×SSB×Z.

2.9. Statistical analyses

Statistical analyses were done in the "TropFishR" package of R program (Mildenberger et al., 2017), FiSAT II and Microsoft® Excel-add-in-DDXL software. The different natural mortality (M) values were estimated using various models through Natural Mortality Estimator (NME).

3. Results

3.1. Growth types

The monthly length and weight measurements data for *E. vacha* in the Kaptai Lake are illustrated in Table 1. The relationship between length and weight was assessed as $W = 0.0088TL^{2.96}$ (Figure 1). After measuring the SSB of *E. vacha*, we used these values to convert length to weight as input data.

3.2. Growth parameters

The seed vales $L_\infty = 43.82$ and $Z/K = 1.52$ were calculated by the Powell-Wetherall method using monthly frequency data series (Figure 2). For the original data set, the K-scan method defined an L_∞ of 44.40 cm TL and K value of 0.70 year^{-1} (Figure 3 and Table 2). The length–frequency histograms and also the von Bertalanffy Growth Curve (VBGC) was presented in Figure 4. These growth curves were overlaid the length–frequency histograms. The growth performance index (Ø), Life span (t_{max}) and age at zero length (t_0) were found 3.14, 2.73 year and 0.027 year, respectively (Table 2).

3.3. Selectivity of gear

In the Kaptai Lake, the selected nets recollected 25% of the 19.82 cm TL fish and 50% of the 20.65 cm TL fish. In addition, the model of selection curves demonstrated that the selected nets recollected at least 75% of all 21.54 cm TL fish (Figure 5).

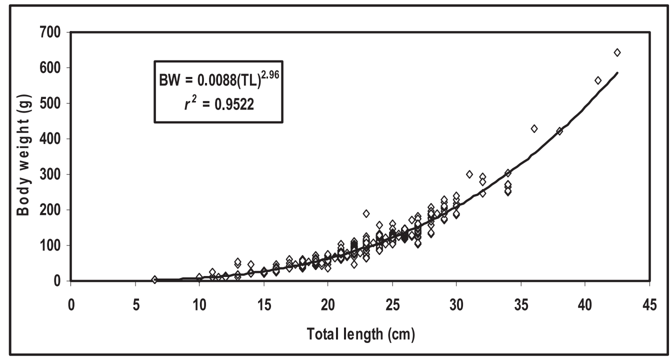

Figure 1. Growth pattern of *Eutropiichthys vacha* (Hamilton 1822) in the Kaptai lake, Bangladesh.

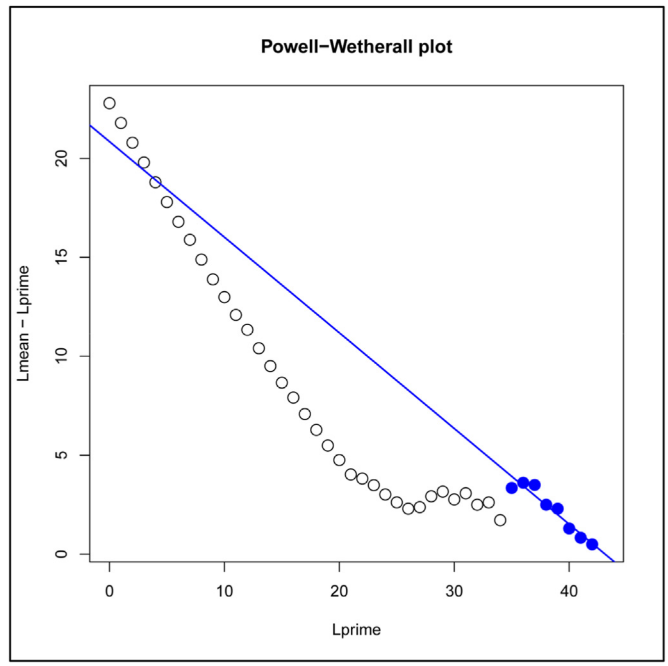

Figure 2. Powel-Wetherall plot for the length frequency data of *Eutropiichthys vacha* in Kaptai lake suggests that values of (L_{mean} - L_{prime}) plotted against a series of cut-off points, L_{prime} as a straight line. Black dots are exploited samples. Solid black symbols are exploited samples that are used in the regression which provides asymptotic TL of 44.40 cm and Z/K of 1.52.

Table 1. Descriptive statistics on the total length (cm) and body weight (g) measurements of *Eutropiicthys vacha* (Hamilton, 1822) in the Kaptai Lake, Bangladesh.

Month	n	TL				BW			
		Min	Max	Mean ± SD	95% CL	Min	Max	Mean ± SD	95% CL
January	191	12.0	31.0	17.741 ± 4.718	15.87 to 19.61	12	300	53.93 ± 64.68	28.34 to 79.51
February	140	13.0	27.0	19.85 ± 3.48	18.22 to 21.48	35	162	73.9 ± 31.91	58.97 to 88.83
March	160	18.0	34.0	23.01 ± 3.97	21.74 to 24.28	44	304	96.6 ± 57.16	78.32 to 114.88
April	126	18.0	41.0	24.21 ± 4.33	22.69 to 25.72	44	566	129.65 ± 106.46	92.50 to 126.79
May	140	13.0	24.0	20.15 ± 2.68	18.90 to 21.40	37	158	67.85 ± 28.80	54.37 to 81.33
June	219	15.0	30.0	24.38 ± 2.65	23.70 to 25.07	22	214	114.55 ± 38.33	104.65 to 124.45
July	157	12.0	27.0	22.80 ± 5.15	20.39 to 25.21	10	142	93.6 ± 45.78	72.18 to 115.02
August	270	6.5	42.5	20.33 ± 9.14	17.41 ± 23.26	2	644	96.18 ± 119.30	58.02 to 134.33
September	271	10.0	34.0	23.80 ± 6.89	20.58 to 27.02	10	270	119.45 ± 73.20	85.18 to 153.72
October	240	15.0	38.0	24.1 ± 4.52	23.09 to 25.11	20	428	120.86 ± 70.88	105.66 to 105.09
November	320	14.0	32.0	21.32 ± 4.09	20.26 to 22.37	20	278	87.53 ± 50.64	74.45 to 100.62
December	278	18.0	30.0	23.79 ± 2.82	23.16 to 24.41	52	238	117.89 ± 43.44	108.22 to 127.55

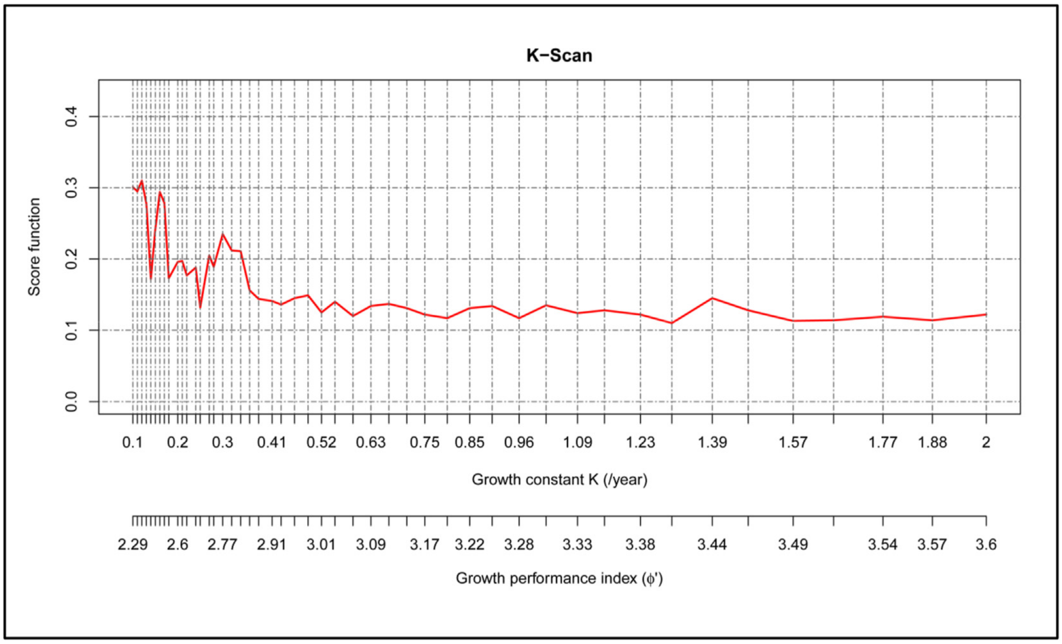

Figure 3. K-scan routine for determining best growth curvature giving best value of asymptotic length with growth performance indices for *Eutropiichthys vacha*.

3.4. Length at recruitment of Eutropiichthys vacha

The recruitment pattern of *E. vacha* in the Kaptai Lake was constant over the year and the major two peaks were identified during June and September (Figure 6).

3.5. Stock assessments of Eutropiichthys vacha

The calculated Z value of the slope of the length-converted catch curve for *E. vacha* are indicated in Figure 7. The instantaneous rate of $Z =$ 4.23 year^{-1} was calculated by the length-converted catch curve analysis. It has been estimated that the average temperature at Kaptai Lake is around 27 °C. The estimated values of the natural mortality instantaneous rates were $M = 1.27$ year^{-1}. The values of estimated natural mortality (M) through different methods were different which are documented in Table 3. Fishing mortality rate (F) was therefore reported as 2.96 years^{-1} using empirical model (M). Exploitation rate was estimated as $E = 0.70$ from the calculations of instant fishing and total mortality for *E. vacha* in the Kaptai Lake (Table 2).

3.6. Maximum sustainable yield (MSY) of Eutropiichthys vacha

The biomass-per-recruit (B'/R) and relative yield-per-recruit (Y'/R) plot against the exploitation rate (E) of *E. vacha* in Kaptai Lake demonstrated in which the maximum Y'/R was achieved at $E_{max} = 0.45$ (Figures 8 and 9). The calculated values of $E_{0.1}$ and $E_{0.5}$ were 0.37 and 0.28, respectively. The selection of the knife edge implies that individuals under the size of L_c will evade the net. The L_c/L_∞ values were determined as 0.20, which is a fundamental prerequisite for the yield isopleth figure construction. The yield isopleth diagram showed that fishing at E of 0.45 and L_c/L_∞ value of 0.20 can be achieved (Figure 9). The relative yield per recruit indicates that the maximum yield can be found at E of 0.45. In addition, the calculated E is around 0.70, which indicates that the *E. vacha* is over exploited from the Kaptai Lake. Based on the probability of capture analysis through selection curves, the calculated optimum TL of *E. vacha* at first capture ($L_c = L_c50$) was 20.65 cm (Figure 9). The approximate total SSB using the FiSAT II routine of length-structured virtual population analysis (VPA) was 16197.32 metric tons (Figure 10). The MSY was measured to be 34257 metric tons if the suggested length ($L_c = 20.65$ cm TL) at the first capture is maintained.

4. Discussion

Stock assessments are elementary management methods to support understanding the growth, recruitment, mortality, maximum sustainable yield and exploitation rate of fish (Jennings et al., 2001) and it also support in estimations of fish populations for the selection of another management option (Hilborn and Walters, 1992).

In our study, a lot of specimens with various lengths were caught through habitual fishing net from the Kaptai Lake all over the year. The

Table 2. 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 *Eutropiicthys vacha* (Hamilton, 1822) in the Kaptai Lake, Bangladesh.

Description of Parameters	Values
Growth and reproduction	
Asymptotic length (L_∞) Asymptotic weight (W_∞)	44.40 cm TL 28.9gm
Growth coefficient (K)	0.70 year^{-1}
Life-span (t_{max})	2.73 year
Growth performance indexes ($Ø'$)	3.14
Age at zero length (t_0)	0.027 year
Size at first sexual maturity (L_m)	23.56 cm TL
Age at first sexual maturity (t_m)	0.76 years
Mortality parameters	
Total mortality (Z)	4.23 year^{-1}
Natural mortality (M),	1.27 year^{-1}
Fishing mortality (F)	2.96 year^{-1}
Fishery parameters	
Exploitation rate(E)	0.70
Exploitation rate producing maximum yield (E_{max})	0.45
Exploitation rate upon which the secondary rise of Y'/R is 10 percent of its virgin biomass ($E_{0.1}$)	0.37
Exploitation rate at which half its virgin biomass of stock is reduced ($E_{0.5}$)	0.28
Total length at first capture (L_c)	20.65 cm TL
Steady state biomass (SSB) Maximum sustainable yield (MSY)	16197.32 Metric ton 34257 Metric ton

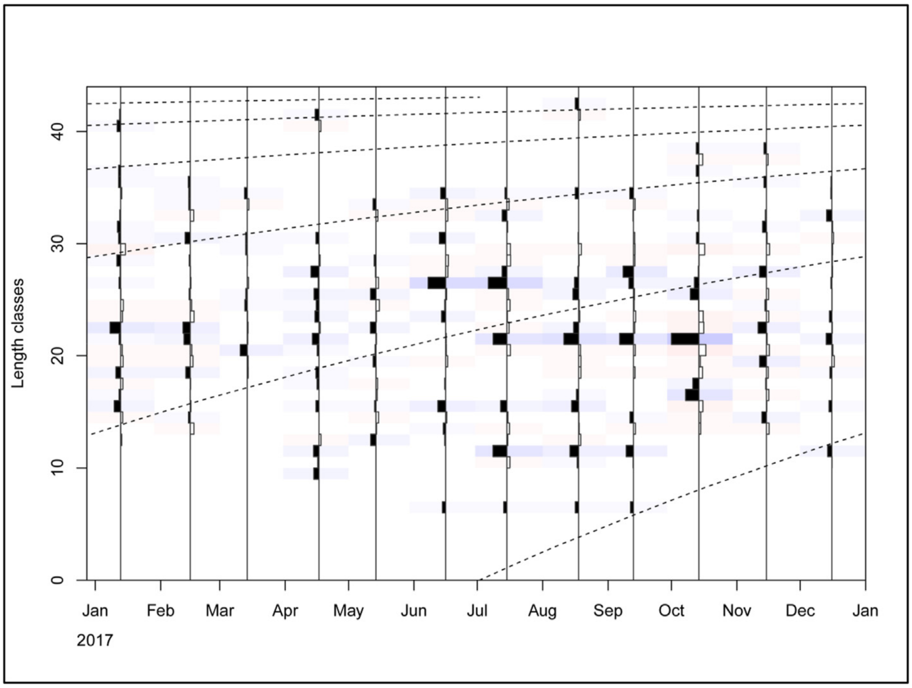

Figure 4. von Bertalanffy growth curve of *Eutropiichthys vacha* (TL_∞ = 44.40cm, K = 0.70 $year^{-1}$) as superimposed on the restructured total length-frequency histogram.

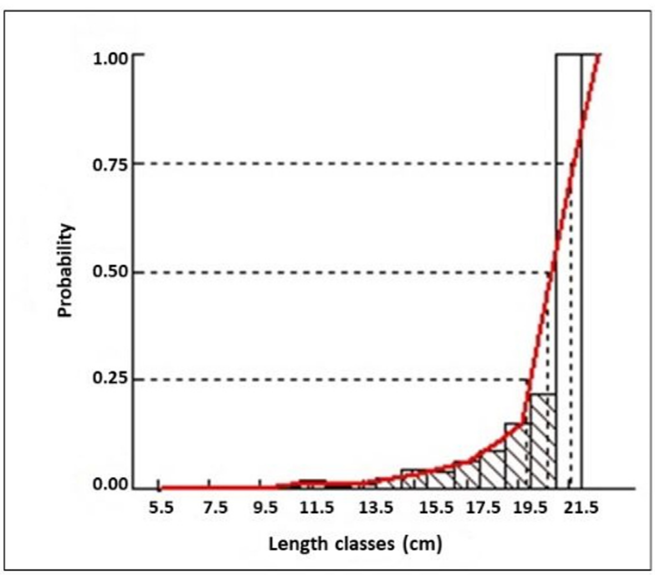

Figure 5. Logistic selection curve for probability of capture, showing 25%, 50% and 75% selection length of *Eutropiichthys vacha* in Kaptai lake, Bangladesh.

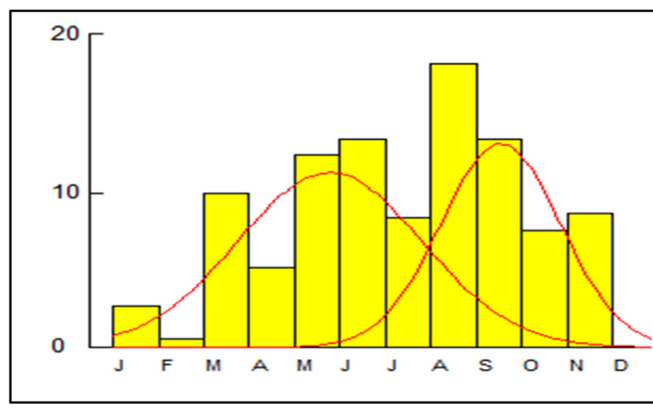

Figure 6. Recruitment pattern of *Eutropiichthys vacha* in Kaptai lake, Bangladesh. The histogram shown relative percentage of recruits per month whereas bell shaped curves show the one recruitment peak.

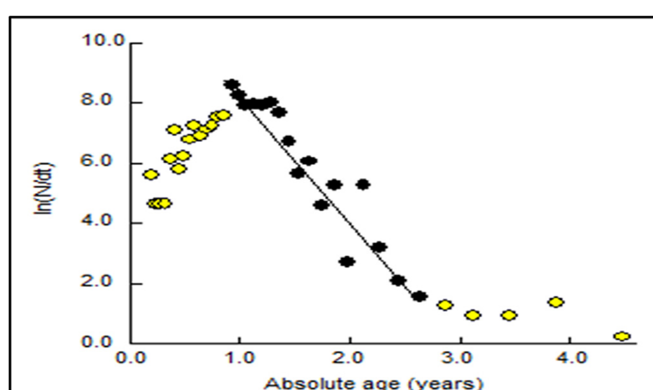

Figure 7. Length-converted catch curve of *Eutropiichthys vacha* in Kaptai lake. Data included in the regression are shown as black solid points.

TL of *E. vacha* was ranged from 6.2–42.5 cm TL which was recorded the maximum length during this study. Though, it was unattainable to collect fishes smaller than 6.2 cm TL and larger than 42.5 cm in TL. The experimental highest length of *E. vacha* was 42.5 cm during this study, which is greater than the maximum recorded value of 25.8 cm from the Padma River, Bangladesh (Hossain et al., 2009) and 34.0 cm TL from the Indus River, Pakistan (Soomro et al., 2012) and also 16.95 cm in the Jamuna River, Bangladesh (Hossain et al., 2013). Moreover, the highest TL for *E. vacha was* described as 30.0 cm from Bangladesh (Rahman, 1989) although the maximum TL for *E. vacha* was reported as 37.00 cm TL from the Ganga River, India (Tripathi and Goseph, 2017). So, our observed length is the recorded maximum length worldwide. The

Table 3. Methods used to calculate natural mortality (M) of *Eutropiicthys vacha* (Hamilton, 1822) in the Kaptai Lake, Bangladesh through natural mortality estimator (NME).

Method*	Natural Mortality (*M*)
Jensen_VBGF 1	1.05
Jensen_VBGF 2	1.12
Pauly_lt	1.27
Roff	2.99
Jensen_Amat	2.17
Ri_Ef_Amat	1.69
Hamel_Amax	2.00
ZM_CA_pel	2.85
ZM_CA_dem	1.67
Then_VBGF	0.91
FishLife	0.88
Then_nls	1.97
Then_lm	2.04

* Detail methodologies for the estimation of natural mortality are presented in http://barefootecologist.com.au/shiny_m (Accessed on: 05 August 2021).

absence of smaller sized fishes in Kaptai Lake was associated due to the fishing gear (Hossen et al., 2019a, b; Rahman et al., 2020) instead of their nonexistence on the fishing ground in the study area.

The allometric co-efficient *b* values may differ from 2 to 4 (Carlander, 1969). But *b* values 2.5 to 3.5 are more common for most fishes (Froese, 2006). In our research work, the regression parameter *b* of the LWR was 2.96 for *E. vacha*. In case of LWR, the overall *b* value indicated negative allometric growth but Hossain et al. (2013) reported isometric growth for male ($b = 3.03$) which is dissimilar with the present findings nevertheless similar with the result of female *E. vacha* ($b = 2.81$) combined sexes ($b = 2.92$) in the Jamuna River, Bangladesh. Moreover, Soomro et al. (2007) reported the positive allometric growth in males ($b = 3.16$) and isometric growth in combined sexes ($b = 3.05$) for *E. vacha* in the Indus River, Pakistan, which are also different from our findings but shows similar result in case of females (negative allometric, $b = 2.96$). Also, Hossain et al. (2009) and Hossain (2010) reported negative allometric growth in combined sex of *E. vacha* from lower Ganges River, Bangladesh. Furthermore, Sani et al. (2010) found similar result for this fish from the Gomti River, India in accordance with our study. Though, this differences occur due to the combination of various factors such as habitat, cyclical effect, amount of stomach fullness and alterations in the observed body sizes of the specimen captured (Hossain, 2010), which were unavailable during this study.

In this study, the overall *a* values *E. vacha* was 0.0088. However, Hossain et al. (2013) reported the *a* value for the same species as 0.0070 whereas Soomro et al. (2007) reported the values as 0.0054 for combined sexes respectively which is quite similar with our study. In another study, Hossain et al. (2009) described the value of *a* as 0.0180 for combined sexes for the same species in the same habitat which is dissimilar with our findings. Besides, Sani et al. (2010) reported the value as 0.0138 for combined sex which is also dissimilar with the present findings.

The growth of *E. vacha* was best expressed by the von Bertalanffy model. This model is most commonly used in fishery biology, and is a good descriptor of fish growth patterns (Soriano et al., 1992). Using $TL_\infty = 43.82$ cm as a seed value for *E. vacha* asymptotic length can be obtained as $TL_\infty = 44.40$ cm. Study on $L\infty$ for Bangladeshi fishes is very scant except Ahamed et al. (2012). We calculated L_∞ as larger than our biggest observed fish. Some researchers (Macpherson, 1998; Vigliola et al., 1998) found the reverse condition and decided that this is because of the von Bertalanffy model being insufficient for reporting growth of fish species from the Sparidae family, mostly because of their quick growth in the first year of life and reducing significantly subsequently. The present result is supported by Ahamed et al. (2012). During this work, the von Bertalanffy growth curve revealed no seasonal oscillation in growth. Moreover, the t_0 was estimated 0.027 year using the equation of King (2007). *E. vacha* was attained 28.69g as asymptotic BW with the growth coefficient (*K*) of 0.70 year^{-1}. According to Memon et al. (2017), the L_∞,

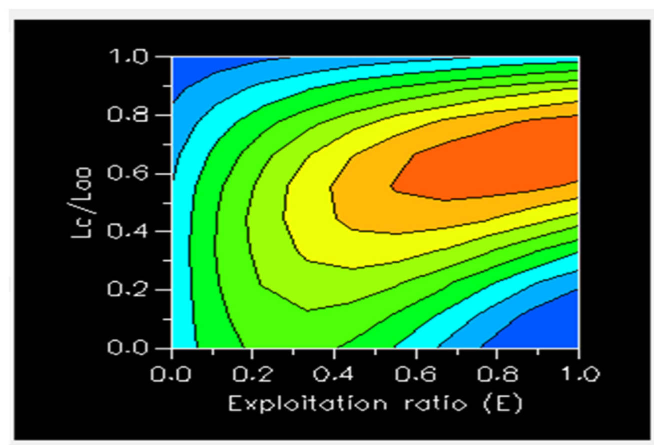

Figure 9. Yield Isopleths, showing optimum fishing activity both in terms of fishing effort and size of first capture of *Eutropiichthys vacha* in the Kaptai lake, Bangladesh.

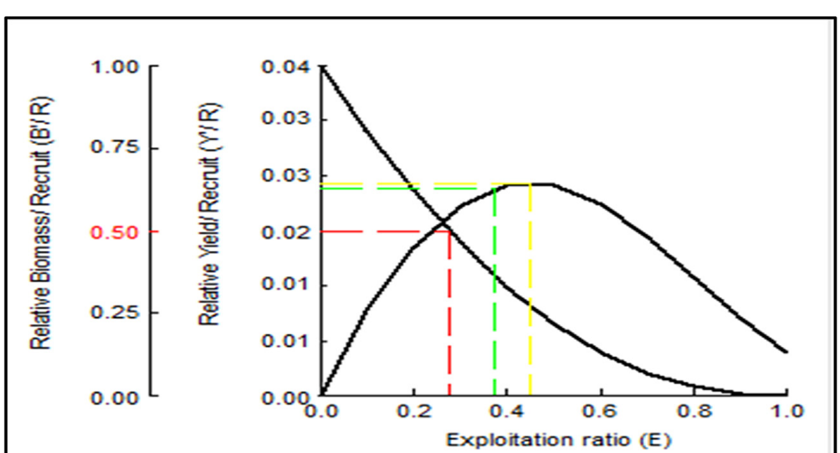

Figure 8. Yield-per-recruit and average biomass per recruit models, showing levels of yield index in *Eutropiichthys vacha* in the Kaptai lake, Bangladesh.

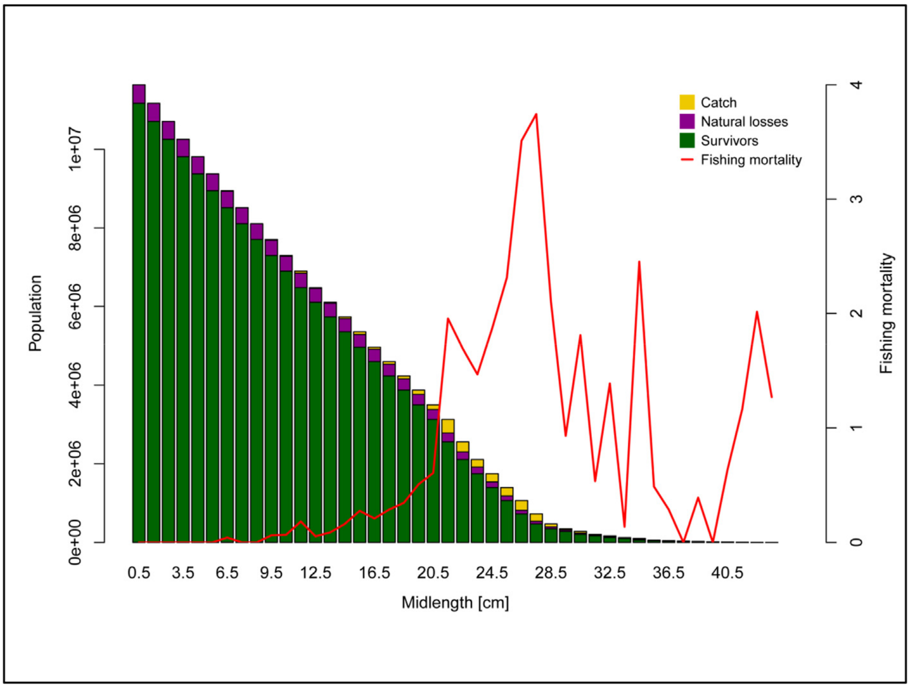

Figure 10. Length-structured virtual population analysis of *Eutropiichthys vacha* in the Kaptai lake, Bangladesh.

t_0 and K were 35.7 cm, -0.358 year and 0.36 year^{-1}, respectively from Indus River, Pakistan.

The growth performance index ($\varnothing'$) is an indicator of the favorable condition of aquatic animals comparative to their environmental feature and it is very simple to relate the between species than comparing L_∞ and K, as these two factors are fundamentally negatively associated (Pauly and Munro, 1984). During this study, the calculated $\varnothing'$ for *E. vacha* was 3.14 based on asymptotic length. Memon et al. (2017) studied that the $\varnothing'$ are 2.662, 2.859, 2.869 for combined sexes, male and females, respectively which is almost similar with our findings. Furthermore, Life span (t_{max}) of *E. vacha* calculated as 2.73 years in the Kaptai Lake. Differences in longevity are primarily imposed to climatic factors, mostly temperature of water (Choi et al., 2005; Sarmin et al., 2021).

Thus, food availability and favorable environmental conditions could influence recruitment pattern of fish. The recruitment pattern of *E. vacha* was throughout the year but two recruitment peaks in June and September in Kaptai Lake (Figure 8). There is no available literature dealing with the recruitment which restrains the comparison of the present result with others.

In stock assessment, natural mortality is the substantial feature for fisheries management. According to Memon et al. (2017), the total mortality (Z), natural mortality (M), and fishing mortality (F) were 1.09 year^{-1}, 0.762 year^{-1}and 0.33 year^{-1} for combined sex but 1.85 year^{-1}, 1.129 year^{-1}and 0.721 year^{-1} for males and 1.51 year^{-1}, 1.041 year^{-1}and 0.469 year^{-1}for females from Indus River, Pakistan. Memon et al. (2017) also reported exploitation rate (E) was 0.302 for combined sex, 0.389 for males and 0.31 for females from Indus River, Pakistan which is dissimilar with our findings.

The relative yield per recruit illustrates that the highest yield for *E. vacha* was obtained at E of 0.70 (70%). In addition, the present $E_{\max}$ is around 0.45 (45%), which indicates that the *E. vacha* is over-exploited from the Kaptai Lake which is similar with Tripathi and Goseph (2017) from the Ganga River, Allahabad, India. Although this species is categorized as least concern but still this species is not widely abundant in the Kaptai Lake and still facing various threats for decline therefore, appropriate measure should be taken to conserve this species in their natural habitat. Based on Memon et al. (2017), *E. vacha* is not over-exploited from Indus River that is not in accordance with our results.

This work will be helpful to develop management policies for this fish and to introduce appropriate fishing guidelines for better management of fishes in hilly region of Bangladesh.

Effective management policies as mesh size selection, gear selectivity, limitation of harvesting during peak spawning period and protecting spawning ground can be appropriate for reducing fishing pressure of *E. vacha* in Kaptai Lake. Though this study provides management approach considering only the biological aspects, it is recommended to study the environmental and socio-economic aspects also. Since fisheries regulations have increasingly addressed other aspects of fisheries management, therefore, it necessitates undertaking further study on economic, social and environmental objectives such as fishers' wellbeing, economic efficacy, the allocation of resources, and protection of environmental of the Kaptai Lake. This management recommendation is suggested to be followed for *E. vacha* stock in the Kaptai Lake and various inland habitats of Bangladesh.

Declarations

Author contribution statement

Md. Abul Bashar; Md. Ataur 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.

Kazi Belal Uddin; Fee Faysal Ahmed; Yahia Mahmud: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Funding statement

This work was supported by the Bangladesh Fisheries Research Institute, Mymensingh 2201, Bangladesh.

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.

Acknowledgements

We deeply remember Mr. S. Sanjib Basak, Scientific Officer, BFRI Rangamati who passed away on February 13, 2019 with a sudden heart attack. We are deeply saddened by his untimely death. Mr. Basak was a co-researcher of the project and his contribution to this work was remarkable. We all wish him peace of mind and dedicate the work to him.

Simultaneously, we express our heartfelt gratitude to the local retailer, aratdar, fishers, and employees of the fish landing centers for their support during sample collection. We also express thanks to all staff of the BFRI, Riverine sub-station, Rangamati for their assistance during laboratory and fieldwork.

References

Abbas, A., 2010. Food and feeding habits of freshwater catfish *Eutropiichthys vacha* (Bleeker). Indian J. Sci. Res. 1, 83–86.
Ahamed, F., Ahmed, Z.F., Hossain, M.Y., Ohtomi, J., 2012. Growth study of the pool barb *Puntius sophore* (cyprinidae: barbinae) through multi-model inferences. Zool. Stud. 51, 1077–1085.
Beverton, R.J.H., Holt, S.J., 1957. On the dynamics of exploited fish populations. Fish. Investig. 19, 1–533.
Beverton, R.J.H., Holt, S.J., 1966. Manual of Methods for FIsh Stock Assessment. Part 2. Tables of Yield Functions, 1. FAO Fisheries Technical Paper, p. 49.
Carlander, K.D., 1969. Handbook of Freshwater Fishery Biology, 1. The Iowa State University Press, Ames., IA, p. 752.
Choi, J.H., Kim, J.N., Ma, C.W., Cha, H.K., 2005. Growth and reproduction of the kiski velvet shrimp, *Metapenaeopsis dalei* (Rathbun, 1902) (Decapoda, Penaeidae) in the western sea of Korea. Crustaceana 78, 947–963.
Dadzie, S., Abou-seedo, F., Moreau, J., 2017. Population dynamics of *Parastromateus niger* in Kuwaiti waters as assessed using length–frequency analysis. J. Appl. Ichthyol. 23, 592–597.
Froese, R., Binohlan, C., 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. J. Fish. Biol. 56, 758–773.
Froese, R., 2006. Cube law, condition factor and weight length relationship, history meta-analysis and recommendations. J. Appl. Ichthyol. 22, 241–253.
FRSS (Fisheries Resources Survey System), 2020. Fisheries Statistical Yearbook of Bangladesh. *Fisheries Resources Survey System (FRSS*), Department of Fisheries, Bangladesh, p. 43.
Garcia, S., 1985. Reproduction, stock assessment models and population parameters in exploited Penaeid shrimp populations. In: Rothlisberg, P.C., Hill, B.J. (Eds.), Proceedings of Second Australian National Prawn Seminar. NSP-2, Cleveland, Australia, pp. 139–158.
The FAO-ICLARM stock assessment tools (FiSAT). Reference manual. In: Gayanilo, F.C., Pauly, D. (Eds.), FAO Comp. Inform. Ser. (Fisheries) 202. No. 8.
Gayanilo, F.C., Sparre, P., Pauly, D., 1994. The FAO-ICLARM stock assessment tools (FiSAT) user's guide. FAO Comp. Info. Ser. (Fisheries). 6, 186.
Gayanilo, F.C., Sparre, P., Pauly, D., 2002. The FAO-ICLARM Stock Assessment Tools II (FiSAT II Ver. 1.0).
Gulland, J.A., 1965. Estimation of mortality rates. In: Annex to Arctic Fisheries Working Group Report ICES C.M./1965/D:3 (Mimeo) (Reprinted as in: Cushing, P.H. (Ed). Key Papers on Fish Populations. IRL Press, Oxford, pp. 231–241.
Gulland, J.A., 1983. Fish Stock Assessment. A Manual of Basic Methods. John Wiley & Sons, Chichester.
Hamilton, F., 1822. An account of the fishes found in the river Ganges and its branches. Archibald Constable 1.
Hilborn, R., Walters, C.J., 1992. Quantitative Fisheries Stock Assessment, Choices, Dynamics and Uncertainty. Chapman & Hall, New York, London.
Hossain, M.Y., Jasmine, S., Ibrahim, A.H.M., Ahmed, Z.F., Rahman, M.M., Ohtomi, J., 2009. Length-weight and length-length relationships of 10 small fish species from the Ganges, Bangladesh. J. Appl. Ichthyol. 25, 117–119.
Hossain, M.Y., 2010. Length-weight, length-length relationships and condition factor of three Schilbid catfishes from the Padma River, northwestern Bangladesh. Asian Fish Sci. 23, 329–339.
Hossain, M.Y., Jewel, M.A.S., Nahar, L., Rahman, M.M., Naif, A., Ohtomi, J., 2012. Gonadosomatic index-based size at first sexual maturity of the catfish *Eutropiichthys vacha* (Hamilton 1822) in the Ganges River (NW Bangladesh). J. Appl. Ichthyol. 28, 601–605.
Hossain, M.Y., Rahman, M.M., Jewel, M.A.S., Hossain, M.A., Ahamed, F., Tumpa, A.S., Abdallah, E.M., Ohtomi, J., 2013. Life history traits of the critically endangered catfish *Eutropiichthys vacha* (Hamilton 1822) in the Jamuna (Brahmaputra River distributary) River, Northern Bangladesh. Sains Malays. 42, 265–277.
Hossen, M.A., Paul, A.K., Hossain, M.Y., Ohtomi, J., Sabbir, W., Rahman, O., Jasmin, J., Khan, M.N., Islam, M.A., Rahman, M.A., Khatun, D., Kamaruzzaman, S., 2019a. Estimation of biometric indices for snakehead *Channa punctata* (bloch, 1793) through multi-model inferences. Jordan J. Biol. Sci. 12 (2), 197–202.
Hossen, M.A., Rahman, M.A., Hossain, M.Y., Islam, M.A., Hasan, M.R., Mawa, Z., Ohtomi, J., 2019b. Estimation of relative growth of Minor carp *Labeo bata* (Cyprinidae) through multi-linear dimensions. Lakes Reservoirs Res. Manag. 24 (3), 302–307.
IUCN, 2015. IUCN Red List of Threatened Species. Downloaded on 03 September 2015.
IUCN Bangladesh, 2015. Red List of Bangladesh, 5. Freshwater Fishes. IUCN, International Union for Conservation of Nature, Bangladesh Country Office, Dhaka, Bangladesh, p. xvi+360.
Jennings, S., Kaiser, M.J., Renolds, J.D., 2001. Marine Fisheries Ecology. Blackwell Science, Ltd, UK, p. 417.
Khatun, D., Hossain, M.Y., Parvin, M.F., Ohtomi, J., 2018. Temporal variation of sex ratio, growth pattern and physiological status of *Eutropiichthys vacha* (Schilbeidae) in the Ganges River, NW Bangladesh. Zool. Ecol. 28, 343–354.
Khatun, D., Hossain, M.Y., Nawer, F., Mostafa, A.A., Al-Askar, A.A., 2019a. Reproduction of *Eutropiichthys vacha* (Schilbeidae) in the Ganges River (NW Bangladesh) with special reference to potential influence of climate variability. Environ. Sci. Pollut. Res. 26, 10800–10815.
Khatun, D., Hossain, M.Y., Rahman, M.A., Islam, M.A., Rahman, O., Sarmin, M.S., Parvin, M.F., Haque, A.T.U., Mawa, Z., Hossain, M.A., 2019b. Life-history traits of the climbing perch *Anabas testeudineus* (Bloch, 1792) in a wetland ecosystem. Jordan J. Biol. Sci. 12 (2), 175–182.
Khan, S.M.M.H., Khan, M.M.H., Ahmed, R., Banu, J.N., Pavel, S., Neela, I.A., Islam, M.A., Nishat, A., 2000. In: Red Book of Threatened Fishes of Bangladesh. The World Conservation Union, Dhaka pp. Xi–116.
King, M., 2007. Fisheries Biology, Assessment and Management, second ed. Wiley-Blackwell Publishing, Oxford, U.K.
Macpherson, E., 1998. Ontogenic shifts in habitat use and aggregation in juvenile sparid fishes. J. Exp. Mar. Biol. Ecol. 220, 127–150.
Memon, A.M., Liu, Q., Baloch, W.A., Soomro, A.N., Mohsin, M., Noman, M., Karim, E., 2017. Population parameters of siluroid catfish (Eutropiichthys vacha) from Indus River, Pakistan. Int. J. Agric. Biol. 19, 751–760.
Mildenberger, T.K., Taylor, M.H., Wolff, M., 2017. TropFishR: an R package for fisheries analysis with length-frequency data. Methods Ecol. Evol. 8, 1520–1527.
Moreau, J., Cuende, F.X., 1991. On improving of resolution of the recruitment pattern of fishes, ICLARM. Fishbyte 9, 45–46.
Parvej, M.R., Islam, M.R., Minar, M.H., Hossain, M.B., Tushar, M.R., 2014. Landmark-based morphometric and meristic variations of the critically endangered catfish, *Eutropiichthys vacha* from three different populations in Bangladesh. World J. Fish Mar. Sci. 6, 378–385.
Pauly, D., 1980. On the interrelationship between natural mortality, growth parameters and the mean environmental temperature in 175 fish stocks. ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 39 (2), 175–192.
Pauly, D., Munro, J.L., 1984. Once more on the comparison of growth in fish and invertebrate. International Centre of Living Aquatic Resource Management. Fishbyte 2, 1–21.
Pauly, D., 1984a. Length converted catch curves: a powerful tool for fisheries research in the tropics. Part II. Fishbyte 2, 12–19.
Pauly, D., 1984b. Length-converted catch curves and the seasonal growth of fishes. ICLARM. *Fishbyte* 8, 33–38.
Pauly, D., Soriano, M.L., 1986. Some practical extensions to the Beverton and Holt's relative yield per recruit model. In: First Asian Fisheries Forum. Asian Fisheries Society, Manila, pp. 491–496.
Powell, D.G., 1979. Estimation of Mortality and Growth Parameters from the Length Frequency of a Catch [model]. Rapports et Proces-Verbaux des Reunions, p. 175 (Denmark).
Rahman, A.K.A., 1989. Freshwater Fishes of Bangladesh. Zoological Society of Bangladesh. Department of Zoology, University of Dhaka, p. 364.
Rahman, M.A., Hasan, M.R., Hossain, M.Y., Islam, M.A., Khatun, D., Rahman, O., Mawa, Z., Islam, M.S., Chowdhury, A.A., Parvin, M.F., Khatun, H., 2019a. Morphometric and meristic characteristics of the Asian stinging catfish *Heteropneustes fossilis* (Bloch, 1794): a key for its identification. Jordan J. Biol. Sci. 12, 467–470.
Rahman, M.A., Islam, M.S., Hossain, M.Y., Hasan, M.R., Islam, M.A., Khatun, D., Rahman, O., Parvin, M.F., Mawa, Z., Chowdhury, A.A., 2019b. Morphometric and meristic characteristics of the banded gourami, *Trichogaster fasciata* (bloch & schneider, 1801) in a wetland ecosystem from northwestern Bangladesh. Jordan J. Biol. Sci. 14 (5), 561–566.
Rahman, M.A., Bashar, M.A., Mawa, Z., Rahman, O., Samad, M.A., Mahfuj, S., Islam, M.A., Sarmin, M.S., Islam, M.R., Hossain, M.Y., 2020. Life history traits of the Barred spiny eel *Macrognathus pancalus* (Hamilton, 1822) in a wetland ecosystem. Egypt. J. Aquat. Biol. Fish. 24 (6), 425–438.
Sani, R., Gupta, B.K., Sarkar, U.K., Pandey, A., Dubey, V.K., Singhlakra, W., 2010. Length–weight relationships of 14 Indian freshwater fish species from the betwa (Yamuna river tributary) and Gomti (Ganga River tributary) rivers. J. Appl. Ichthyol. 26, 456–459.
Sarmin, M.S., Hossain, M.Y., Islam, M.A., Rahman, M.A., Khatun, D., Mawa, Z., Chowdhury, A.A., Ohtomi, J., 2021. Estimation of population parameters for a data deficient *Salmostoma bacaila* (Hamilton 1822) stock from the Mahananda River (tributary of the Ganges) in NW Bangladesh. Indian J. Geo Mar. Sci. 50, 403–409.
Sokal, R.R., Rohlf, F.J., 1987. Introduction to Biostatistics, second ed. Freeman Publication, New York.

Soomro, A.N., Baloch, W.A., Jafri, S.I.H., Suzuki, H., 2007. Studies on length-weight and length-length relationship of catfish *Eutropiichthyes vacha* Hamilton (schilbeidae-siluriformes) from Indus River, sindh, Pakistan. Casp. J. Environ. Sci. 5, 143–145.
Soomro, A.N., Baloch, W.A., Jafri, S.I.H., Burdi, G.H., Fulanda, B., 2012. Reproduction and feeding habits of the river catfish *Eutropiichthys vacha* (Hamilton, 1822) (siluriformes. Schilbidae) in an impacted habitat. Kotrihydrodam, river Indus, Pakistan. Our Nat. 10, 269–280.
Soriano, M., Moreau, J., Hoeing, J.M., Pauly, D., 1992. New functions for the analysis of two-phase growth of juvenile and adult fishes, with application to Nile perch. Trans. Am. Fish. Soc. 121, 486–493.
Sparre, P., 1987. Computer programs for fish stock assessment: length-based fish stock assessment (LFSA) for apple II computers. Food Agric. Organ 2, 218.
Tripathi, S., Gopesh, A., 2017. Reproductive profile of *Eutropiichthys vacha* (Hamilton, 1822) from the middle stretch of the Ganga River, India. J. Nehru Gram Bharati Univ. 6, 20–26.
Vigliola, L., Harmelin-vivien, M., Biagi, F., Galzin, R., Garciarubies, A., Harmelin, J.G., Jouvenel, J.Y., Le direach-boursier, L., Macpherson, E., Tunesi, L., 1998. Spatial and temporal patterns of settlement among sparid fishes of the genus Diplodus in the northwestern Mediterranean. Mar. Ecol. Prog. Ser. 168, 45–56.
Wetherall, J.A., 1986. A new method for estimating growth and mortality parameters from length-frequency data. Fishbyte 4, 12–15.