



Estimation of population parameters for a data deficient *Salmostoma bacaila* (Hamilton 1822) stock from the Mahananda river (tributary of the Ganges) in NW Bangladesh

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Salmostoma bacaila known as Razorbelly minnow (Hamilton in 1822) is an indigenous fish species in Bangladesh. This study emphasizes on population structure, growth pattern (length-weight and length-length relations), growth considerations (asymptotic length, L_{∞} ; weight, W_{∞} ; growth coefficient, K ; age at zero length, t_0), size and age at sexual maturity (L_m), growth performance index (ϕ), life-span (t_{max}), conditions factor (Allometric, K_A ; Fulton's, K_F and Relative, K_R), prey-predator status through relative weight (W_R), form factor ($a_{3,0}$), total (Z), natural (M) and fishing mortality (F), exploitation rate (E) and maximum sustainable yield (MSY) of *S. bacaila* in the Mahananda river, northwestern Bangladesh. Total 305 specimens of *S. bacaila* were hardly sampled (ranging between 5.5 to 11.9 cm total length (TL), and 1.05 – 9.20 g total body weight (BW)) through regular fishing gears during August 2016 – July 2017. The regression coefficient 'b' of length-weight relations specified negative allometric growth. Growth parameters (GP) were figured as $L_{\infty} = 12.66$ cm, $K = 0.60$ year⁻¹, $W_{\infty} = 11.36$ g, $t_0 = 0.048$, $t_{max} = 5.00$ year⁻¹ and $\phi' = 1.98$. The L_m was 7.34 cm in TL. Relative weight did not create any significant dissimilarity of 100 that would suggest a healthy habitat for *S. bacaila*. The $a_{3,0}$ was 0.0052 specifying that this fish could be described as elongated. In addition, the Z was calculated to be 1.57 year⁻¹. The M and F values obtained were 0.92 and 0.65 year⁻¹, respectively. The E was 0.41 and MSY (E_{max}) was estimated as 0.35 year⁻¹ by yield per recruitment model. Present research knowledge will be very useful in planning the sustainable and appropriate management of this species in Bangladesh and bordering countries.

[Keywords: Exploitation, Growth parameters, Maximum sustainable yield, Mortality, *Salmostoma bacaila*, Size at sexual maturity]

Introduction

Salmostoma bacaila is the cyprinid species found predominantly in the Indian sub-continent, which inhabits rivers, beels, wetlands, ponds and flooded fields. *S. bacaila* is widespread through Bangladesh, India, Pakistan, Nepal, and Afghanistan^{1,2}. Awareness of life history and stock status is very crucial for proper management approaches to preserve valuable fishes like *S. bacaila*³. Length frequency distributions (LFDs) typically include fish ecology and life-history information⁴. Length-weight relationships (LWRs) are used handy method in fisheries edifications for biomass and conditions index⁵⁻⁷.

Estimating parameters of growth and reproduction for fish is significant in distinguishing their life history, behavior, and potential productivity^{8,9}. Information on growth factors; von Bertalanffy growth constant (K), asymptotic length (L_{∞}), age at

zero length (t_0), maximum reported age (t_{max}) as well as the natural mortality (M) is essential for constructing ecosystem models¹⁰. Besides, these parameters also allow for the testing of life-history theories and the discovery of tentative assessment of additional parameters from those previously obtainable¹¹⁻¹³. To assess if enough juveniles in a collected stock are mature or spawn the first sexual size (L_m) is a significant management parameter for a given fish population¹⁴. Besides, overall productivity, health, and physiology of a fish population are assessed by fish conditions^{15,16}. Furthermore, relative weight (W_R) is a commonly used index to ascertain the fish conditions¹⁷, and it has also been observed in Bangladesh^{18,19}.

A sum of studies on length-weight relationships²⁰⁻²⁴ was performed in the past. Accordingly, the present research work stated inclusive stock status

information including population structure, growth pattern, growth parameters (asymptotic length, asymptotic weight, growth coefficient, age at zero length), growth performance index, life-span, reproduction (size at sexual maturity) condition factor, prey-predator status, form factor, mortality and exploitation of data deficient *S. bacaila* stock in Mahananda river, NW Bangladesh through a year-round analysis of small to large individuals.

Materials and Methods

The research was operated in the Mahananda river, NW Bangladesh (Lat. 24°29 N; Long. 88°18 E). In total, 305 samples of *S. bacaila* were exploited from the Mahananda river throughout August 2016 – July 2017 from the fisher's catch collected by regular fishing gears (seine net, mesh size: ~1.0 cm).

The caught individuals were promptly chilled on site with ice, and thereafter preserved in 10 % formalin in the laboratory. Body weight (BW) was weighed through an electronic balance (0.01 g accuracy) and lengths were taken with digital calipers (0.01 cm). The length frequency distributions (LFDs) for *S. bacaila* were formatted with 1.0 cm intervals of TL. The growth pattern was assessed through LWR with $W = aL^b$ (W , body weight (g) and L , lengths in cm). On the basis of $\ln(W) = \ln(a) + b \ln(L)$ through linear regression analysis, a and b of the LWR and statistical significance level of r^2 with 95 % confidence limits were estimated. The von Bertalanffy (VBG) model as $L_t = L_\infty [1 - \exp\{-K(t-t_0)\}]$ of length basis and $W_t = W_\infty [1 - \exp\{-K(t-t_0)\}]^b$ for weight basis were performed to describe growth parameters (L_t , mean length at age t ; t , the age year¹ and t_0 , the hypothetical age of zero length)²⁵. Moreover, the growth parameter, asymptotic length (L_∞) was calculated based on maximum observed length through $\log(L_\infty) = 0.044 + 0.9841 * \log(L_{max})$ ^(ref. 11). The L_m of *S. bacaila* was estimated based on maximum observed length by $\log(L_m) = -0.1189 + 0.9157 * \log(L_{max})$ ^(ref. 26). Besides, the age at maturity (t_m) was assessed by the equation of t_m (50 %) = $(-1/1) * \ln(1 - L_m/L_\infty)$ ^(ref. 27). The other parameter, growth coefficient (K) was calculated by $K = \ln(1 + L_m/L_\infty) / t_m$ ^(ref. 28). The age at zero length was determined by $\log(-t_0) = -0.3922 - 0.2752 \log L_\infty - 1.038 \log K$ ^(ref. 29). The asymptotic weight (W_∞) was estimated by $W_\infty = aL_\infty^b$. Furthermore, the growth performance index was studied by $\Phi' = \log_{10} K + 2 \log_{10} L_\infty$ ^(ref. 30). The life-span or longevity was obtained by $t_{max} = 3/K$ ^(ref. 30).

The equation, $K_A = W/L^{b(\text{ref. 31})}$ was used to calculate allometric condition factor (K_A). Fulton's condition factor was attained by $K_F = 100 * (W/L^3)$. Relative condition factor was estimated via $K_R = W/(a * L^b)$ ^(ref. 32). The relative weight was taken with $W_R = ((W/W_S) * 100)$ ^(ref. 6), W_S refers standard weight calculated by $W_S = a * L^b$. The equation $a_{3,0} = 10^{\log a - s(b-3)}$ ^(ref. 6) was used to compute the form factor; where, s is the regression slope ($S = -1.358$).

The parameters of mortality (Z , M , and F) were evaluated from length frequency distribution data and growth parameters. The instantaneous total mortality (Z) was assessed by $\ln(N_t/\Delta t) = a + b * t$ (N_t is an individual number of relative age (t) and Δt , the time required)³³. Natural mortality was obtained by $M = -\ln[0.01]/t_{max}$ ^(ref. 27). Fishing mortality was estimated with $F = Z - M$. Exploitation rate was considered using the formula: $E = F / (F + M)$ ^(ref. 34). An index of yield-per-recruit can be functioned as L_c/L_∞ , F/K , M/K ^(ref. 35), and F/M :

$$Y'/R = \frac{F/M}{1+F/M} (1-L_c/L_\infty)^{M/K}$$

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

GraphPad Prism 6.5 Software was introduced for statistical analyses. The one sample t -test³⁶ was applied to compare the mean W_R with 100. To examine the relationship between condition factor with TL and BW, a Spearman rank-correlation test was followed. All analyses were deliberated at 5 % significance ($p < 0.05$).

Results

LFDs showed that the largest individual was of length 11.9 cm and smallest individual was 5.5 cm in length; whereas, the body weight was ranged between 1.05 – 9.20 g with 95 % confidence limit (CL) (Table 1). The size group of 9.00 – 10.00 cm TL was numerically dominant contributing to 33.11 % of its total population (Fig. 1). In this research, the b value of LWRs indicated negative allometric growth ($b < 3$) which is represented in Figure 1. The LLRs were significant ($p < 0.001$) with a coefficient of determination > 0.979 . The regression parameter, 95 % confidence interval of a and b , coefficient of determination (r^2), and growth type (GT) of *S. bacaila* are presented in Table 1.

The von Bertalanffy growth parameters obtained for *S. bacaila* were $L_\infty = 12.66$ cm, $W_\infty = 11.36$ g, $K = 0.60$ and $t_0 = 0.048$ year⁻¹. The observed

Table 1 — Descriptive statistics and relationships of length (cm) and body weight (g) of *Salmostoma bacaila*

Measurements	n	Min	Max	Mean ± SD	95 % CL	
TL	305	5.5	11.9	8.584 ± 1.112	8.458 – 8.709	
FL		4.9	10.6	7.621 ± 1.016	7.507 – 7.735	
SL		4.4	9.5	6.744 ± 0.920	6.641 – 6.848	
BW		1.05	9.2	3.855 ± 1.513	3.684 – 4.025	
Equation	a	b	95% CL of a	95% CL of b	r ²	GT
BW = a*TL ^b	0.007	2.89	0.006 – 0.008	2.82 – 2.96	0.959	A-
BW = a*FL ^b	0.012	2.81	0.011 – 0.014	2.74 – 2.88	0.955	A-
BW = a*SL ^b	0.021	2.70	0.018 – 0.025	2.62 – 2.78	0.931	A-
TL = a+b(SL)	0.519	1.20	0.385 – 0.652	1.18 – 1.22	0.979	A-
TL = a+b(FL)	0.260	1.09	0.191 – 0.330	1.08 – 1.10	0.995	A-
FL = a+b(SL)	0.272	1.08	0.148 – 0.419	1.07 – 1.11	0.975	A-

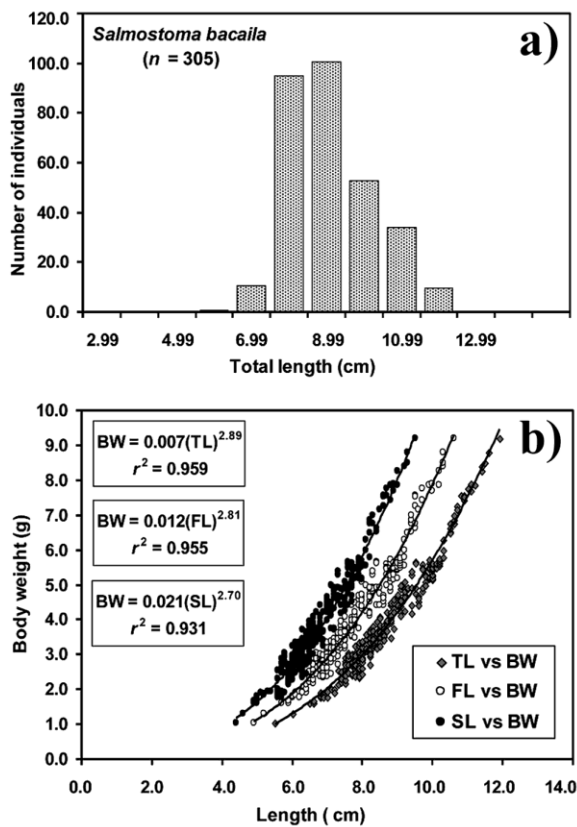


Fig. 1 — (a) Total length frequency distribution, and (b) length-weight relationships of *Salmostoma bacaila* from the Mahananda river, Bangladesh (TL - total length; FL - fork length; and SL - standard length)

and predicted maximum total length was 12.01 and 12.66 cm, respectively (Fig. 2). Similarly, the observed and predicted maximum BW was 9.76 and 11.36 g, respectively (Fig. 2). The t_m was 0.87 year, and the growth performance index (ϕ) was 1.98. The longevity of age t_{max} was 5.00 years (Table 2). The L_m was calculated as 7.34 cm (Fig. 3). Furthermore, the L_m from different water-bodies through the maximum length was calculated by following the available literature as shown in Table 3.

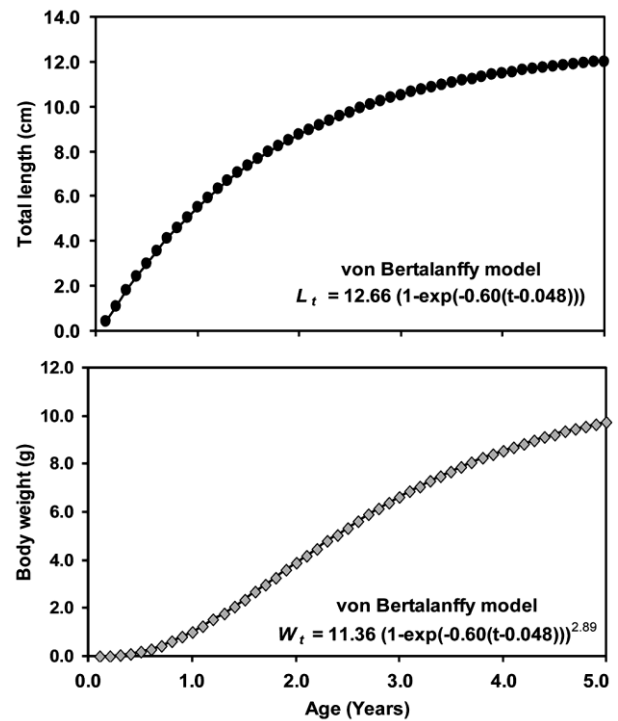


Fig. 2 — The von Bertalanffy growth curve based on length (upper) and weight (below) of *Salmostoma bacaila* from the Mahananda river, Bangladesh

Table 2 — Growth and reproduction parameters of *Salmostoma bacaila*

Parameters	Values
Asymptotic length in cm (L_∞)	12.66
Asymptotic weight in g (W_∞)	11.36
Growth coefficient per year (K)	0.60
Age at zero length in cm (t_0)	0.048
Growth performance index (ϕ)	1.98
Life-span/ Longevity in year (T_{max})	5.00
Size at sexual maturity in cm (L_m)	7.34
Age at sexual maturity in year (t_m)	0.87
Natural mortality per year (M)	0.92
Total mortality per year (Z)	1.57
Exploitation per year (E)	0.41
(Y-R) Maximum sustainable yield (MSY)	0.35
Length at maximum yield per recruit in cm (L_{opt})	8.38

The values of all condition factors (K_A , K_F , K_R) and W_R are given in Table 4. Spearman rank-correlation test revealed highly significant correlation in all condition factors with BW but did not show any relationship with TL. Moreover, there was a significant relation between BW vs. W_R but not between TL vs. W_R (Fig. 4). The W_R did not exhibited any notable variation from 100 for *S. bacaila* ($p = 0.4208$) by following one sample t -test. The form factor ($a_{3,0}$) was estimated as 0.0052 through length-

weight regression, where the parameters were $a = 0.0074$ and $b = 2.89$. To compare with present study, the $a_{3,0}$ of *S. bacaila* from several water-bodies is also calculated through available data (Table 3).

The total mortality assessed from the slope of the length converted catch curve was $Z = 1.57 \text{ year}^{-1}$ for *S. bacaila* (Table 2; Fig. 5). The calculated natural mortality was $M = 0.92 \text{ year}^{-1}$ and fishing mortality (F) was 0.65 year^{-1} . From the evaluated fishing and total mortality, the exploitation rate was calculated as

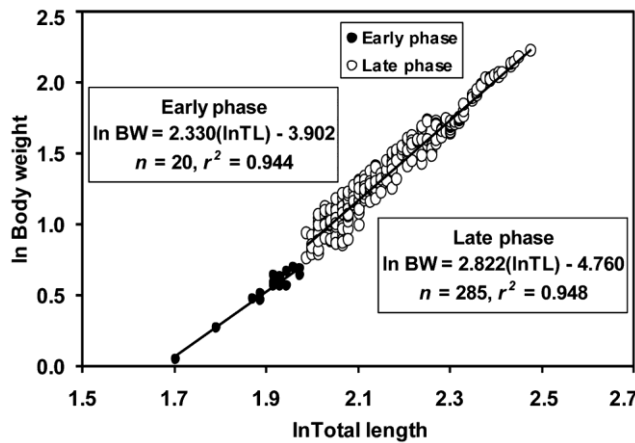


Fig. 3 — Size at first sexual maturity of *Salmostoma bacaila* from the Mahananda river, Bangladesh

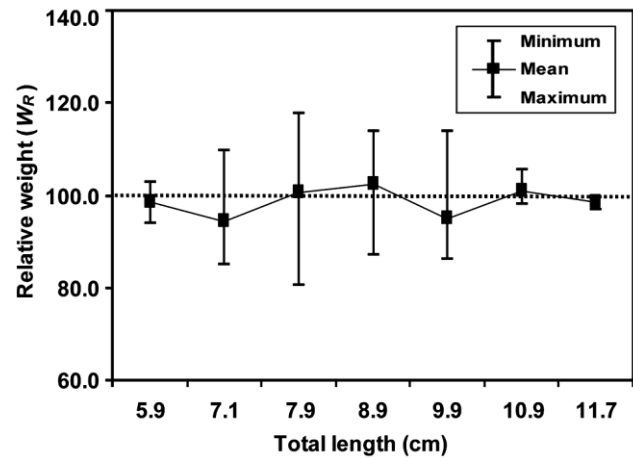


Fig. 4 — Relationship between total length and relative weight of *Salmostoma bacaila* from the Mahananda river, Bangladesh

Table 3 — Calculated size at sexual maturity (L_m) and form factors of *Salmostoma bacaila* reported from different water-bodies world-wide

Water body	TL _{max}	Regression parameter		References	$a_{3,0}$	L_m	95 % CL of L_m
		a	b				
Indus river, Pakistan	16.3	0.1153	2.88	Muhammad <i>et al.</i> ²²	0.0792	9.80	7.80-12.32
Gandak river, Bihar, India	15.7	0.0115	2.80	Baitha <i>et al.</i> ²³	0.0062	9.47	7.55-11.89
Barak river, Assam, India	10.4	0.0180	2.47	Nath <i>et al.</i> ²⁴	0.0034	6.49	5.26-8.05
Atrai river, Dinajpur, Bangladesh	10.5	0.0090	2.76	Islam & Mia ²¹	0.0042	6.55	5.31-8.12
Mahananda river, NW Bangladesh	11.9	0.0074	2.89	Present study	0.0052	7.34	5.92-9.15

Table 4 — Condition factors and their relationships with total length (TL) and body weight (BW) of *Salmostoma bacaila*

Condition factors	n	Min	Max	Mean \pm SD	95% CL
K_F	305	0.475	0.697	0.584 \pm 0.045	0.5784 – 0.5886
K_A		0.006	0.009	0.007 \pm 0.001	0.0073 – 0.0074
K_R		0.806	1.176	0.997 \pm 0.076	0.9885 – 1.0056
W_R		80.553	117.648	99.707 \pm 7.580	98.853 – 100.561
Relationships	r_s values	95 % CL of r_s		P -values	Degree of significance
TL vs. K_A	0.0304	-0.0855 – 0.1455		$p = 0.5968$	NS
TL vs. K_F	-0.1949	-0.3006 – -0.0844		$p > 0.0006$	***
TL vs. K_R	-0.0199	-0.1319 – 0.0927		$p = 0.7298$	NS
TL vs. W_R	0.0197	-0.1317 – 0.0929		$p = 0.7325$	NS
BW vs. K_A	0.2158	0.1027 – 0.3233		$p > 0.0001$	***
BW vs. K_F	-0.0351	-0.1468 – 0.0776		$p = 0.5420$	NS
BW vs. K_R	0.1369	0.0249 – 0.2454		$p > 0.0168$	*
BW vs. W_R	0.1371	0.0251 – 0.2456		$p > 0.0166$	*

NS - not significant; * - significant; *** - highly significant; and P - level of significance

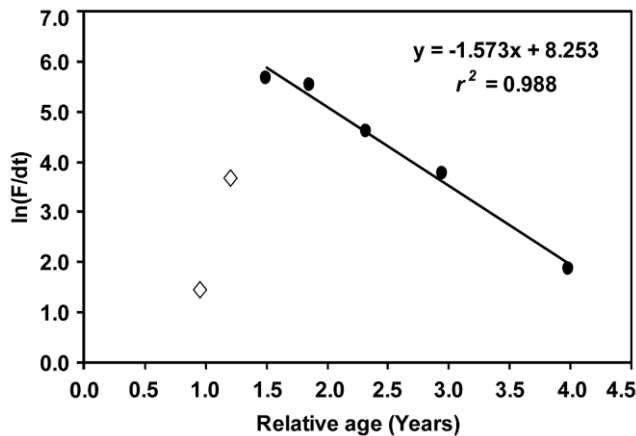


Fig. 5 — Mortality of *Salmostoma bacaila* from the Mahananda river, Bangladesh

$E = 0.41$. The maximum yield-per-recruit (Y'/R) estimated for *S. bacaila* was 0.35 in the Mahananda river showing an overexploitation of 6 %. The value of L_{opt} observed was 8.38 cm.

Discussion

In general, the estimate of population parameters and stock status is rendered using certain three methodologies *viz.* (i) hard-part analysis method, (ii) mark-recapture method, and (iii) length-frequency distributions method with consecutive twelve months series data. Present study estimated the growth parameters and size at maturity of *S. bacaila* from Mahananda river using the empirical models^{11,26} where, the fish under study could not be collected for 12 months consecutively. Additionally, this is the first attempt by the empirical models to estimate the population parameters. Therefore, contributions will be made in the FishBase and /or in other online databases.

In the present study, it was quite difficult to capture *S. bacaila* of length < 5.5 cm in sampling due to either because of inadequate selection of fishing gear or because fishers were unable to catch a smaller size³⁷⁻⁴¹ or they were absent at the fishing grounds^{37,42-44}. In addition, fisher's tendency to discard small-sized fish may be another reason for this constraint⁴⁵.

The maximum size of *S. bacaila* found as 11.9 cm TL which is higher than the maximum size recorded from the Atrai river, Bangladesh (TL 10.50 cm)²¹ and also from India (TL 10.4 cm)²⁴; however it was lower than the earlier study which reported 18.0 cm TL⁴⁶. Besides, some other previous studies recorded the maximum length of 15.2 cm total length at Yamuna river, India²⁰ and 15.7 cm from Gandak river, Bihar,

India²³ which are also higher than the present study. Furthermore, TL 16.3 cm has been documented in the Indus river, Pakistan²² which is also higher than the present study. Maximum length statistics are needed to determine population parameters as well as L_{∞} and K , which are very much imperative for planning, supervision and managing of fisheries resource⁴⁴.

In current research, the b value of the LWRs was 2.89, which showed a negative allometric growth of *S. bacaila* in the Mahananda river. The results of present study, however, was comparable to the other studies e.g., reported negative allometric growth ($b = 2.76$) in river Yamuna, India²¹; negative growth pattern ($b = 2.80$) was also observed from Gandak River, India²³ and from the Indus River, Pakistan ($b = 2.88$)²² which are nearly identical to the current study. Moreover, LLRs of present study were extremely significant ($p < 0.001$). Since this is the very first LLR study on *S. bacaila*, which restricts contrast with others.

The growth parameters K and L_{∞} were 0.60 year⁻¹ and 12.66 cm, respectively for *S. bacaila*. The age at zero length was 0.048 year⁴⁷ specified negative t_0 that point to juveniles growing more rapidly than adults from the expected growth curve. Growth performance index (ϕ) was 1.98. The L_m of *S. bacaila* for combined sexes was 7.34 cm in (TL). Previous studies were interested on one condition factor, however several condition factors (K_A ; K_F ; K_R and W_R) were assessed in the present study to assess the health and habitual condition of *S. bacaila*. According to the earlier study¹⁷, the W_R supports to think through the overall health and appropriateness along with ecosystem instabilities up to population level. However, no significant dissimilarities from 100 were discovered in the present study, which indicated that the population is in a healthy state with fewer predators and plenty of food.

The value of $a_{3.0}$ was 0.0052 for combined sex indicating that *S. bacaila* can be categorized as an elongated fish that is a distinct character of many riverine fishes. The M of *S. bacaila* was estimated to be 0.92 year⁻¹, while the F was found as 0.65 year⁻¹. The catch amounts of *S. bacaila* declined gradually because of overfishing in the Mahananda river. This study verified that the fishing mortality was lower than the natural mortality.

The exploitation rate of *S. bacaila* was assessed as 0.41. Depending on the relationship between the exploitation and yield per recruit for this species, it

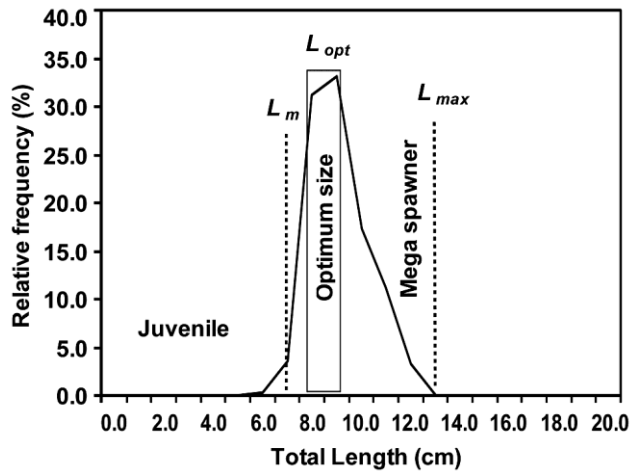


Fig. 6 — Optimum catchable length of *Salmostoma bacaila* stock from the Mahananda river

could be inferred that the exploitation is higher than the MSY level and the effort should be decreased by 6 % to obtain maximum sustainable yield. From the present investigation, it is found that about 50 % fishes were spawned when the length was 7.34 cm, smaller than this sized fishes are highly prohibited to catch and the value of L_{opt} observed was 8.34 cm indicating the length range where optimum yield could be obtained, hence fish sizes above 8.34 TL are recommended for exploitation (Fig. 6).

Unfortunately, this research work is the first effort to evaluate the growth parameters, size at maturity, conditions factor and mortality for *S. bacaila* from the Mahananda river as well from any water bodies and would be baseline study for the future studies to detect the factors affecting the L_m and spawning season and to ascertain the causes of fish mortality.

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Conflict of Interest

The authors report no conflict of interest.

Author Contributions

MSS: contributed to analysis, writing and editing. MYH: developed the concept. MAI & MAR: collected data. DK, ZM & AAC: assisted in formatting and editing. JO: performed revision.

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