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RESEARCH ARTICLE

Life-history traits of ten commercially important small indigenous fish species (SIFS) in the Oxbow lake (Southwestern Bangladesh): key for sound management

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Abstract

For the first time, we revealed the life-history traits including growth pattern (length–weight relationships, LWRs), condition factors, form factor ($a_{3.0}$), first sexual maturity (L_m), age at first sexual maturity (t_m), life span (t_{max}), natural mortality (M_w), asymptotic length (L_∞), and optimum catchable length (L_{opt}) of ten commercially important small indigenous fish species (SIFS) in the Oxbow lake (Baor), southwestern regions of Bangladesh. A total of 1651 specimens were sampled during January to December 2020 with traditional fishing gears including seine nets, gill nets, and lift nets. Individual total length (TL) and body weight (BW) were measured by digital slide calipers and digital balance, respectively. To calculate the L_m, empirical maximum length-based model was considered, and L_{opt} was calculated based on L_∞. The TL vs. BW relationship indicated positive allometric growth for *Chanda nama* (Hamilton 1822), *Channa punctata* (Bloch 1793), *Channa striata* (Bloch 1793), *Lepidocephalichthys guntea* (Hamilton 1822), *Macrognathus pancalus* (Hamilton 1822), and *Puntius sophore* (Hamilton 1822), but negative allometric growth for *Badis badis* (Hamilton 1822), *Gudusia chapra* (Hamilton 1822), *Glossogobius giuris* (Hamilton 1822), and *Hyporhamphus limbatus* (Valenciennes, 1847). All r^2 values exceed 0.910 that indicated all LWRs were highly significant ($P < 0.001$). According to Spearman correlation test, Fulton's condition factor (K_F) vs. BW was highly correlated ($P < 0.001$), indicating better well-being for these species. Moreover, $a_{3.0}$ indicates *B. badis*, *C. punctata*, *C. striata*, *G. giuris*, *H. limbatus*, *L. guntea* were elongated; *C. nama*, *P. sophore*, were short and deep; *G. chapra* was fusiform, and *M. pancalus* was eel-like body shape respectively. The minimum t_m and t_{max} were obtained as 0.74 year and 2.66 year for *C. striata* and maximum were 0.93 year and 3.31 year for *B. badis*, respectively. This study provided information on t_m and t_{max} for ten SIFS that is globally absent. From empirical models, the smallest mean value of L_m was found for *B. badis* (3.98 cm), and the greatest was found for *C. striata* (16.96 cm). The minimum L_{opt} was obtained as 3.78 cm TL for *B. badis* and maximum was 14.09 cm TL for *C. punctata.* The minimum M_w was documented as 1.39 for *B. badis* and maximum was 1.73 for *C. striata*. The output of this research will be helpful for developing sustainable management policies and protection of SIFS through the application of mesh size based on L_m and L_{opt} in the Oxbow lakes, Bangladesh and neighboring countries.

Keywords Growth pattern · Sexual maturity · Optimum catchable length · Small indigenous fish species (SIFS) · Oxbow lake

Introduction

Baors are oxbow lakes formed by dead river arms that are found in the Ganges delta in the western region of the country (Abdullah-Bin-Farid et al. 2013). In Bangladesh, Baors or oxbow lakes are one of the vital inland water assets, which are made due to the changed course of the waterways. Above 600 Baors are located in Jashore, Kushtia, and Faridpur districts in the southwestern part of Bangladesh,

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mostly in greater Jashore district. According to DoF (2020), the current production of Baor is 10,343 MT. These water bodies are common properties, which have a high capability of fisheries production. Bangladesh appreciates an especially wealthy biodiversity due to its special geophysical area with 253 native freshwater fish species (IUCN Bangladesh 2015).

Small indigenous fish species (SIFS) refers to the fishes having a maximum length of 25 cm, and more than 120 fish species are categorized as SIFS in Bangladesh (Felts et al. 1996; Hanif et al. 2016). The SIFS shows an expansive cluster of novel natural qualities, mirroring their variable vulnerability to abuse by fisheries. However, the aquatic animals of Bangladesh are under expanding dangers of overfishing, environment obliteration, and contamination (Alam et al. 2015; Hasan et al. 2021a, b; Mawa et al. 2021). Different predatory species (*Notopterus chitala*, *Wallaga attu* etc.) and cannibalistic nature of some species, e.g., *Channa striata*, are of the main declining factors for the reduced abundance of SIFS. Though, because of the reduction of SIFS in natural water bodies and restricted market availability, these fish have become prohibitively expensive and mostly unattainable for rural households. Besides, research have proven that SIFS comprise 50–80% of all fish ate up in the course of durations of apex production in countryside Bangladesh. Small indigenous fish species have long been part of rural household diets, and these small fishes are more nutrient compact than IMCs (Indian Major Carps). SIFS are a potential source of essential vitamins and minerals, protein, and fatty acids (Roos et al. 2007). SIFS served a pivotal role to the countryside people dieting in Bangladesh as fishes are eaten whole, head to tail, providing calcium, iron, vitamin A, and zinc (Roos et al. 2003) as well as source of earnings of the surrounding people of oxbow lake. The rural populations perceived that SIFS are not as profitable for culture as IMCs. However, work on management of these species is not done yet in the oxbow lakes.

The life-history attributes of fish species are essential to conserve the SIFS biodiversity and regular assessment of local fish fauna. Growth patterns are essential and basic components of fisheries management tools (Jobling 2002; Froese 2006; Kumari et al. 2018). These management tools have been used to analyze the health of individuals and to identify possible discrepancy between distinct unit stocks of the same species in an ecosystem (King 2007; Zolkhiflee et al. 2017). Condition factor (K_n) or ponderal index is broadly applied to compare the body condition, fatness, or well-being of fish (Ahmed et al. 2007). Fulton's condition factor (K_F) is a prominent biological indicator that infers important data on growth, sexual maturity, food source availability, sex, and age of species (Okgerman 2005; Rahman et al. 2020; Hossain et al. 2021). First sexual maturity (L_m) is a key management metric for determining if adequate juveniles in a depleted stock mature and reproduce (Beverton and Holt 1959; Jennings et al. 1998; Hasan et al., 2021a, b; Bashar et al. 2021). Age at maturity (t_m) is an important part of fishes' life histories, and it has been widely utilized in modeling and classifying fish species based on their characteristics (Rochet 2000; King and McFarlane 2003), as well as an anxiety predictor for fisheries (Trippel 1995). Two significant factors in conservation management are life span (t_{max}) and age at first maturity (t_m) (IUCN 1994; Bashar et al. 2021). The t_{max} is inversely proportional to biological adult maturity. For fishery stock evaluation and management, a precise estimate of natural mortality (M_w) is essential. It is proven tough to calculate because natural deaths are scarcely observed (Quinn and Deriso 1999). The optimal catchable length (L_{opt}) is the length at which an unexploited cohort's biomass will be at its peak (Froese et al. 2016), and documents on optimum catchable length can aid in the development of fisheries management techniques (Sadovy 1996; Bashar et al. 2021). Selection of fishing gear is a crucial component of fisheries conservation and management because of L_{opt}. Fishing gear should be designed and utilized in such a way that individuals of this size are not harmed (Ahmad et al. 2020).

Information on growth pattern (length–weight relationships, LWRs), condition factors, form factor ($a_{3.0}$), first sexual maturity (L_m), age at first sexual maturity (t_m), life span (t_{max}), natural mortality (M_w), asymptotic length (L_∞), and optimum catchable length (L_{opt}) of *B. badis*, *C. nama*, *C. punctata*, *C. striata*, *G. chapra*, *G. giuris*, *H. limbatus*, *L. guntea*, *M. pancalus*, and *P. sophore* of oxbow lake are very rare in literature and elsewhere. However, several studies have been carried out on growth (Hossain et al. 2009a, 2012a, 2016; Satrawaha and Pilasamorn 2009; Garcia 2010; Li et al. 2013; Kaushik et al. 2015; Sharma et al. 2015; Borah et al. 2017; Islam et al. 2017; Karna et al. 2017, 2018; Jumawan and Seronay 2017; Djumanto et al. 2020; Islam et al. 2020; Rahman et al. 2020) on these SIFS from different water bodies. Length-length relationships (LLRs) and length–weight relationships (LWRs) are still deficient for most tropical and sub-tropical ichthyofauna (Ecoutin et al. 2005; Hossain et al. 2006, 2009b; Hossain and Ahmed 2008).

To date, there is no prior study on life-history attributes of these species from the oxbow lake (Bukvora Baor) in Bangladesh. Therefore, the present research was conducted in the Bukvora Baor to estimate the growth pattern, condition factors, form factor ($a_{3.0}$), first sexual maturity (L_m), age at first sexual maturity (t_m), life span (t_{max}), natural mortality (M_w), asymptotic length (L_∞), and optimum catchable length (L_{opt}) of ten SIFS using data over 1-year study period covering small to big sizes.

Materials and methods

Site selection

The current study was performed in Bukvora Baor (23°10′33.0″N 89°07′00.1″E) at Jashore district, southwestern Bangladesh (Fig. 1). A total of 1651 specimens were sampled from January to December 2020. Specimen collections were executed monthly using seine net, gill nets, and lift nets.

Fish measurement

The total length (TL, cm) of individual fish was determined with digital slide calipers, and total body weight (BW, g) of each fish was determined by electronic balance with an accuracy of 0.01 cm and 0.01 g upon arrival in the laboratory.

Length frequency distribution (LFD)

The LFD of each fish was established with 1-cm intervals of TL. In accordance with Hasselblad's maximum-likelihood equation (Hasselblad 1966), the normal distribution was plotted with TL frequency distributions.

Growth patterns

Growth patterns were evaluated by using the formula: BW = a*(TL)^b. Linear regression study was applied to measure the parameters a and b and to evaluate natural logarithms: ln (W) = ln (a) + b*ln (L). In addition, the 95% confidence interval of a and b and the coefficient of determination r^2 have been determined. According to Froese (2006), extreme outliers were omitted from regression studies.

Condition factor analysis

Multiple condition factors, namely, allometric condition factor (K_A), relative condition factor (K_R), Fulton's condition factors, and relative condition factors were investigated during this study. Based on the equation of Tesch (1968), allometric condition factor (K_A) was estimated via $K_A = W/L^b$, where W is the body weight (g), L is the TL (cm), and b is the LWR parameter. Moreover, the relative condition factor (K_R) was analyzed following the equation of Le Cren (1951): $K_R = W/(a*L^b)$. According to Fulton (1904), Fulton's condition factor (K_F) was analyzed via $K_F = (W/L^3)*100$. The scaling factor of 100 was used to bring the K_F adjacent to unit. The relative weight (W_R) was analyzed in accordance with the work of Rypel and Richter (2008): $W_R = (W/Ws)*100$. Where Ws is the predicted body weight of fish in gram.

Form factor ($a_{3.0}$)

The $a_{3.0}$ of selected fish species was estimated through the equation of Froese (2006) as: $a_{3.0} = 10^{\log a - s\,(b-3)}$, where a and b are the regression parameters of LWR, and s is the regression slope of ln a vs. b. The researchers used a mean slope $S = -1.358$ for calculating the form factor due to lack of information on LWR for these selected species to calculate the regression (S) of ln a vs. b.

Size at first sexual maturity (L_m)

In this research, the L_m of these selected species in the Bukvora Baor were calculated using the equation, log (L_m) = −0.1189 + 0.9157* log (L_{max}), by Binohlan and Froese (2009). The gonadosomatic index (GSI) was calculated by the equation, GSI (%) = (GW / BW) × 100.

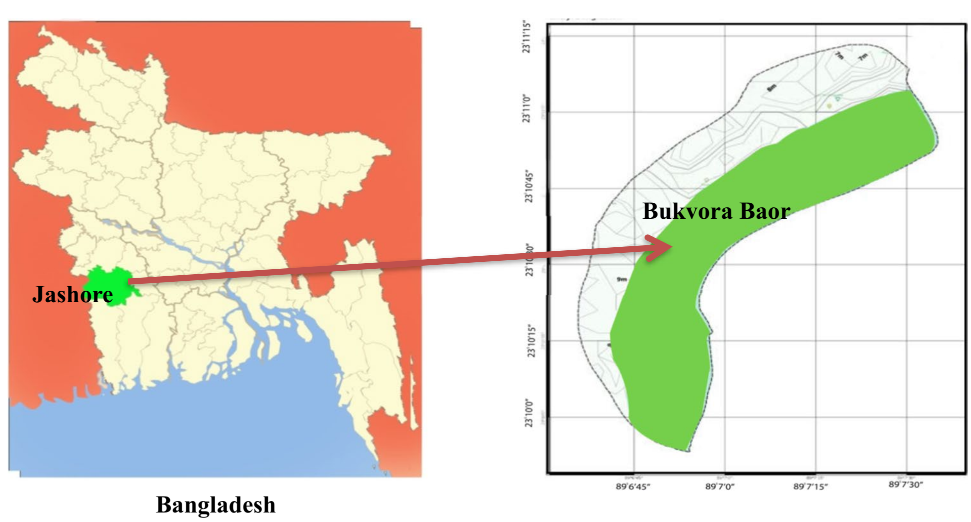

Fig. 1 Geographical location of the study area (Bukvora Baor)

Asymptotic length (L_∞)

Asymptotic length (L_∞) was estimated through log $L_\infty = 0.044 + 0.9841 * \log(L_{max})$ (Froese and Binohlan 2000). Asymptotic weight (W_∞) was estimated through $W\infty = a * L_\infty{}^b$ (Ricker 1975).

Life span (t_{max})

Using the Froese and Binohlan (2000) model: *log* $t_{max} = 0.5496 + 0.957*\log(t_m)$, where, t_{max} = maximum age or life span reach in a population (years), t_m (mean age at first sexual maturity in year), $t_m = (-1/1)*\ln(1 - L_m/L_\infty)$ (King 2007).

Natural mortality (*M*).

According to King (2007), natural mortality was assessed through, $M = -\ln[0.01]/t_{max}$ (King 2007), where, M = natural mortality year^{-1}, ln = natural logarithm, t_{max} = life span/longevity in year (Beverton 1987). The different natural mortality (*M*) values were estimated using various models through Natural Mortality Estimator (NME).

Optimum catchable length (L_{opt})

The optimum catchable length (L_{opt}) is the length from which maximum fishes would be achieved (Froese et al. 2018). Using the Froese and Binohlan (2000) model, L_{opt} was estimated:

Log $L_{opt} = 1.0421*\log(L_\infty) - 0.2742$, where L_∞ = asymptotic length.

Data analysis

The observed data of total length and body weight; condition factors were analyzed by using Microsoft excel add-in solver and GraphPad prism 6.5 software. An unweight pair group (UPGMA) and cluster dendrogram were constructed based on the mean values of best condition factor (K_F) and relative weight (W_R) data of ten SIFS were used. All statistical analyses were done using R program, Microsoft excel add-in solver, and GraphPad prism 6.5 software.

Results

A total of 1651 of ten commercially important SIFS were collected from fishers' catch at different parts of the Bukvora Baor during this study. The length frequency distribution (LFD) displayed that the smallest and largest individuals of *B. badis*, *C. nama*, *C. punctata*, *C. striata*, *G. chapra*, *G. giuris*, *H. limbatus*, *L. guntea*, *M. pancalus*, and *P. sophore* were 4.20 cm and 6.10 cm, 2.3 cm and 8.00 cm, 7.70 cm and 22.60 cm, 9.70 cm and 31.00 cm, 5.96 cm and 11 cm, 4.44 and 12.90, 8.40 cm and 11.00 cm, 5.50 cm and 9.00 cm, 7.00 cm and 15.80 cm, 4.00 cm and 8.50 cm, respectively that are given in Table 1 and Fig. 2.

The length and weight relationships of ten SIFS fishes in the Bukvora Oxbow Lake are illustrated in Table 2 and Fig. 3. The parameters *a* and *b* of ten commercially important SIFS fishes in the LWR were derived from the length and weight data and the relationship between length and weight. The TL vs. BW relationship indicated positive allometric growth for *C. punctata*, *C. striata L. guntea*, *M. pancalus*, and *P. sophore*, but negative allometric growth for *B. badis*, *C. nama*, *G. chapra*, *G. giuris*, and *H. limbatus.*

During the study, minimum and maximum K_A values were 0.0192and 0.0233 for *B. badis*, 0.0048and 0.0140 for *C. nama*, 0.0038 and 0.0073 for *C. striata*, 0.0065and 0.0134 for *C. punctata*, 0.0118 and 0.0191 for *G. chapra*, 0.0089and 0.0170 for *G. giuris*, 0.0016 and 0.0021 for *H. limbatus*, 0.0027 and 0.0047 for *L. guntea*, 0.0007 and 0.0031 for *M. pancalus*, and 0.0068 and 0.0163 for *P. sophore* in the Bukvora Baor, southwestern Bangladesh.

The calculated minimum and maximum K_R values were 0.9214 and 1.1195 for *B. badis*, 0.6619 and 1.9396 for *C. nama*, 0.6033 and 1.2519 for *C. punctata*, 0.6400 and 1.2100 for *C. striata*, 0.7579 and 1.2220 for *G. chapra*, 0.6164 and 1.1846 for *G. giuris*, 0.8915 and 1.1393 for *H. limbatus*, 0.6518 and 1.1474 for *L. guntea*, 0.3940 and 1.6189 for *M. pancalus*, and 0.5214 and 1.2372 for *P. sophore* in the Bukvora Baor, southwestern Bangladesh.

The calculated minimum and maximum K_F values were 1.0098 and 1.3497 for *B. badis*, 0.6222 and 1.7119 for *C. nama*, 0.6634 and 1.3734 for *C. punctata*, 0.5124 and 0.9704 for *C. striata*, 0.7418 and 1.1864 for *G. chapra*, 0.5641 and 1.1198 for *G. giuris*, 0.2044 and 0.2540 for *H. limbatus*, 0.5598 and 0.9916 for *L. guntea*, 0.1559 and 0.6713 for *M. pancalus*, and 0.8368 and 1.9949 for *P. sophore* in the Bukvora Baor, southwestern Bangladesh.

During the study, minimum and maximum W_R values were 92.14 and 111.95 for *B. badis*, 66.19 and 193.96 for *C. nama*, 60.33 and 125.19 for *C. punctata*, 64.00 and 120.10 for *C. striata*, 76.26 and 122.98 for *G. chapra*, 62.27 and 119.85 for *G. giuris*, 89.27 and 110.69 for *H. limbatus*, 65.18 and 114.74 for *L. guntea*, 39.99 and 161.89 for *M. pancalus*, and 52.14 and 123.72 for *P. sophore* in the Bukvora Baor, southwestern Bangladesh.

The first two components (PC1 and PC2) of the PCA analysis revealed that the Fulton Condition Factor (K_F) explained about 75.3% of the variability of ten SIFS (Fig. 4). In the bi-plot of PCA, four species viz., *Channa striata*, *Channa punctata*, *Macrognathus pancalus*, and *Lepidocephalicthys guntea* completely showed isolation, while the other six species completely showed close association to each other based on Fulton Condition Factor (K_F).

Table 1 Descriptive statistics of ten small indigenous fish species (SIFS) from Bukvora Baor, southwestern Bangladesh

Species name	*n*	Measurement		Mean ± SD	95% CL
Badis badis (Hamilton 1822)	31	TL	4.20–6.10	5.2290 ± 0.5337	5.0333–5.4248
		BW	1.00–2.38	1.6165 ± 0.4305	1.4585–1.7744
Chanda nama (Hamilton 1822)	188	TL	2.30–8.00	4.5521 ± 1.0769	4.3972–4.7071
		BW	0.14–4.35	1.0799 ± 0.7036	0.9787–1.1812
Channa punctata (Bloch 1793)	256	TL	7.70–22.60	13.3937 ± 2.6695	13.0652–13.7223
		BW	4.88–115.08	29.6690 ± 19.4686	27.27–32.0652
Channa striata (Bloch 1793)	102	TL	9.70–31.00	21.3167 ± 3.9339	20.5440–22.0894
		BW	7.28–224.80	83.7838 ± 44.0758	75.1265–92.4411
Gudusia chapra (Hamilton 1822)	171	TL	5.96–11.00	7.7485 ± 0.8292	7.6233–7.8736
		BW	2.28–11.25	4.7207 ± 1.5235	4.4907–4.9507
Glossogobius giuris (Hamilton 1822)	257	TL	4.44–12.90	7.3245 ± 1.4319	7.1486–7.5004
		BW	0.82–18.18	3.9623 ± 2.4277	3.6640–4.2605
Hyporhamphus limbatus (Valenciennes, 1847)	50	TL	8.40–11.00	9.464 ± 0.7507	9.6773–9.2506
		BW	1.41–3.33	1.9542 ± 0.5205	2.1021–1.8063
Lepidocephalichthys guntea (Hamilton 1822)	150	TL	5.50–9.00	7.3740 ± 0.6868	7.2632–7.4848
		BW	1.38–6.80	3.4116 ± 1.0567	3.2411–3.5821
Macrognathus pancalus (Hamilton 1822)	204	TL	7.00–15.80	10.4907 ± 1.6015	10.2696–10.7118
		BW	0.74–17.68	5.0233 ± 2.5075	4.6771–5.3694
Puntius sophore (Hamilton 1822)	242	TL	4.00–8.50	6.0383 ± 0.8214	5.9343–6.1424
		BW	0.81–9.98	3.6143 ± 1.5128	3.4228–3.8059

SD standard deviation, *CL* confidence limit for mean values

In cluster analysis, two clusters were mainly formed based on Fulton Condition Factor (K_F), where *Chanda nama* species singly formed a single cluster while *Channa striata* formed another cluster with other species through multiple sub-cluster bases (Fig. 5).

Similarly, the first two components (PC1 and PC2) of a PCA analysis revealed that relative weight (WR) explained approximately 100.0% of the variability of ten SIFS (Fig. 6). In the bi-plot of PCA, only a single species *Channa striata* partially showed isolation while the other nine species completely showed close association to each other based on relative weight (WR).

In cluster analysis, two clusters were primarily formed based on relative weight (WR), with *Chanda nama* species forming a single cluster and *Channa striata* forming a second cluster with other species via multiple sub-cluster bases (Fig. 7).

We also assessed form factor ($a_{3.0}$), size at first sexual maturity (L_m), asymptotic length (L_∞), life span (t_{max}), natural mortality (M), and optimum catchable length (L_{opt}) of ten SIFS in the oxbow lake which are demonstrated in Tables 3 and 4. The values of assessed natural mortality (M) through different using Natural Mortality Estimator (NME) methods were shown in Table 5. The smallest t_m and t_{max} were obtained as 0.74 year and 2.66 year for *C. striata* and largest were 0.93 year and 3.31 year for *B. badis*. This study was provided information on t_m and t_{max} for ten newly fish species that is globally absent. From empirical equations, the smallest mean value of L_m was found for *B. badis* (3.98 cm) and greatest was found for *C. striata* (14.26 cm) (Fig. 8). The smallest L_{opt} was found as 3.78 cm TL for *B. badis* and largest was 16.96 cm TL for *C. striata.* The smallest M_w was documented as 1.39 for *B. badis* and largest was 1.73 for *C. striata*. The spawning season of selected SIFS from different water bodies worldwide is illustrated in Table 6.

Discussion

Studies on the length–weight relationships, condition factors, length at first sexual maturity (L_m), optimum catchable length (L_{opt}) of selected SIFS have been done in different water bodies of Bangladesh, but complete life-history traits (growth coefficient (k), age at first sexual maturity (t_m), life span (t_{max}), theoretical age (t_0), natural mortality (M_w) using various model, asymptotic length (L_∞), and asymptotic weight (W_∞)) of selected SIFS have not been done yet in oxbow lakes (total 600 oxbow lakes covering areas of 5488 hectare) and other water bodies of Bangladesh.

This study was observed the minimum and maximum length of ten SIFS from Bukvora Baor. However, the minimum length was 2.30 cm for *C. nama*, and maximum length was 31.00 cm for *C. striata* which are different from other water bodies in Bangladesh and other countries. The

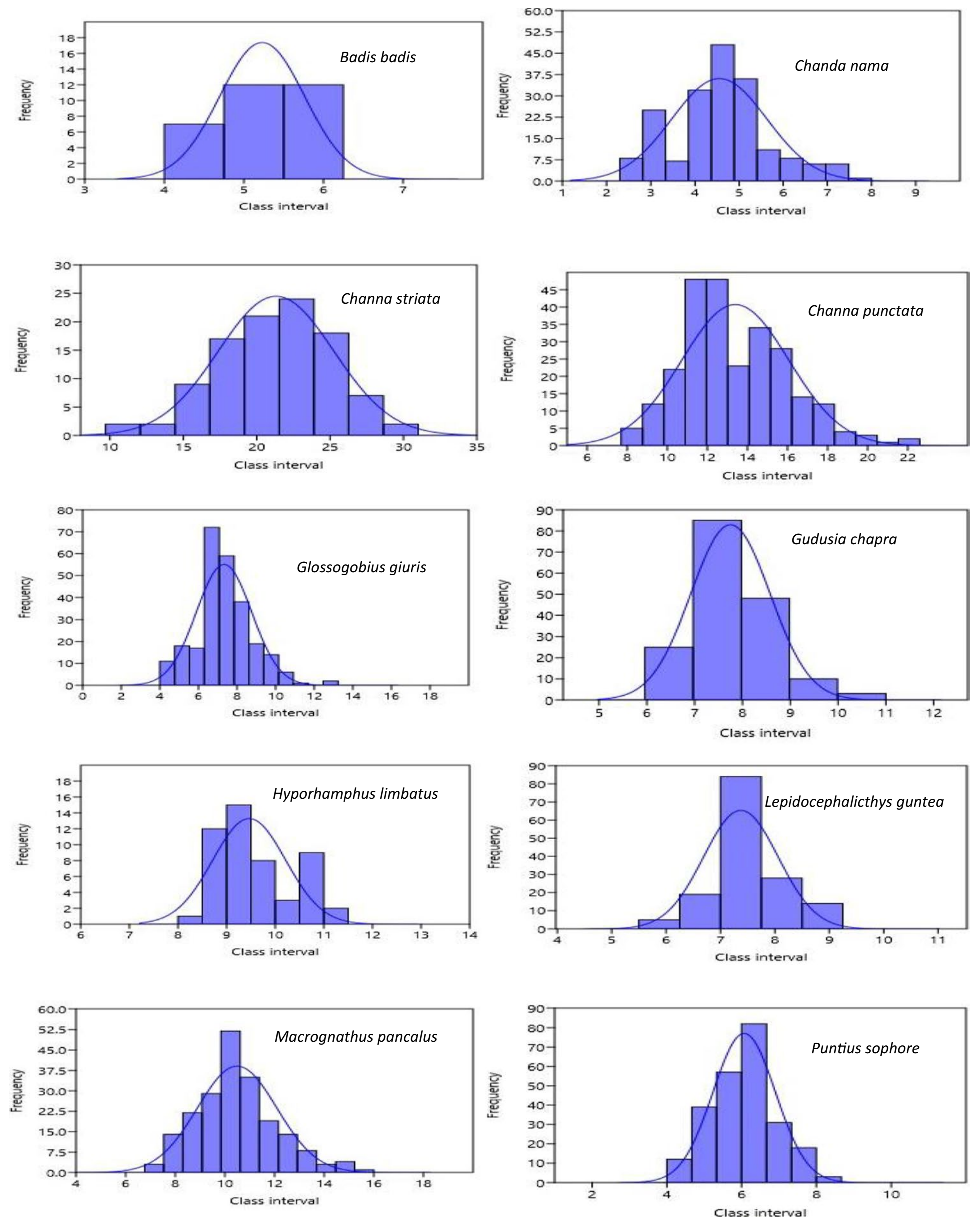

Fig. 2 Length frequency distributions of ten small indigenous fish species (SIFS) from Bukvora Baor, southwestern Bangladesh

Table 2 Estimated parameters of the length–weight relationship and form factor of ten small indigenous fish species (SIFS) from Bukvora Baor, southwestern Bangladesh

Species name	Regression parameter		95% CL of *a*	95% CL of *b*	r^2	Growth types (GT)
	a	*b*				
B. badis	0.0208	2.62	0.0157–0.0275	2.450–2.787	0.972	**A −**
C. nama	0.0161	2.69	0.0051–0.0101	2.966–3.392	0.936	**A −**
C. punctata	0.0089	3.08	0.0077–0.0149	2.880–3.138	0.978	**A +**
C. striata	0.0058	3.10	0.0036–0.00973	2.941–3.267	0.966	**A +**
G. chapra	0.0167	2.75	0.0911–0.0207	2.636–2.910	0.904	**A −**
G. giuris	0.0116	2.88	0.0120–0.0174	2.682–2.867	0.982	**A −**
H. limbatus	0.0025	2.96	0.0011–0.0028	2.905–3.301	0.952	**A −**
L. guntea	0.0041	3.35	0.0022–0.0077	3.065–3.700	0.919	**A +**
M. pancalus	0.0026	3.20	0.0011–0.0032	3.130–3.576	0.911	**A +**
P. sophore	0.0093	3.28	0.0087–0.0200	2.893–3.356	0.904	**A +**

a and *b* are regression parameters of length–weight relationships

r^2 coefficient of determination, *GT* growth type, *A +* positive allometric, *A –* negative allometric

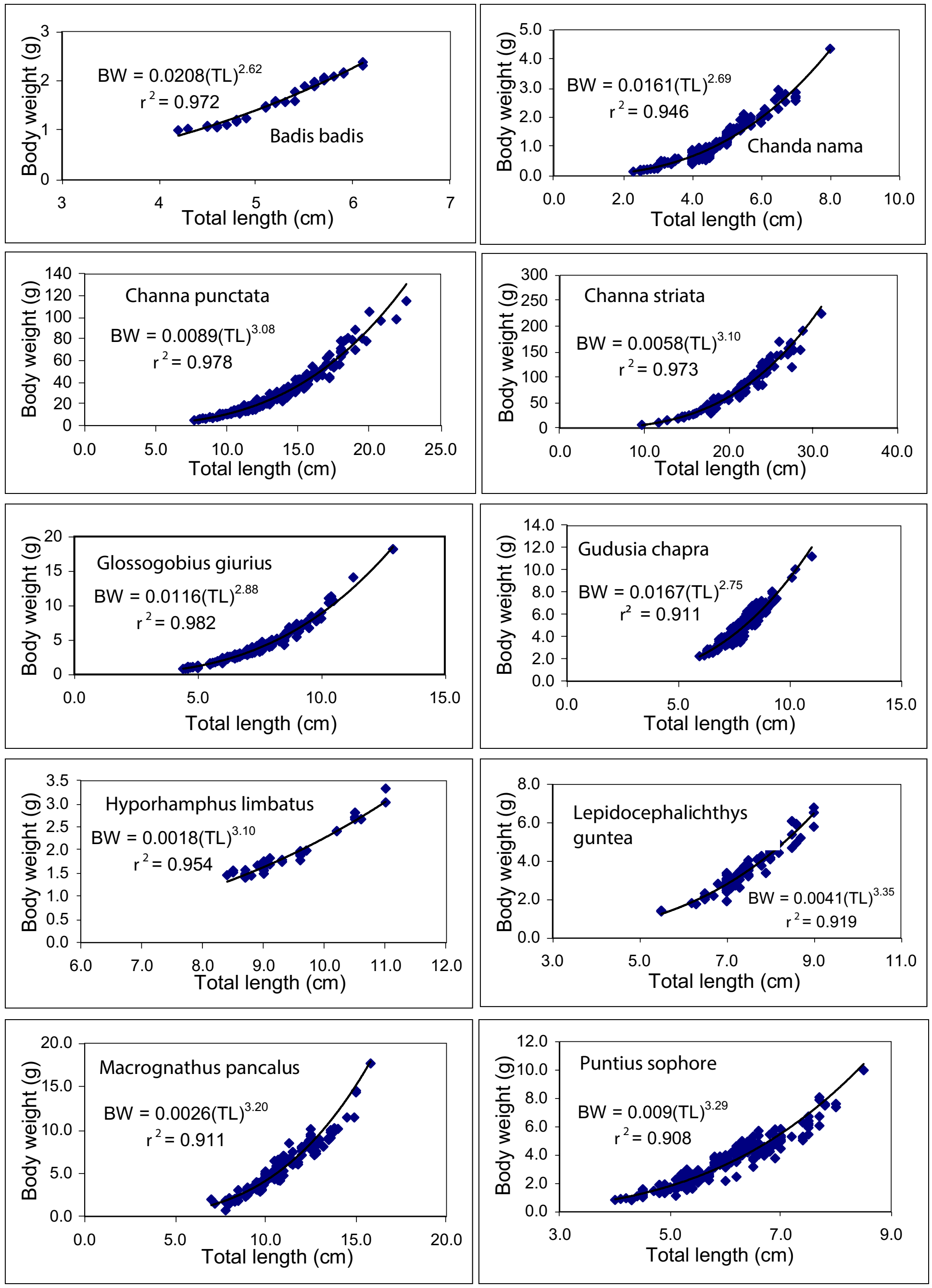

Fig. 3 Length–weight relationships of ten small indigenous fish species (SIFS) from Bukvora Baor, southwestern Bangladesh

variance in length for chosen SIFS is due to poor fishing gear selection or fishermen failing to capture the particular sites (Rahman et al. 2020).

Life-history traits including growth pattern either isometric or allometric were estimated through the LWR. The *b* value of ten SIFS varied within the Froese (2006) suggested range (2.5–3.5) for aquatic animals. According to Tesch (1968), despite a lot of differences in fish forms between individual species, *b* values nearby to 3, demonstrating that fish grow isometrically and dissimilar from 3.0, indicate allometric growth (positive allometry (> 3) and negative allometry (< 3)). According to Kaushik et al. (2015), *b* value was 2.96 which are similar with our study, but in case of Sharma et al. (2015), *b* value was 3.04 for *B. badis* in Indian waters which is dissimilar to our findings. Borah et al. (2017), Hossain et al. (2012a), Islam et al. (2017), Karna et al. (2017), and Sandhya et al. (2020) reported negative allometric growth for *C. nama* which are in accordance with our research but Hossain et al. (2016) and Mortuza et al. (2020) reported positive allometric growth for this fish. Most of the studies found negative allometric growth ($b < 3.0$) (Haniffa et al. 2006; Karna et al. 2017), but Hossain et al.

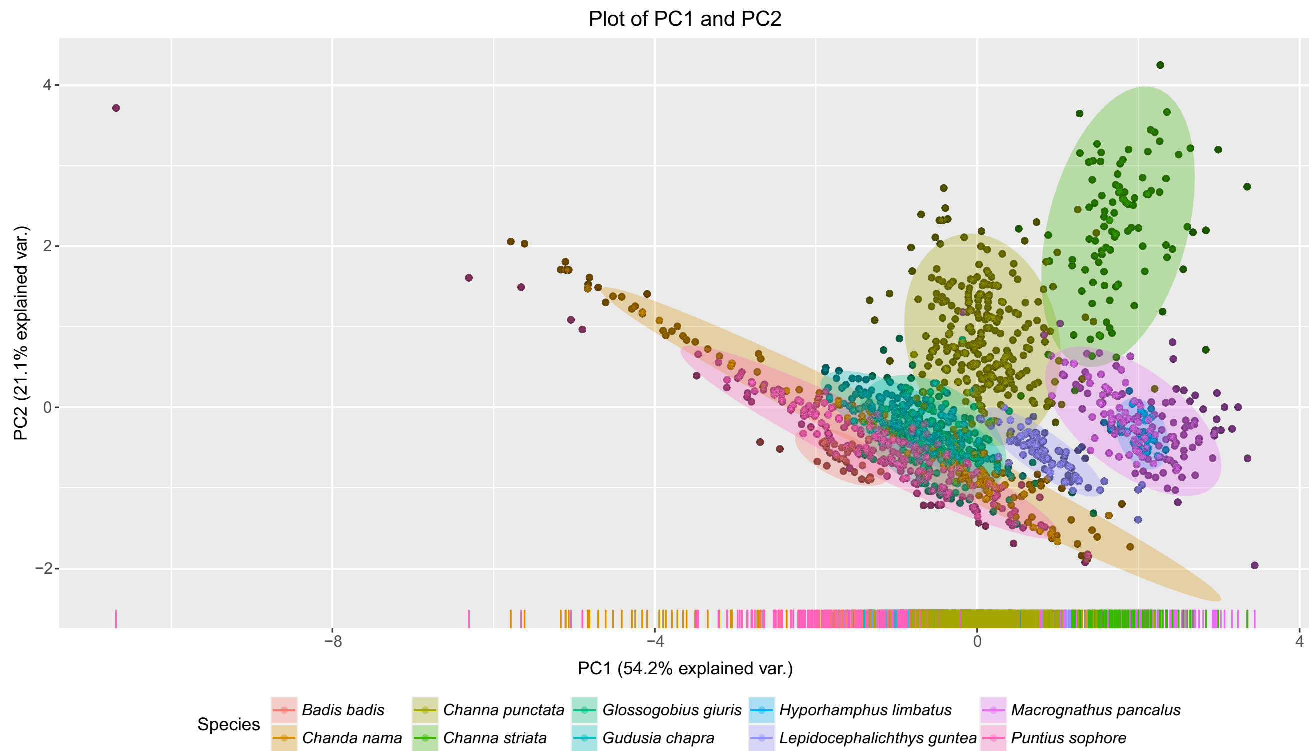

Fig. 4 Bi-plot of principal component analysis (PCA) of Fulton's condition factor (K_F) of ten small indigenous fish species (SIFS) from Bukvora Baor, southwestern Bangladesh

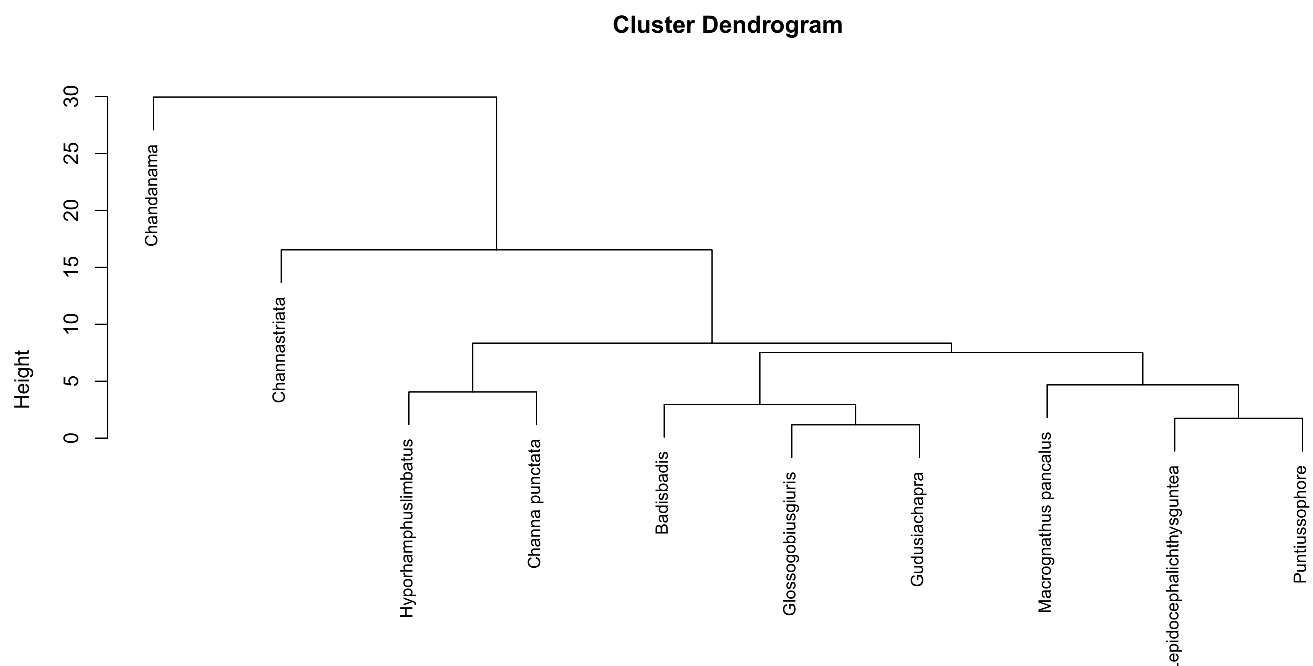

Fig. 5 UPGMA dendrogram based on the Euclidean distance between the species centroids from Fulton's condition factor (K_F) variables of ten small indigenous fish species (SIFS) from Bukvora Baor, southwestern Bangladesh

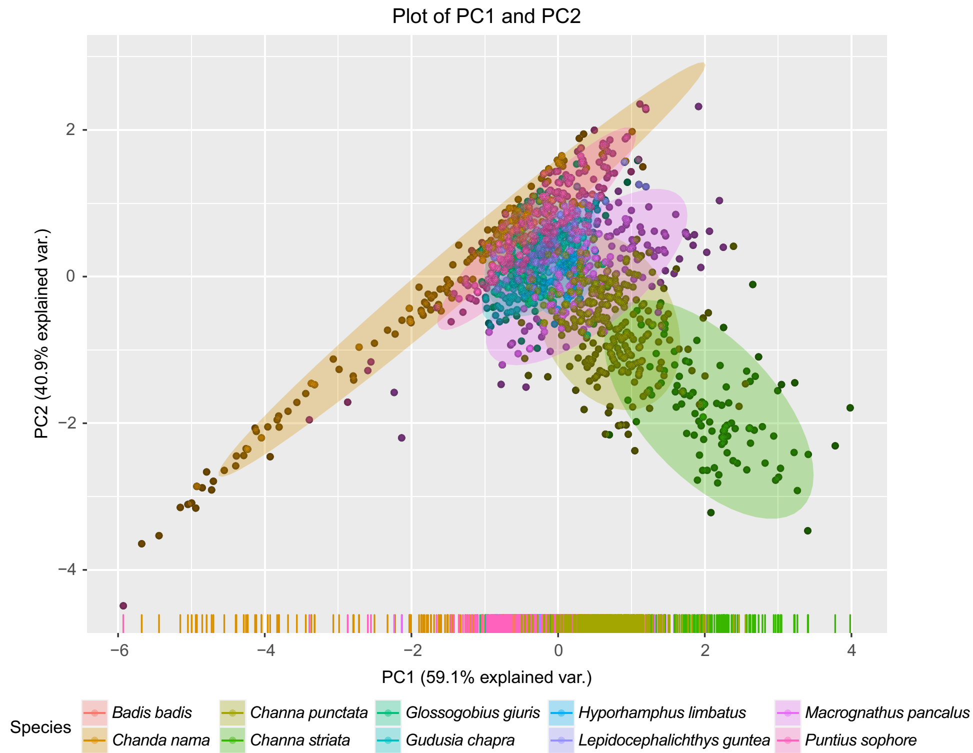

Fig. 6 Bi-plot of principal component analysis (PCA) of relative weight (W_R) of ten small indigenous fish species (SIFS) from Bukvora Baor, southwestern Bangladesh

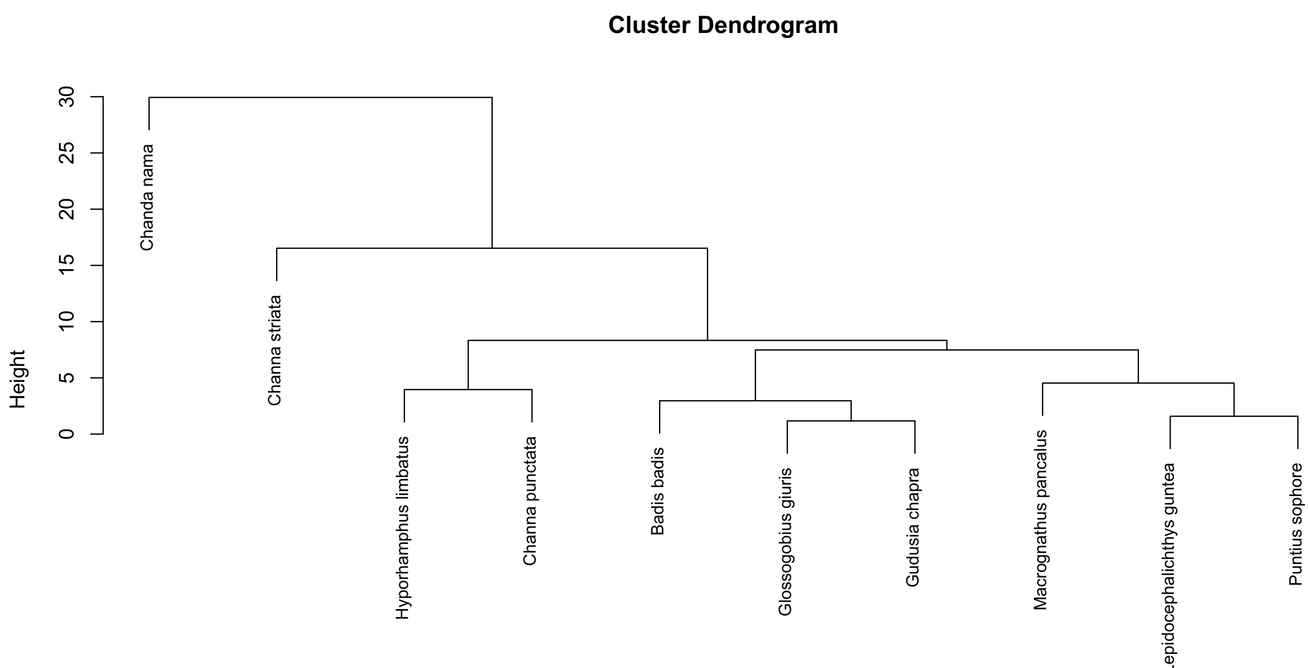

Fig. 7 UPGMA dendrogram based on the Euclidean distance between the species centroids from relative weight (W_R) variables of ten small indigenous fish species (SIFS) from Bukvora Baor, southwestern Bangladesh

Table 3 Form factors ($a_{3.0}$), mean age at first sexual maturity (t_m), life span (t_{max}), natural mortality (M) of ten small indigenous fish species (SIFS) from Bukvora Baor, southwestern Bangladesh

Species name	$a_{3.0}$	Body shape	k	t_m (year)	t_{max} (year)	t_0	M
B. badis	0.0063	Elongated	0.91	0.93	3.31	0.027	1.39
C. nama	0.0130	Short and deep	1.00	0.84	3.00	0.021	1.54
C. punctata	0.0114	Elongated	1.06	0.79	2.83	0.014	1.63
C. striata	0.0079	Elongated	1.13	0.74	2.66	0.010	1.73
G. chapra	0.0076	Fusiform	0.97	0.87	3.10	0.020	1.49
G. giuris	0.0080	Elongated	1.05	0.80	2.86	0.016	1.61
H. limbatus	0.0028	Elongated	1.03	0.81	2.90	0.018	1.59
L. guntea	0.0122	Elongated	1.01	0.83	2.97	0.019	1.55
M. pancalus	0.0049	Eel like	1.06	0.79	2.83	0.015	1.63
P. sophore	0.0223	Short and deep	1.00	0.84	3.00	0.020	1.54

Table 4 Calculated size at first sexual maturity (L_m), asymptotic weight (W_∞), asymptotic length (L_∞), and optimum catchable length (L_{opt}) based on maximum length (L_{max}) of fishes from Bukvora Baor, southwestern Bangladesh based on maximum length

SL no	Species name	L_{max} (cm)	L_m (95% CL) (cm)	W_∞ (g)	L_∞ (cm)	L_{opt}(cm)
1	*B. badis*	6.10	3.98 (3.30–4.86)	5.78	6.56	3.78
2	*C. nama*	8.00	4.86 (3.62–6.51)	5.20	8.57	4.99
3	*C. punctata*	22.60	12.67 (8.96–17.90)	6.64	23.20	14.09
4	*C. striata*	31.00	16.96 (11.81–24.35)	4.52	32.48	20.00
5	*G. chapra*	11.00	6.83 (5.53–8.49)	6.13	11.72	6.91
6	*G. giuris*	12.90	7.55 (5.49–10.37)	5.63	13.71	8.14
7	*H. limbatus*	11.00	6.51(4.78–8.88)	1.44	11.72	6.91
8	*L. guntea*	9.00	5.41(4.01–7.30)	5.46	9.62	5.63
9	*M. pancalus*	15.80	9.10 (6.56–12.63)	2.51	16.73	10.02
10	*P. sophore*	8.50	5.13 (3.82–6.91)	10.66	9.03	5.27

Table 5 Methods used to calculate natural mortality of ten small indigenous fish species (SIFS) from Bukvora Baor, southwestern Bangladesh through natural mortality estimator (NME)

Species name	Jensenk 1	Jensen k 2	Pauly lt	Roff	Jensen_Amat	Ri_Ef_Amat	Hamel_Amax	ZM_CA_pel	ZM_CA_dem	Hamel_k
B. badis	1.37	1.46	2.43	2.05	1.77	1.44	1.63	1.92	1.02	1.60
C. nama	1.50	1.60	2.49	2.28	1.96	1.56	1.80	2.10	2.13	1.75
C. punctata	1.59	1.70	1.96	2.43	2.09	1.64	1.91	2.21	1.83	1.86
C. striata	1.70	1.81	1.86	2.59	2.23	1.73	2.03	2.34	1.25	1.98
G. chapra	1.46	1.55	2.24	2.20	1.90	1.52	1.74	2.08	1.03	1.70
G. giuris	1.58	1.68	2.26	2.39	2.06	1.62	1.89	2.19	1.17	1.80
H. limbatus	1.55	1.65	2.32	2.37	2.04	1.61	1.86	2.18	1.16	1.81
L. guntea	1.52	1.62	2.84	2.31	1.99	1.58	1.82	2.12	1.13	1.77
M. pancalus	1.59	1.70	2.15	2.43	2.09	1.64	1.91	2.22	1.18	1.86
P. sophore	1.50	1.60	2.46	2.28	1.96	1.56	1.75	2.10	1.12	1.80

*Detail methodologies for the estimation of natural mortality are presented in http://barefootecologist.com.au/shiny_m (Accessed on: 03 September 2021)

(2006) and Sandhya et al. (2020) found positive allometric growth ($b > 3.0$) for *C. punctata*, but in our study we found positive allometric growth ($b > 3$). For *C. striata*, Garcia (2010), Li et al. (2013), Satrawaha and Pilasamorn (2009), and Jumawan and Seronay (2017) found negative allometric growth ($b < 3.0$), but in our study it was positive allometric growth ($b > 3.0$) which is dissimilar to previous findings. According to Sarkar et al. (2013), the b value was 2.16 for *G. chapra*, which indicated negative allometric growth, and also Ahmed et al. (2014) indicated negative allometric which supports our findings. For *G. giuris* species, the b value represents negative growth pattern in our study. Same growth pattern ($b < 3.0$) of *G. giuris* was described from Ganges River, Bangladesh (Hossain et al. 2009b), from the Hongshui

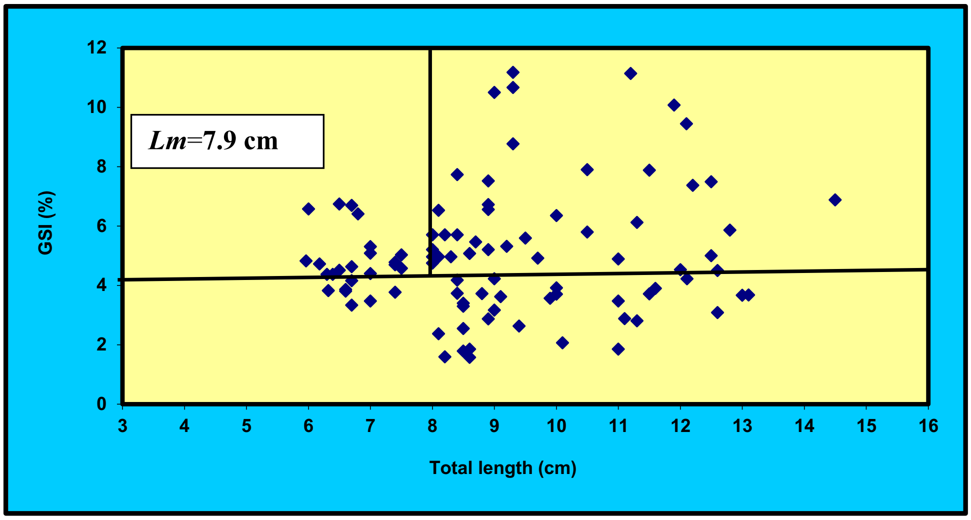

Fig. 8 Graphical presentation of length at first sexual maturity of *Gudusia chapra* from Bukvora Baor, southwestern Bangladesh

Table 6 Spawning season of selected SIFS in Bangladesh from different worldwide water bodies

Species	Spawning season	Peak spawning season	References
B. badis	Late July to December	July	Dutta et al. 2020
C. nama	July to August	July	Ahmed et al. 2019
C. punctata	June to September	June	Aung and Sein 2019
C. striata	April to June	April	Morioka et al. 2016
G. chapra	February to October	April	Kumari et al. 2021
G. giuris	March to September	March	Qambrani et al. 2015
**H. limbatus*			
L. guntea	June-July	June	Sayeed et al. 2009
M. pancalus	February to September	February/March and July/August	Zahid et al. 2013
P. sophore	March to July	April and June	Hasan et al. 2018

*Spawning and peak spawning season of *H. limbatus* have not been done yet

River, southwest China (Que et al. 2015), and from Brahmaputra River, Bangladesh (Islam et al. 2017), separately. On the other hand, isometric growth was noticed by Hossain et al. (2009b) ($b = 3.03$) and Garcia (2010) ($b = 3.06.$) which differ from our findings. For *H. limbatus*, Karna et al. (2017) found that the *b* value was 2.94 which is in accordance with our study. In case of *L. guntea*, both Islam et al. (2017) and Hossain et al. (2009a) found positive allometric growth ($b > 3$) which is similar to our research. But negative growth pattern was reported in the Pathri Khola, Morang District, Nepal (Dhakal and Subba, 2003) and in the Haora River, Tripura, India (Biswas et al. 2018), respectively. Positive growth pattern was reported in the Gajner *Beel* (Hossain et al. 2017) in the Mathabhanga River, Bangladesh (Hossain et al. 2006) and in the Gomti River, India (Abujam and Biswas, 2016) for *M. pancalus* which are in accordance with our findings. But, negative allometric growth was revealed from the Atrai and Brahmaputra River, Bangladesh ($b < 3.0$) observed by Islam et al. (2017) which are distinct from our finding. Hossain et al. (2006), Hossain et al. (2012a), Kaushik et al. (2015), Karna et al. (2018), and Sandhya et al. (2020) described positive growth pattern for *P. sophore* species which are supportive to our study but negative growth pattern were found in the Bangladeshi waters (Hossain et al. 2012b) and in the Indian waters (Patiyal and Mir, 2017). The factors involving in variations of b value for the similar species are increase in growth, disparities in age, stage of maturity, feeding practice, preservation procedure, variation in observed fish length, abiotic factors (i.e., water quality parameters), and also biotic factors (i.e., microbial and parasitic invasions to the host) (Bandilla et al. 2006).

Several condition factors (K_A, K_R, K_F, and W_R) were investigated during this research work to indicate the fish health status and water body condition and their interactions. Due to a lack of findings on condition factors, it was difficult to compare the current findings to others (except *C. nama*, *G. giuris*, *L. guntea*, and *M. pancalus* by Islam et al. (2017); *M. pancalus* by Rahman et al. (2020); *G. giuris* by Azad et al. 2020; *C. nama* by Hossain et al. (2021)).

According to Rahman et al. (2020), K_A was 0.001–0.003 for *M. pancalus* in Gajner *Beel*, Bangladesh, and Hossain et al. (2021) documented that K_A was 0.0056–0.0125 for *C.*

nama in the Mathabhanga River, Southwestern Bangladesh. Rahman et al. (2020) reported that K_R was 0.245–0.662 for *M. pancalus* in Gajner Beel, Bangladesh, and Hossain et al. (2021) described that K_R was 0.68–1.52 for *C. nama* in the Mathabhanga River, Bangladesh.

In accordance with Spearman rank correlation test, the K_F performed the best with BW for all selected species ($p < 0.001$), implying that the K_F is the best predictor for well-being of these species. Islam et al. (2017) reported that K_F was 0.77–1.16 for *C. nama*; 0.47–1.17 for *G. giuris*; 0.34–0.50 for *M. pancalus*; and 0.78–0.99 for *L. guntea* in Atrai and Brahmaputra River, Bangladesh which is in accordance with our findings. A similar K_F was reported by Rahman et al. (2020) (0.60–1.59 for *M. pancalus* in Gajner *Beel*, Bangladesh) and Hossain et al. (2021) (0.55–1.25 for *C. nama* in the Mathabhanga River, Southwestern Bangladesh).

At the population level, relative weight (W_R) helps to estimate the prey-predator status as well as ecosystem disturbances (Rypel and Richter 2008). Islam et al. (2017) reported that W_R was 83.44–126.17 for *C. nama*; 55.20–132.84 for *G. giuris*; 84.76–127.69 for *M. pancalus*; and 86.83–111.31 for *L. guntea* in Atrai and Brahmaputra River, Bangladesh which is similar with our study. According to Rahman et al. (2020), W_R was 60.05–159.03 for *M. pancalus* in Gajner *Beel*, Bangladesh, and Hossain et al. (2021) reported that W_R for *C. nama* was 67.87–152.44 in the Mathabhanga River, Bangladesh that is also similar within range of our findings. The mean W_R had no significant difference from 100 for almost all selected SIS fish in the Bukvora Baor, Southwestern Bangladesh. This indicates that there was a balanced condition of population with a small number of predators relative to the occurrence of prey and food accessibility. The confounding factors associated in fluctuations of condition factor value for the similar species are preservation method, stock status, stomach condition, gonadal development, or topographical location (Khatun et al. 2019).

Form factor can be used to describe how individuals in a certain population or species differ from one another in terms of body shape (Froese 2006). It was unable to make a comparison between the current findings and the previous ones due to the absence of available information on form factors except by *C. nama* by Hossain et al. (2021) and *M. pancalus* by Rahman et al. (2020) of selected SIFS in Bangladesh and elsewhere. So, it will be the baseline study for further research. Hossain et al. (2021) reported that form factor for *C. nama* was 0.0082 which is similar with our results. Rahman et al. (2020) documented that form factor for *M. pancalus* was 0.0055 which is also in accordance with our findings.

The selection of optimum catchable length (L_{opt}) is a key trait in fisheries management that is mostly used in open water bodies (Lucifora et al. 1999; Hossain et al. 2012b). Several methods have been applied for assessment of size at first sexual maturity, i.e., gonadosomatic index based (Hossain et al. 2017; Ahmed et al. 2014; Khatun et al. 2019), logistic equation (King 2007), maximum length-based method, brooding of eggs over time (for crustaceans), the presence of the ovary and maturation phases over time (King 2007), etc. We assessed size at first sexual maturity through maximum length-based method. According to Hasan et al., 2021a, b, the estimated L_m were 4.15 for *C. nama*, 9.00 for *M. pancalus*, 6.20 for *L. guntea*; 6.95 for *G. chapra*; 8.45 for *G. giuris*; 6.50 for *P. sophore*; 24.70 for *C. striata*; 11.25 for *C. punctata* and L_{opt} were 4.80 for *C. nama*, 10.47 for *M. pancalus*; 6.87 for *L. guntea*; 9.73 for *G. chapra*; 9.80 for *G. giuris*; 7.33 for *P. sophore*; 30.67 for *C. striata*; 12.93 for *C. punctata* from Gajner *Beel*, northwestern Bangladesh. The fluctuation of L_m of fish occurs because of different factors like feeding habit, sex and gonadal maturity, season, water current, population's compactness, and water temperature (Hossain et al. 2012b). According to Djumanto et al. (2020), asymptotic length (L_∞) of *C. striata* was 60.32, theoretical age (t_0) was 0.14, and growth coefficient (k) was 0.71 which is dissimilar with our study. It was not possible for other species to compare with others due to lack of prior information on as L_∞, t_{max}, and M. As it was the first study on above this parameter, so it will be the baseline study for SIFS in Bangladesh.

Around 80% 0f selected SIFS species were sexually matured in larger than 5.00 cm TL. Therefore, it is strongly suggested that ≤ 5.00 cm TL fishes cannot be harvested. As a result, at least 80% of selected SIFS survive in the oxbow lake ecosystem.

SIFS are facing declining trends in the oxbow lake of Bangladesh due to different anthropogenic and climatic factors. Documentation of the causal factors for declining of SIFS species, the development of suitable sanctuaries, habitat conservation, removal of predatory species, and brood fish of SIFS protection during the spawning and peak spawning season are all strongly suggested. Peak spawning season of the most selected SIFS were June and July. Banning of SIFS fishing could be recommended during peak spawning season. Generally rainy season in our country sets on April and extended to September. During rainy season, the water level of Bukvora Baor including all Baors has been raised up maximally; most of the self-sustaining species migrate to the adjacent wetland areas (*Beels*, Canals, Rivers) for grazing and spawning purposes. As a result, SIFS harvesting has been become difficult from Baor during this period due to rising of water level. It would not impact on livelihoods and nutrition if the banning period is imposed during this peak rainy season. Baor fishermen's including subsistence fishers harvest fish from the Baor surrounding wetlands along with the other floodplain areas for their livelihoods and household consumption. Apart from that, for sustainable management, the mesh size of harvesting nets should be set throughout the year based on size at sexual maturity. Moreover, conservation of the natural stock of oxbow lake, additional population surveys, and stock assessments are immediately needed. After all, the most crucial factor in the protection of this species is public awareness.

Conclusion

The findings of this research work will be useful for sustainable management along with the in situ conservation of small indigenous fish species (SIFS) in the oxbow lake that will supposedly play a significant role to contribute for nutritional demand with our national economy. As this study is the first attempt for SIFS in situ conservation, it will be the baseline research for sustainable management of oxbow lake in Bangladesh.

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Author contribution AS, AR, and YH conceive the concept of the review. AR, FFA, SMY, and FS collect and analyzed the data. AS, AR, HR, and SM wrote and edited the manuscript.

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Data availability Data are stored in a laboratory computer.

Declarations

Ethics approval and consent to participate All the procedures followed in this study were maintained. Informed consent is not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interest.

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