Journal of Fisheries
Volume 11 Issue 3 December 2023
Peer Reviewed | Open Access

eISSN 2311-3111
pISSN 2311-729X

DOI: https://doi.org/10.17017/j.fish.648

Original Article

Morphological relationships, growth patterns and some aspects of reproductive biology of Sind Danio *Devario devario* (Hamilton 1822)

Md Mokaddes Alam[1] • Humayon Ahmmed[2] • Shihad Shahoriare Sujan[2] • Anika Tabassum Sama[2] • Md Rezoanul Haque[1] • Md Rashidul Islam[3]

[1] *Department of Fisheries Management, Hajee Mohammad Danesh Science and Technology University, Dinajpur−5200, Bangladesh*
[2] *Faculty of Fisheries, Hajee Mohammad Danesh Science and Technology University, Dinajpur−5200, Bangladesh*
[3] *Department of Fisheries Biology and Genetics, Hajee Mohammad Danesh Science and Technology University, Dinajpur−5200, Bangladesh*

Correspondence
Md Rashidul Islam; Department of Fisheries Biology and Genetics, Hajee Mohammad Danesh Science and Technology University, Dinajpur−5200, Bangladesh.
mrislam_fbg@hstu.ac.bd

Manuscript history
Received 4 June 2023 | Accepted 28 December 2023 | Published online 31 December 2023

Citation
Alam MM, Ahmmed H, Sujan SS, Sama AT, Haque MR, Islam MR (2023) Morphological relationships, growth patterns and some aspects of reproductive biology of Sind Danio *Devario devario* (Hamilton 1822). Journal of Fisheries 11(3): 113206. DOI: 10.17017/j.fish.648

Abstract
This study examined the morphological relationships, growth population factors and reproductive biology of *Devario devario* collected from the Atrai River of Dinajpur, Bangladesh, for sustainable management and conservation aspects. The length-weight relationships (LWRs) commonly indicated the isometric growth. The Fulton's condition factor (CF_f) and relative body weight (BW_r) varied across sexes. A positive correlation was found in length-length relationships (LLRs); among total length (TL), standard length, head length and fork length. The asymptotic lengths were 7.5, 7.2 and 7.5 cm, with growth rates of 0.78–1.8, 0.6–3.4 and 1.8–3.6 year^{-1} while total mortality was 1.22–3.06, 0.97–7.07 and 3.70–6.09 year^{-1}; fishing mortality was –0.87 to –1.04, –0.97 to 1.09 and –0.05 to –0.23 year^{-1}; natural mortality was 2.26–3.93, 1.94–5.98 and 3.93–6.14 year^{-1} for female, male and combined sexes respectively. The highest probability of capture (L_{50}) was 5.74–6.15 cm. The gonado-somatic index ranged from 32.75±1.82 to 44.12±2.73, with a peak in April to May. Fecundity was recorded from 3253±289 to 4831±342, with a significant correlation among TL, BW, gonad length (GL) and gonad weight (GW). These initial findings on *D. devario* will serve as the basis for future research and management.

Keywords: *Devario devario*; growth; morphology; reproductive biology; river

1 | INTRODUCTION

Bangladesh has 260 freshwater fish species (Rahman 2005), including 150 small indigenous species (SIS) with a maximum body length of 25 cm, which supply various macro- and micro-nutrients, vitamins, and minerals (Hanif *et al*. 2015a; Islam *et al*. 2023). Presently, SIS are at risk of extinction due to indiscriminate fishing pressure and pollution (Hanif *et al*. 2015b; Siddik *et al*. 2015) in all aquatic habitats including rivers. Thus, understanding the stock structure, growth, recruitment, mortality and reproductive biology of SIS are crucial and demanding. *Devario devario*, a bentho-pelagic species, is regularly declining in abundance due to various factors in the Atrai River, a prime river of Dinajpur district in Bangladesh (Islam and Mia 2016; Islam *et al*. 2017a, 2017b, 2018, 2019; Mia *et al*. 2019).

Length-weight relationships (LWRs) are vital population indicators for fish stock assessment and management, providing information on growth, health and community status (Philips 2014; Chaklader *et al*. 2015). Besides, length-length relationships (LLRs) are also essential tools for estimating fish yield, biomass, stock, population, growth parameters and mortality rates in aquatic animals (García and Duarte 2006; Kara and Bayhan 2008). Condition factors (CFs) such as Fulton's condition factor (CF_f) were used to understand the physical status, productivity, and life cycles of aquatic populations (Muchlisin *et al.* 2010; Victor *et al.* 2014). Relative body weight (BW_r) is a crucial physiological indicator for comparing fish body weight, understanding prey availability, food abundance, sexual maturity and conservation purposes (Giannetto *et al*. 2012). The form factor ($a_{3.0}$) of a species can determine if an individual's phenotypes significantly differ from others (Froese 2006). Besides, growth indicators and mortality rates are essential inputs for stock assessment and observing fish life histories (Stergiou 2000). Growth patterns, which change in magnitude in body size and morphometric features, are crucial in fishery management (Abowei *et al*. 2009). They convert growth in length to growth in weight, estimate fish biomass, and study the natural life history of fish (Alex *et al*. 2012; Moradinasab *et al*. 2012). Knowledge of fish mortality is used to estimate total annual instantaneous mortality rates (Memon *et al*. 2016). Natural mortality is essential for fishing and future prediction and can be useful for size-dependent fisheries management measures like mesh-size regulations (Gislason *et al*. 2010). Lastly, reproductive physiology is needed to understand fish population dynamics and fishing's impact on stocks (Mekkawy and Hassan 2011). Here, the gonado-somatic index (GSI) helps to detect spawning days and seasons, increasing with maturity and predicting breeding seasons (Islam and Mollah 2012). Fecundity, the number of eggs laid during a spawning season, provides information on reproductive potential and commercial potential (Zin *et al*. 2011). Accurate fecundity assessment is essential for successful fisheries management, including aquaculture, to estimate egg output and reproductive capacity (Tracey *et al*. 2007).

To the best of our knowledge, few earlier studies are available on *D. devario* such as LWRs (Koundal *et al*. 2014; Sreelekshmi *et al*. 2017; Kalita *et al*. 2018) and CF_f (Sreelekshmi *et al*. 2017) in India, as well as our previous study on LWRs and CF_f for this species collected from the Atrai River of Bangladesh (Islam *et al*. 2017a). However, all earlier reports were only conducted for the unknown sexes of this species, with short study periods and a small number of samples. Moreover, no previous studies are available on LLR growth patterns and reproductive biology, such as the gonado-somatic index (GSI) and fecundity of *D. devario*. Therefore, this study was aimed at estimating the LWR, LLR, condition factors, growth parameters and reproductive biology such as GSI and fecundity of Sind Danio *D. devario* in Bangladesh. This study will establish a baseline for future research on this small indigenous species in Bangladesh.

2 | METHODOLOGY

2.1 Study area and sample collection

A study was conducted in the Atrai River in Dinajpur district of Bangladesh, capturing fish specimens from two stations, Khansama (KS, 25.937°N 88.722°E) and Mohonpur (MP, 25.534°N 88.762°E). The fish specimens were collected on monthly basis during January–December 2021 in the morning (07:00–10:00 AM) using a push net (1.5 × 1.0 m^2, mesh size 6 mm) and a seine net (15 × 3.5 m^2, 4 mm) with the help of commercial fishermen. The samples were preserved in ice boxes and transferred to the Fisheries Biology and Genetics Laboratory of Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh. Body weight (BW) was taken using a digital electronic balance (HD-602ND, Mega, Japan) to the nearest 0.1 g accuracy. Five morphometric characteristics, such as total length (TL), standard length (SL), head length (HL), folk length (FL) and body weight (BW), were measured using slide calipers described by the methods (Froese 2006; Islam and Mia 2016; Islam *et al.* 2017a). The fish specimens were preserved with 10% buffered formalin for future study.

2.2 Measurement of morphological relationships

2.2.1 Length-weight relationship

In this study, the LWR of *D. devario* was measured using the conventional cubic or log-transformed formula described by (Le Cren 1951) as $BW = a\ TL^b$ or Log BW = log a + b log TL. Where BW = Body weight of each sample of *D. devario* (g); TL = Total length (cm); a = coefficient related to body form, and b = an exponent indicating isometric growth (b = 3.0) or allometric growth (3.0 < b > 3.0) followed by (Simon and Mazlan 2008). Here, the estimation was done for female, male and combined sexes. Moreover, the regression parameters "a" and "b" of the linear equation were calculated through the following equation as

$$b = \frac{[n\sum XY - \sum X \sum Y]}{[n\sum X^2 - (\sum X)^2]} \text{ and } a = Y - bX$$

Where b = exponent (slope), Y = dependent variable, X = independent variable, a = intercept (constant), n = number of individuals.

2.2.2 Condition factors

The condition factors of the present species were calculated according to our previous study (Islam *et al.* 2017a). Briefly, the condition factors, such as Fulton's condition factor (CF_f) were calculated as $CF_f = (BW \times 100) / TL^3$ (Fulton 1904). Where BW = body weight (g); TL = total length (cm). Besides, relative body weight (BW_r) was calculated

as BW_r = (BW/a TL^b) × 100 (Froese 2006). Where BW = body weight (g), TL = total length (cm) and "a" and "b" = regression parameters estimated from LWRs. Lastly, form factor ($a_{3.0}$) was also using an equation as $a_{3\cdot0}$ = 10 log a–S (b–3) (Froese 2006). Where "a" and "b" = regression parameters; S = –1.358 reported by Froese (2006) to estimate $a_{3.0}$ by plotting log10 "a" vs. "b" due to a lack of information on LWRs for *D. devario.*

2.2.3 Length-length relationship

There exists a simple linear relationship between two linear dimensions of aquatic animals since increases in length measurements are proportional to each other over the period of growth progression. The relationship between two length types of *D. devario* is linear that can be measured in the form of a straight-line equation as Y = a + bX. Where Y = dependent variable; X = independent variable a = intercept (constant); b = exponent (slope).

2.3 Measurement of growth population parameters

To determine the fish population dynamic indicators, such as seasonal variation in length frequency, growth, and mortality were considered. For this purpose, FAO-ICLARM Stock Assessment Tools (Version 1.2.1) was used to analyze the monthly length-frequency data of *D. deverio* (Gayanilo and Pauly 1997). Monthly collected length data of *D. devario* were pooled and consequently grouped into length classes at 0.3 cm as the length was ranged as (4.5 – 8.1 cm) representing a small indigenous species of Bangladesh. The asymptotic length (L_∞) and growth constant (K) of this species were calculated using the following Von Bertalanffy equation as: $L_t = L_\infty$ [1–exp {–K ($t–t_0$)}]. Where L_∞ = asymptotic length at which an average fish would achieve until they live and grow, K = Growth coefficient defining how fast the fish reached at L_∞, and t_o = hypothetical age for L_t at age zero (0).

Moreover, based on length frequency data, L_∞ was taken from the Powell-Wetherall plot using the equation as: L_∞ = - a/b (Sparre and Venema 1998). Where L_∞ = asymptotic length "a" and "b" = regression parameters from LWR. According to Munro and Pauly (1983), other growth parameters such as growth performance index (Ø) was also considered through the following equation: Ø = log K + 2 log L_∞. Where L_∞ = asymptotic length (cm), K = growth coefficient of the fish species ($year^{-1}$).

Finally, natural mortality (M) was calculated by using an indirect method based on relationships with life history factors, where an empirical formula described by (Pauly 1980) was exploited. The L_∞, K and average annual water temperature from both stations, namely Khansama (28.91°C) and Mohanpur (29.61°C) were measured directly from these stations at a monthly interval using a digital thermometer (Digi-thermo) from both stations of the Atrai River respectively. Moreover, total mortality (Z) of this Sind Danio species was assessed using the Z/K ratio resulting from the Powell-Wetherall plot using the following formula: Z/K = – (1+b) /b (Sparre and Venema 1998). The fishing mortality rate (F) was also derived from the difference between total mortality (Z) and natural mortality (M) expressed as F = Z–M with the rate of exploitation (E) calculated by the quotient between fishing and total mortality (Pauly 1984).

2.4 Determination of reproductive biology

2.4.1 Collection of fish gonad

In this study, 7 – 19 gravid females of *D. devario* were collected monthly from the Atrai River and transferred to the Department of Fisheries Biology and Genetics under Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh. Next, the TL (cm) and BW (g) of each specimen were measured using a slide calliper and a portable sensitive electronic balance as described in Section 2.1. The abdomen of *D. devario* was first cut by a scissor, following a direction from the anus to the lower jaw. The belly was opened and gonads were collected with the help of forceps very carefully without causing any injury, as followed by Islam and Mollah (2012). After observing the gonads with the naked eye, fishes were identified as male or female. At that time, the gonad length (GL, cm) and gonad weight (GW, g) of each ovary were also taken with the help of a slide calliper and an electronic balance. Moreover, a microscopic examination was considered to recognize the sexes for very small gonads. Finally, the gonads were preserved with 10% buffered formalin in the small vials for further study.

2.4.2 Estimation of gonado-somatic index (GSI)

The GSI is the percentage of gonad weight in the total body of fish. The value of GSI from the collected sample was calculated using the following formula (Islam and Mollah 2012).

$$\text{GSI} = \frac{\text{Weight of ovary (g)}}{\text{Weight of female fish (g)}} \times 100$$

2.4.3 Estimation of fecundity

Fecundity is the number of eggs in a fish's ovary. Gravimetric methods can be used to estimate fecundity when counting eggs is impractical. Islam and Das (2006) used the gravimetric or weight method to count and record the number of eggs. After collecting the gonad, 5 mg of ovarian parts were taken from the anterior, middle, and posterior portions of each lobe. The number of eggs was then determined by manual counting. The mean number of eggs in 5 mg was then multiplied by the total weight of the ovary to calculate the fecundity (Fe) of the fish as Fe = (N × gonad weight) / sample weight. Where N is the number of eggs.

2.4.4 Determination of linear relationship

A cubic relationship (Y = a X^b), which is equal to linear

regression (Y = a + b X), analysis was used to determine different relationships such as fecundity (Fe) with TL, BW, GL and GW respectively (Islam and Mollah 2012). Where Y = dependent variable, X = independent variable, BW = body weight, GL = gonad length and GL = gonad length, "b" = slope and "a" = intercept.

2.5 Statistical analysis

Statistical analysis was conducted on each species using add-in functions in Microsoft Office Excel 2016 (Microsoft, Redmond, WA, USA), SPSS (version 22) and PAST (version 3.10) software. The normal distribution of the dataset was checked using Shapiro-Wilk's test. Outliers were removed using a log-log plot. The 95% confidence interval (CI) was determined for the regression parameters "a" and "b" based on Froese (2006). To find out the significant differences between the regression coefficient (b) and the isometric value (b = 3) for LWR (Sokal and Rohlf 1987), a student t-test (Pauly 1984) was applied using the following equation:

$$t = \frac{SD_{(X)}}{SD_{(Y)}} . \frac{b - 3}{\sqrt{1 - r^2}} . \sqrt{n - 2}$$

Where SD_X = standard deviation of the log TL, SD_Y = standard deviation of the log BW, n = sample size, and r^2 = coefficient of determination. The study used critical values to determine the isometric or allometric range of b values for *D. devario*. One-way analysis of variance (ANOVA) and the Tukey test were used to identify dissimilarities ($p < 0.05$ or 0.01) among sexes based on CF_f and BW_r values. FAO-ICLARM Stock Assessment Tools (Version 1.2.1) were used to analyse monthly-distributed length data. Lastly, the log-log plots were also applied to eliminate the outliers from different linear relationships of fecundity (Fe) with TL, BW, GL and GW.

3 | RESULTS AND DISCUSSION

In this study, this is the first report on *D. devario* except for LWRs and CF_f. The maximum TL of *D. devario* was recorded 10 cm (Patiyal and Mir 2017), which was less than 25 cm; thus, it is considered one of the SIS in Bangladesh. Therefore, the findings of closely related SIS were used to make a comparison with *D. devario* from the Atrai River.

3.1 Length-weight relationship

A total of 1300 fish individuals of *D. devario* were caught from the Atrai River of Dinajpur district, Bangladesh. TL of this species ranged from 5.10 to 8.10, 4.60 to 7.80 and 4.60 to 8.10 cm, while BW varied from 1.28 to 6.94, 1.14 to 5.84 and 1.12 to 6.94 g for female, male and combined sexes respectively. TL and BW of *D. devario* ranged from 3.0 to 7.1 cm and 1.0 to 4.1 g collected from the Atrai River in Bangladesh (Islam *et al.* 2017a) and the Western Himalaya in India (Koundal *et al.* 2014), which are close to the current findings. Besides, the present maximum length of 8.10 cm of *D. devario* was higher than the earlier reports (Koundal *et al.* 2014; Islam *et al.* 2017a; Sreelekshmi *et al.* 2017; Kalita *et al.* 2018) but lower than 10 cm (Patiyal and Mir 2017).

LWRs of the present species were recorded as BW = 0.0069 $TL^{2.253}$ to BW = 0.0340 $TL^{3.248}$, BW = 0.0064 $TL^{2.512}$ to BW = 0.0287 $TL^{3.248}$, and BW = 0.0041 $TL^{2.908}$ to BW = 0.0145 $TL^{3.500}$ for female, male and combined sexes respectively. This result is close to BW = 0.010 $TL^{3.120}$, BW = 0.011 $TL^{3.140}$ for this species (Islam *et al.* 2017a; Kalita *et al.* 2018) and BW = 0.0073 $TL^{3.26}$ for *D. aequipinnatus* (Hussain *et al.* 2016). The study found that the values of "a" (0.0064 – 0.0340) for *D. devario* were within the expected limit, as noted by Froese *et al.* (2014). The values of "b" (2.512 – 3.500) from LWRs varied for female, male and combined sexes, with values fluctuating within the Bayesian boundary (Froese 2006). The values of b = 3 indicate isometric growth; b < 3 shows negative allometric growth; and b > 3 shows positive allometric growth. Islam *et al.* (2017a) found a value of "b" of 3.120, indicating positive allometric growth, while 2.751 represents negative allometric growth. The coefficient of determination (r^2) varied from 0.885 to 0.969, 0.758 to 0.950 and 0.510 to 0.955 for female, male and combined sexes in the river respectively. The values of regression factors may vary due to differences in sample size, range of length, age, sex, season, ecology, habitats, gonadal maturity and fish behaviour (Tarkan *et al.* 2006; Muchlisin *et al.* 2010; Khan and Sabah 2013).

3.2 Condition factors

The mean (± standard error, SE) values of CF_f were ranged from 1.068 ± 0.011 to 1.336 ± 0.014, 1.027 ± 0.011 to 1.207 ± 0.012 and 1.054 ± 0.007 to 1.247 ± 0.006 while BW_r ranged from 99.427 ± 0.553 to 103.071 ± 0.995, 99.372 ± 100.936, and 99.690 ± 101.757 for female, male and combined sexes respectively (Table 1). Moreover, a significant difference was observed among the sexes from March to July for CF_f, whereas from March and June for BW_r (Table 1), which might be due to the variation of sex and gonad weight. The values of CF_f recorded as 0.99 to 1.54 and BW_r as 80.24 to 124.29 for this species captured from the Atrai River of Dinajpur district in Bangladesh (Islam *et al.* 2017a) or CF_f recorded as 1.056 to 1.222 from three river systems in South Kerala (Sreelekshmi *et al.* 2017), which are close to the present findings. Moreover, a fish was scanty and elongated with a lean (CF_f = 1.00), sound (CF_f = 1.20) and healthy body (CF_f = 1.40) reflected by Barnham and Baxter (1998).

Therefore, the female (1.068 ± 0.011 < CF_f < 1.336 ± 0.014), male (1.027 ± 0.011 < CF_f < 1.207 ± 0.012) and combined (1.054 ± 0.007 < CF_f < 1.247 ± 0.006) sexes of *D. devario* were in lean, sound health, and healthy bodies of the fish collected from the Atrai River. Besides, values of BW_r decreasing under 100 for a specimen, stock, or fish community represent little prey availability or high preda-

tion, whereas values above 100 designate vice versa (Rypel and Richter 2008). The foam factor of *D. devario* ranged from 0.004 to 0.021, 0.004 to 0.021 and 0.004 to 0.021 for the female, male and combined sexes respectively. Islam *et al.* (2017a) observed that the value of this indicator was recorded as 0.014 for the unknown sex of this species in the Atrai River. Some disparities may be due to season, food staff, environmental parameters, and breeding period, which were not considered in this study.

3.3 Length-length relationship

In this study, the values of estimated parameters from LLRs (among TL, SL, HL and FL) of female, male and combined sexes of *D. devario* are presented in Table 2. Briefly, the values "a" were 1.327 to 2.983 from TL and SL; 1.007 to 1.857 from TL and FL; 1.099 to 1.882 from FL and SL; 0.042 to 0.760 from HL and TL; 0.127 to 0.627 from HL and SL; and 0.040 to 0.642 from HL and FL respectively (Table 2). Besides, the values of "b" were 0.232 to 0.974 from TL and SL; 0.197 to 0.966 from TL and FL; 0.538 to 1.045 from FL and SL; 0.200 to 1.777 from HL and TL; 0.279 to 1.173 from HL and SL; and 0.289 to 1.888 from HL and FL respectively (Table 2). Moreover, a positive relationship was found between TL vs. SL (r^2 > 0.201), TL vs. FL (r^2 > 0.012), FL vs. SL (r^2 > 0.332), HL vs. TL (r^2 > 0.010), HL vs. SL (r^2 > 0.003), and HL vs. FL (r^2 > 0.047) among the sexes of this species, respectively (Table 2). However, there are no earlier results on these relationships for *D. deverio* that would be in contrast to the present findings. Thus, the present findings may serve as the baseline data to know the yield, biomass and community status in the Atrai River.

TABLE 1 Descriptive statistics and one-way ANOVA of condition factors for *Devario devario* in the Atrai River, Bangladesh.

Month	Source	Sex	*n*	Fulton's condition factor				Relative body weight				Foam factor ($a_{3.0}$)
				Min	Max	Mean±SE	*F*-value	Min	Max	Mean±SE	*F*-value	
January	KS	F	23	0.951	1.251	1.085±0.010	0.06	88.075	115.803	99.914±0.844	< 0.01	0.015
		M	41	0.902	1.119	1.080±0.008	(0.94)	83.415	118.524	99.964±0.705	(0.99)	0.011
		C	64	0.912	1.282	1.082±0.006		84.320	117.004	99.947±0.545		0.012
	MP	F	21	1.066	1.280	1.156±0.008	1.46	92.493	111.104	100.307±0.675	0.20	0.012
		M	25	1.073	1.222	1.176±0.009	(0.23)	90.996	112.074	99.675±0.722	(0.82)	0.012
		C	46	1.006	1.323	1.167±0.006		89.916	113.004	99.967±0.497		0.010
February	KS	F	17	0.970	1.193	1.068±0.011	0.88	90.473	110.369	100.072±0.991	0.01	0.009
		M	40	0.935	1.134	1.048±0.008	(0.41)	79.888	117.828	99.911±0.772	(0.99)	0.010
		C	57	0.838	1.244	1.054±0.007		80.813	118.582	99.954±0.622		0.012
	MP	F	30	1.053	1.335	1.203±0.011	0.02	87.065	112.670	99.728±0.930	0.01	0.015
		M	36	0.988	1.233	1.207±0.012	(0.98)	87.927	117.090	99.908±0.980	(0.99)	0.013
		C	66	1.034	1.410	1.205±0.008		85.027	116.935	99.826±0.677		0.014
March	KS	F	19	1.027	1.340	1.175±0.013	0.62	86.607	113.712	99.699±1.063	0.03	0.014
		M	35	0.989	1.249	1.157±0.009	(0.54)	87.011	109.926	100.019±0.810	(0.97)	0.013
		C	54	0.994	1.348	1.163±0.008		85.924	114.712	99.909±0.642		0.014
	MP	F	23	1.104	1.372	1.195±0.012^{a}	3.32*	98.493	122.461	103.071±0.995^{a}	7.61**	0.013
		M	36	0.974	1.374	1.153±0.008^{b}	(< 0.05)	84.658	118.921	100.588±0.655^{b}	(< 0.01)	0.014
		C	59	0.904	1.227	1.162±0.007^{b}		86.045	119.841	101.757±0.592^{b}		0.014
April	KS	F	20	1.031	1.394	1.195±0.008^{a}	14.58**	87.426	118.868	100.084±0.668	0.05	0.014
		M	27	0.907	1.296	1.135±0.006^{b}	(< 0.01)	85.175	114.588	100.381±0.606	(0.95)	0.012
		C	47	0.979	1.221	1.163±0.006^{b}		86.677	116.008	100.243±0.448		0.014
	MP	F	20	1.007	1.132	1.159±0.013^{a}	2.86*	88.270	115.901	100.703±1.137	0.01	0.015
		M	33	0.986	1.214	1.117±0.009^{b}	(< 0.05)	90.036	111.663	100.936±0.874	(0.99)	0.012
		C	53	0.993	1.231	1.140±0.009^{a}		88.270	113.958	100.809±0.733		0.015
May	KS	F	30	1.087	1.306	1.215±0.013^{a}	9.87**	89.263	106.145	100.360±2.918	0.01	0.015
		M	32	0.999	1.114	1.027±0.011^{b}	(< 0.01)	92.703	110.058	100.021±1.090	(0.99)	0.014
		C	62	0.951	1.125	1.077±0.023^{b}		88.541	108.586	100.110±1.064		0.012
	MP	F	25	1.098	1.238	1.173±0.018^{a}	7.38**	93.939	106.101	100.396±1.516	0.03	0.008
		M	34	0.909	1.214	1.058±0.014^{b}	(< 0.01)	85.054	104.003	99.815±1.302	(0.97)	0.004
		C	59	1.001	1.216	1.090±0.015^{b}		89.640	113.983	99.977±1.014		0.015
June	KS	F	26	1.184	1.441	1.314±0.018^{a}	36.88**	91.700	108.657	100.165±0.763	<0.01	0.009
		M	23	0.994	1.289	1.103±0.011^{c}	(< 0.01)	93.190	112.059	100.190±0.921	(0.99)	0.006
		C	49	1.031	1.327	1.247±0.006^{b}		88.070	111.965	100.177±0.590		0.020
	MP	F	22	1.276	1.437	1.336±0.014^{a}	17.89**	97.363	103.010	100.972±1.565^{a}	20.04**	0.008
		M	22	1.003	1.108	1.057±0.001^{c}	(< 0.01)	88.586	105.432	100.198±0.855^{b}	(< 0.01)	0.006
		C	44	1.018	1.301	1.196±0.032^{b}		96.870	104.010	100.585±8.206^{c}		0.021

Month	Source	Sex	*n*	Fulton's condition factor				Relative body weight				Foam factor ($a_{3.0}$)
				Min	Max	Mean±SE	*F*-value	Min	Max	Mean±SE	*F*-value	
July	KS	F	23	1.003	1.289	1.126±0.012[b]	3.19[*]	88.370	112.124	99.658±0.658	0.01	0.010
		M	28	0.988	1.255	1.184±0.008[a]	(< 0.05)	85.890	109.987	100.012±0.247	(0.99)	0.011
		C	51	0.996	1.279	1.159±0.007[b]		89.121	110.547	100.089±0.601		0.010
	MP	F	21	0.994	1.311	1.160±0.013	0.08	86.320	113.014	100.807±0.408	0.01	0.012
		M	37	1.020	1.320	1.145±0.005	(0.92)	87.489	117.222	100.354±0.840	(0.99)	0.010
		C	58	1.001	1.298	1.153±0.011		85.584	114.650	99.905±0.621		0.011
August	KS	F	18	0.965	1.327	1.126±0.020	0.03	89.147	112.214	100.100±0.154	0.01	0.013
		M	28	0.998	1.279	1.115±0.011	(0.97)	86.512	110.587	100.256±0.206	(0.99)	0.012
		C	56	1.013	1.305	1.129±0.010		87.011	109.145	100.110±0.514		0.011
	MP	F	23	0.904	1.278	1.140±0.009	0.01	85.987	111.339	100.650±0.409	0.01	0.012
		M	40	0.889	1.295	1.135±0.017	(0.99)	86.458	115.120	99.780±0.605	(0.99)	0.014
		C	63	1.004	1.229	1.089±0.012		86.509	117.321	99.990±0.314		0.012
September	KS	F	20	1.050	1.303	1.174±0.011	0.01	90.125	114.209	100.988±0.228	0.01	0.014
		M	38	0.908	1.287	1.148±0.013	(0.99)	88.328	109.012	100.664±0.980	(0.99)	0.013
		C	58	0.984	1.276	1.167±0.008		86.789	118.002	100.551±0.507		0.012
	MP	F	17	0.920	1.334	1.120±0.014	<0.01	87.514	114.201	99.558±0.310	0.01	0.013
		M	28	0.989	1.268	1.109±0.011	(0.99)	85.625	110.470	100.225±0.528	(0.99)	0.013
		C	45	0.955	1.257	1.118±0.017		86.075	112.157	100.369±0.295		0.012
October	KS	F	13	1.008	1.276	1.116±0.009	0.01	88.904	116.228	100.117±0.512	0.01	0.011
		M	27	0.998	1.245	1.161±0.015	(0.99)	89.009	114.205	100.140±0.400	(0.99)	0.010
		C	40	1.001	1.259	1.147±0.014		87.514	111.227	99.740±0.687		0.011
	MP	F	38	0.932	1.288	1.080±0.009	0.01	86.367	115.304	100.110±0.501	0.01	0.009
		M	23	0.987	1.256	1.118±0.004	(0.99)	87.825	119.480	100.221±0.669	(0.99)	0.012
		C	51	1.010	1.301	1.155±0.010		86.913	114.007	100.080±0.504		0.011
November	KS	F	22	1.014	1.290	1.093±0.005	0.01	88.809	113.074	99.427±0.553	0.01	0.012
		M	37	0.980	1.260	1.139±0.003	(0.99)	88.124	113.543	100.009±0.329	(0.99)	0.011
		C	59	1.000	1.335	1.117±0.001		86.841	110.228	99.689±0.488		0.011
	MP	F	21	1.017	1.348	1.096±0.014	0.07	90.121	109.855	100.254±0.690	0.01	0.012
		M	27	0.957	1.307	1.115±0.013	(0.93)	86.014	114.881	100.147±0.712	(0.99)	0.010
		C	48	0.991	1.291	1.130±0.005		87.040	109.580	100.125±0.636		0.012
December	KS	F	21	1.073	1.451	1.147±0.016	<0.01	87.407	115.110	100.188±0.495	0.01	0.011
		M	29	0.980	1.354	1.190±0.011	(0.99)	86.545	111.781	100.014±0.208	(0.99)	0.010
		C	50	1.008	1.280	1.157±0.006		87.210	115.250	100.150±0.331		0.009
	MP	F	26	0.965	1.365	1.125±0.008	<0.01	86.188	121.909	100.405±0.744	0.01	0.011
		M	35	0.948	1.268	1.146±0.014	(0.99)	85.905	113.254	99.372±0.650	(0.99)	0.090
		C	61	1.012	1.287	1.118±0.011		87.049	112.053	99.690±0.470		0.010

KS, Khansama; MP, Mohanpur; F, female; M, male; C, combined sex; n, number of specimens; BW, body weight; TL, total length; Min, minimum; Max, maximum; SE, standard error.

TABLE 2 Length-length relationships of total length (TL), standard length (SL), head length (HL) and fork length (FL) of *Devario devario* in the Atrai River, Dinajpur, Bangladesh.

Month	Source	Sex	*n*	TL = a SL^b			TL = a FL^b			FL = a SL^b			HL = a TL^b			HL = a SL^b			HL = a FL^b		
				*a**	b	r^2	*a**	b	r^2	*a**	b	r^2	*a**	b	r^2	*a**	b	r^2	*a**	b	r^2
January	KS	F	23	2.087	0.690	0.781	1.445	0.841	0.954	1.609	0.796	0.771	0.393	0.585	0.202	0.601	0.405	0.160	0.487	0.492	0.193
		M	41	1.694	0.808	0.821	1.292	0.901	0.925	1.419	0.866	0.827	0.169	1.063	0.666	0.312	0.824	0.503	0.231	0.932	0.584
		C	64	1.728	0.800	0.820	1.301	0.898	0.937	1.429	0.864	0.824	0.220	0.909	0.537	0.376	0.702	0.411	0.290	0.795	0.477
	MP	F	21	1.406	0.933	0.888	1.156	0.966	0.916	1.311	0.922	0.884	0.228	0.843	0.180	0.293	0.809	0.170	0.241	0.853	0.181
		M	25	2.814	0.466	0.646	1.719	0.725	0.773	1.304	0.538	0.587	0.281	0.721	0.083	0.585	0.345	0.056	0.310	0.703	0.116
		C	46	1.860	0.749	0.815	1.309	0.893	0.917	1.577	0.799	0.804	0.235	0.826	0.240	0.390	0.622	0.917	0.267	0.793	0.254
February	KS	F	17	2.442	0.591	0.609	1.318	0.887	0.930	1.125	0.629	0.584	0.042	1.777	0.046	0.627	0.347	0.003	0.040	1.888	0.061
		M	40	2.107	0.657	0.666	1.624	0.750	0.763	1.836	0.696	0.550	0.459	0.411	0.043	0.616	0.279	0.030	0.438	0.462	0.073
		C	57	1.733	0.797	0.842	1.287	0.896	0.921	1.524	0.828	0.794	0.153	1.063	0.114	0.318	0.747	0.074	0.174	1.038	0.124
	MP	F	30	1.397	0.94	0.943	1.135	0.873	0.941	1.107	1.034	0.925	0.363	0.564	0.291	0.418	0.56	0.306	0.470	0.442	0.22
		M	36	1.327	0.974	0.961	1.218	0.933	0.970	1.144	1.016	0.940	0.299	0.667	0.297	0.367	0.642	0.277	0.355	0.602	0.268
		C	66	1.366	0.955	0.951	1.287	0.902	0.954	1.130	1.022	0.930	0.329	0.618	0.294	0.392	0.601	0.291	0.411	0.519	0.243

Month	Source	Sex	*n*	TL = a SL^b			TL = a FL^b			FL = a SL^b			HL = a TL^b			HL = a SL^b			HL = a FL^b		
				*a**	b	r^2	a*	b	r^2	a*	b	r^2	a*	b	r^2	a*	b	r^2	a*	b	r^2
March	KS	F	19	1.784	0.792	0.950	1.328	0.884	0.936	1.463	0.867	0.951	0.137	1.042	0.457	0.288	0.881	0.495	0.200	0.884	0.392
		M	35	1.350	0.963	0.887	1.266	0.915	0.965	1.106	1.034	0.887	0.315	0.593	0.230	0.431	0.485	0.147	0.360	0.546	0.225
		C	54	1.527	0.886	0.914	1.317	0.891	0.958	1.220	0.974	0.915	0.231	0.763	0.343	0.127	0.313	0.317	0.291	0.668	0.318
	MP	F	23	1.569	0.871	0.928	1.472	0.835	0.875	1.394	0.886	0.765	0.156	0.987	0.568	0.237	0.877	0.549	0.196	0.911	0.607
		M	36	1.554	0.876	0.902	1.304	0.901	0.907	1.372	0.897	0.848	0.217	0.821	0.370	0.325	0.692	0.309	0.295	0.688	0.291
		C	59	1.554	0.876	0.902	1.348	0.883	0.897	1.379	0.894	0.824	0.201	0.859	0.412	0.301	0.738	0.361	0.264	0.749	0.361
April	KS	F	20	1.469	0.918	0.941	1.165	0.958	0.973	1.307	0.942	0.936	0.314	0.638	0.428	0.379	0.619	0.450	0.331	0.635	0.450
		M	27	2.114	0.668	0.684	1.323	0.890	0.920	1.882	0.708	0.623	0.271	0.716	0.326	0.507	0.437	0.175	0.288	0.715	0.378
		C	47	1.715	0.821	0.827	1.255	0.919	0.954	1.497	0.855	0.793	0.295	0.671	0.395	0.431	0.540	0.314	0.318	0.659	0.431
	MP	F	20	1.442	0.934	0.916	1.198	0.948	0.967	1.244	0.962	0.904	0.371	0.570	0.370	0.482	0.496	0.294	0.394	0.565	0.390
		M	33	1.587	0.862	0.906	1.308	0.900	0.901	1.356	0.901	0.890	0.154	1.033	0.303	0.210	0.993	0.342	0.193	0.960	0.291
		C	53	1.432	0.928	0.928	1.246	0.927	0.958	1.214	0.974	0.917	0.252	0.769	0.391	0.327	0.724	0.373	0.286	0.737	0.401
May	KS	F	30	2.007	0.232	0.754	1.644	0.197	0.012	1.834	0.746	0.337	0.659	0.439	0.099	0.556	0.434	0.018	0.045	1.746	0.484
		M	32	2.814	0.530	0.526	1.091	0.430	0.457	1.139	1.021	0.789	0.060	1.529	0.384	0.160	1.173	0.423	0.112	1.260	0.644
		C	62	2.307	0.647	0.363	1.007	0.284	0.105	1.099	1.045	0.731	0.760	0.200	0.011	0.170	1.136	0.305	0.103	1.309	0.606
	MP	F	25	2.139	0.707	0.844	1.857	0.719	0.917	1.249	0.968	0.893	0.207	0.834	0.174	0.217	0.929	0.364	0.417	0.502	0.112
		M	34	1.637	0.854	0.953	1.384	0.872	0.944	1.297	0.940	0.930	0.415	0.506	0.127	0.587	0.375	0.092	0.618	0.315	0.062
		C	59	1.704	0.833	0.909	1.483	0.835	0.934	1.240	0.968	0.918	0.462	0.445	0.087	0.484	0.482	0.133	0.642	0.289	0.049
June	KS	F	26	1.728	0.831	0.840	1.267	0.921	0.970	1.382	0.910	0.880	0.199	0.861	0.415	0.287	0.775	0.409	0.249	0.783	0.393
		M	23	1.948	0.755	0.740	1.552	0.813	0.914	1.410	0.891	0.746	0.384	0.534	0.105	0.374	0.626	0.187	0.328	0.644	0.211
		C	49	1.655	0.853	0.838	1.337	0.892	0.961	1.284	0.949	0.859	0.271	0.710	0.301	0.326	0.704	0.341	0.303	0.683	0.336
	MP	F	22	1.787	0.808	0.919	1.517	0.828	0.836	1.432	0.883	0.902	0.144	1.040	0.453	0.194	1.015	0.608	0.148	1.073	0.588
		M	22	2.983	0.510	0.201	1.646	0.780	0.854	1.733	0.776	0.332	0.679	0.260	0.010	0.223	0.936	0.096	0.450	0.486	0.047
		C	44	1.851	0.786	0.771	1.487	0.836	0.831	1.501	0.858	0.771	0.202	0.872	0.242	0.200	0.997	0.394	0.188	0.947	0.340
July	KS	F	23	1.452	0.802	0.810	1.521	0.851	0.913	1.105	0.789	0.841	0.158	0.452	0.247	0.327	0.754	0.128	0.124	0.854	0.269
		M	28	1.634	0.741	0.882	1.421	0.873	0.941	1.254	0.854	0.790	0.324	0.354	0.365	0.224	0.680	0.321	0.368	0.687	0.120
		C	51	1.355	0.787	0.765	1.333	0.855	0.932	1.112	0.803	0.800	0.235	0.390	0.221	0.310	0.711	0.187	0.258	0.844	0.325
	MP	F	21	1.478	0.778	0.841	1.241	0.894	0.899	1.457	0.911	0.781	0.268	0.658	0.365	0.332	0.684	0.331	0.463	0.683	0.117
		M	37	1.687	0.841	0.650	1.641	0.910	0.944	1.214	0.841	0.668	0.169	0.456	0.245	0.380	0.751	0.121	0.158	0.760	0.423
		C	58	1.421	0.769	0.783	1.452	0.875	0.915	1.320	0.884	0.710	0.190	0.584	0.369	0.338	0.698	0.158	0.322	0.950	0.331
August	KS	F	18	1.547	0.800	0.854	1.337	0.934	0.927	1.354	0.786	0.658	0.322	0.710	0.125	0.368	0.810	0.325	0.510	0.843	0.470
		M	28	1.652	0.777	0.798	1.601	0.887	0.931	1.210	0.854	0.745	0.350	0.421	0.248	0.258	0.741	0.099	0.125	0.685	0.224
		C	56	1.489	0.755	0.699	1.450	0.911	0.940	1.330	0.821	0.691	0.288	0.628	0.154	0.298	0.674	0.247	0.358	0.745	0.358
	MP	F	23	1.674	0.698	0.747	1.455	0.886	0.880	1.605	0.935	0.704	0.125	0.457	0.368	0.441	0.565	0.307	0.510	0.920	0.147
		M	40	1.480	0.754	0.785	1.290	0.811	0.937	1.354	0.845	0.877	0.250	0.650	0.257	0.321	0.780	0.158	0.247	0.584	0.358
		C	63	1.595	0.711	0.778	1.384	0.843	0.918	1.421	0.896	0.783	0.187	0.587	0.148	0.387	0.666	0.255	0.350	0.788	0.268
September	KS	F	20	1.688	0.840	0.888	1.710	0.789	0.947	1.574	0.760	0.685	0.421	0.783	0.452	0.268	0.840	0.402	0.560	0.578	0.471
		M	38	1.784	0.798	0.709	1.623	0.718	0.882	1.540	0.807	0.760	0.327	0.901	0.356	0.204	0.365	0.109	0.114	0.857	0.244
		C	58	1.487	0.824	0.854	1.555	0.732	0.911	1.550	0.789	0.697	0.328	0.885	0.520	0.233	0.654	0.277	0.500	0.658	0.331
	MP	F	17	1.734	0.866	0.900	1.465	0.785	0.874	1.204	0.721	0.695	0.247	0.369	0.334	0.487	0.755	0.366	0.481	0.756	0.551
		M	28	1.639	0.765	0.845	1.632	0.885	0.918	1.119	0.833	0.707	0.269	0.474	0.235	0.225	0.354	0.111	0.220	0.877	0.244
		C	45	1.753	0.799	0.890	1.389	0.874	0.888	1.188	0.769	0.680	0.300	0.395	0.388	0.324	0.644	0.445	0.455	0.824	0.473
October	KS	F	13	1.495	0.807	0.788	1.239	0.822	0.961	1.632	0.881	0.844	0.147	0.651	0.564	0.220	0.889	0.652	0.247	0.544	0.228
		M	27	1.659	0.769	0.853	1.582	0.721	0.949	1.574	0.809	0.783	0.254	0.334	0.440	0.332	0.677	0.333	0.488	0.811	0.588
		C	40	1.528	0.766	0.808	1.621	0.774	0.938	1.520	0.789	0.822	0.220	0.477	0.358	0.269	0.840	0.489	0.225	0.775	0.331
	MP	F	38	1.457	0.845	0.785	1.487	0.845	0.897	1.609	0.890	0.868	0.369	0.559	0.432	0.457	0.365	0.111	0.333	0.453	0.570
		M	23	1.854	0.702	0.811	1.569	0.745	0.932	1.557	0.767	0.702	0.357	0.657	0.360	0.325	0.655	0.451	0.258	0.693	0.208
		C	51	1.691	0.748	0.910	1.359	0.801	0.900	1.548	0.837	0.774	0.305	0.600	0.440	0.411	0.487	0.288	0.440	0.559	0.457
November	KS	F	22	1.590	0.783	0.851	1.468	0.857	0.961	1.708	0.654	0.820	0.268	0.832	0.556	0.470	0.669	0.770	0.158	0.966	0.119
		M	37	1.693	0.798	0.756	1.641	0.836	0.954	1.655	0.780	0.763	0.314	0.620	0.423	0.331	0.478	0.259	0.358	0.780	0.457
		C	59	1.752	0.789	0.822	1.602	0.800	0.923	1.600	0.687	0.773	0.275	0.753	0.567	0.390	0.744	0.475	0.244	0.803	0.358
	MP	F	21	1.705	0.900	0.943	1.337	0.778	0.877	1.350	0.852	0.567	0.219	0.882	0.259	0.340	0.621	0.226	0.440	0.609	0.098
		M	27	1.842	0.879	0.884	1.265	0.882	0.880	1.401	0.900	0.748	0.411	0.789	0.345	0.256	0.356	0.654	0.228	0.407	0.423
		C	48	1.741	0.800	0.912	1.330	0.840	0.853	1.384	0.887	0.668	0.321	0.801	0.421	0.287	0.489	0.400	0.329	0.753	0.259
December	KS	F	21	1.658	0.887	0.888	1.489	0.901	0.943	1.124	0.855	0.871	0.354	0.988	0.412	0.426	0.615	0.351	0.404	0.921	0.357
		M	29	1.448	0.799	0.905	1.203	0.890	0.907	1.379	0.951	0.835	0.113	0.887	0.510	0.330	0.774	0.695	0.210	0.688	0.721
		C	50	1.471	0.897	0.920	1.253	0.922	0.932	1.299	0.917	0.877	0.201	0.963	0.670	0.289	0.870	0.625	0.267	0.846	0.668
	MP	F	26	1.800	0.784	0.877	1.354	0.889	0.909	1.650	0.779	0.931	0.208	0.988	0.455	0.411	0.902	0.478	0.365	0.836	0.452
		M	35	1.564	0.841	0.857	1.189	0.906	0.930	1.488	0.886	0.780	0.125	0.950	0.623	0.290	0.753	0.654	0.144	0.980	0.759
		C	61	1.691	0.817	0.876	1.205	0.939	0.915	1.515	0.832	0.876	0.203	0.990	0.599	0.334	0.825	0.545	0.243	0.932	0.550

KS, Khansama; MP, Mohanpur; F, female; M, male; C, combined sex; n, number of specimens; TL, total length; SL, standard length; FL, fork length; HL, head length; a*, anti-log a; a, intercept; b, slope; r^2, coefficient of determination.

3.4 Length-based growth patterns

3.4.1 Assessment of growth indices

In the growth parameters analysis of *D. devario*, asymptotic lengths (L_∞) were observed as 7.5, 7.2 and 7.5 cm while the growth performance index (Ø) ranged from 1.642 to 2.01, 1.49 to 2.25 and 2.01 to 2.31 for female, male and combined sexes respectively (Figure 1). Zakeyuddin *et al.* (2017) found that L_∞ values were 10.90 cm, which is comparatively higher than the present value, which might be due to the geographical variation, whereas the Ø value was 2.15 for *D. regina* from the Sungai Kerian Basin in Malaysia, which is close to the present findings. Azadi and Mamun (2009) also estimated the asymptotic length (L_∞) for *Amblypharyngodon mola* as 10.465 cm and the Ø as 4.017, which were higher than *D. devario* and may be due to different taxa. The growth coefficient (K) of *D. devario* varied from 0.78 to 1.8 year^{-1} for females, 0.6 to 3.4 year^{-1} for males, and 1.8 to 3.6 year^{-1} for combined sexes, suggesting that female had faster growth to reach their maximum length than males, whereas 1.2 year^{-1} was recorded for *D. regina* (Zakeyuddin *et al.* 2017). Differences in ecological factors and latitudes influence, as well as food staffs, the values of L_∞ and K, resulting in the alteration of the growth performance index (Ghorbani *et al.* 2018).

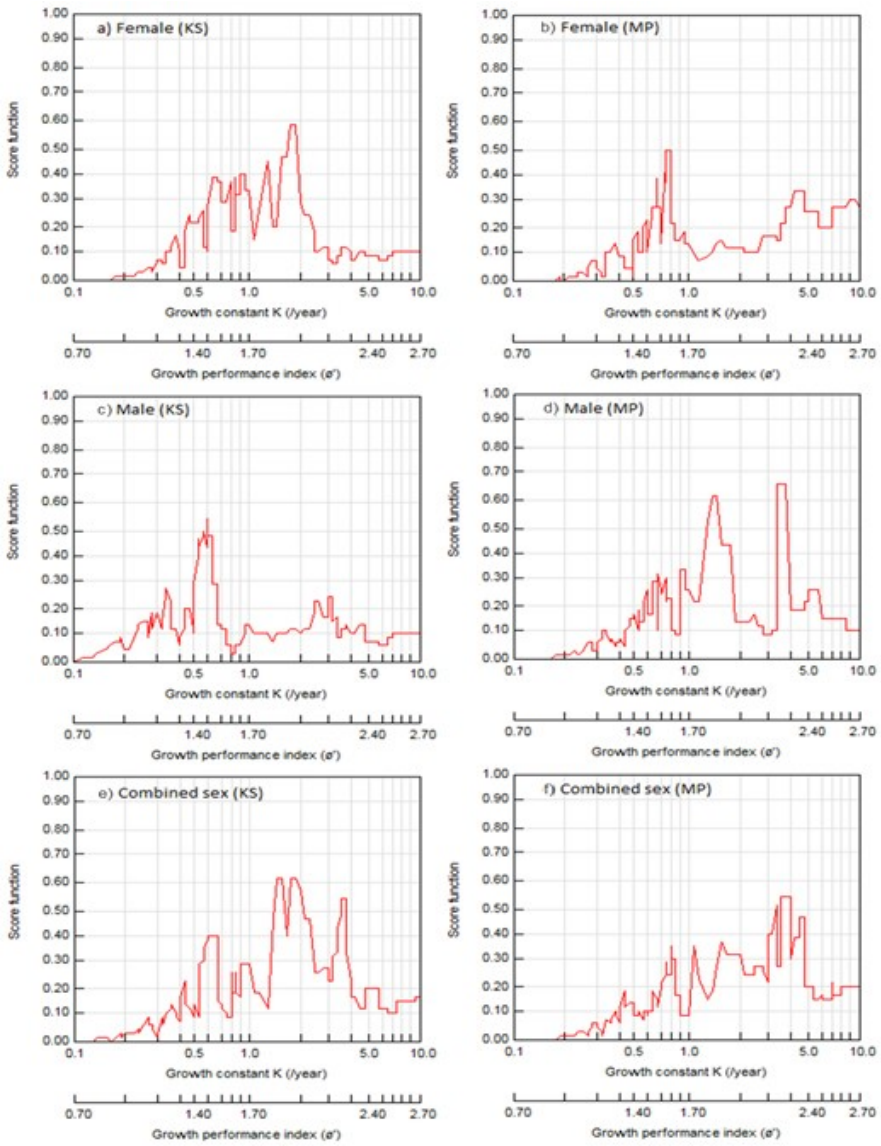

FIGURE 1 Non-parametric scoring of VBGF fit using ELEFAN-I method with maximum score (Smax) appropriate to the best value of growth coefficient of *Devario devario* at the Khansama (KS) and Mohanpur (MP) stations for female (a–b), male (c–d) and combined sexes (e–f) in the Atrai River, Dinajpur, Bangladesh.

Fish from open waterbody always show a low L_∞ value with high Ø- and K-values indicating rapid growth compared to captive conditions (Pauly 1981, 1994), which is similar to the present data and habitat. Moreover, the score values (R_n) of *D. devario* varied from 0.496 to 0.591, 0.539 to 0.661 and 0.545 to 0.614 for female, male and combined sexes respectively. Besides, the theoretical age (t_o) of this fish was noted as –0.90, –0.40 and –0.90 year^{-1} at KS station, whereas –0.52, –1.18 and –1.21 year^{-1} for female, male and combined sexes at MP station and

which was similar (t_o = –0.929) to *Sardinella longiceps* (Nadeem *et al.* 2017).

According to the Powell-Wetherall plot, L_∞ values were noted as 7.47 to 7.52, 7.13 to 7.15 and 7.38 to 7.47 cm, while Z/K values varied from 0.812 to 1.125, 0.934 to 1.09 and 0.979 to 1.295 for the female, male and combined sexes of *D. devario* respectively (Figure 2). Azadi and Mamun (2009) observed that values of L_∞ and Z/K recorded as 10.338 and 3.310 cm for *A. mola* were relatively higher than the present fish species for their taxonomic variations.

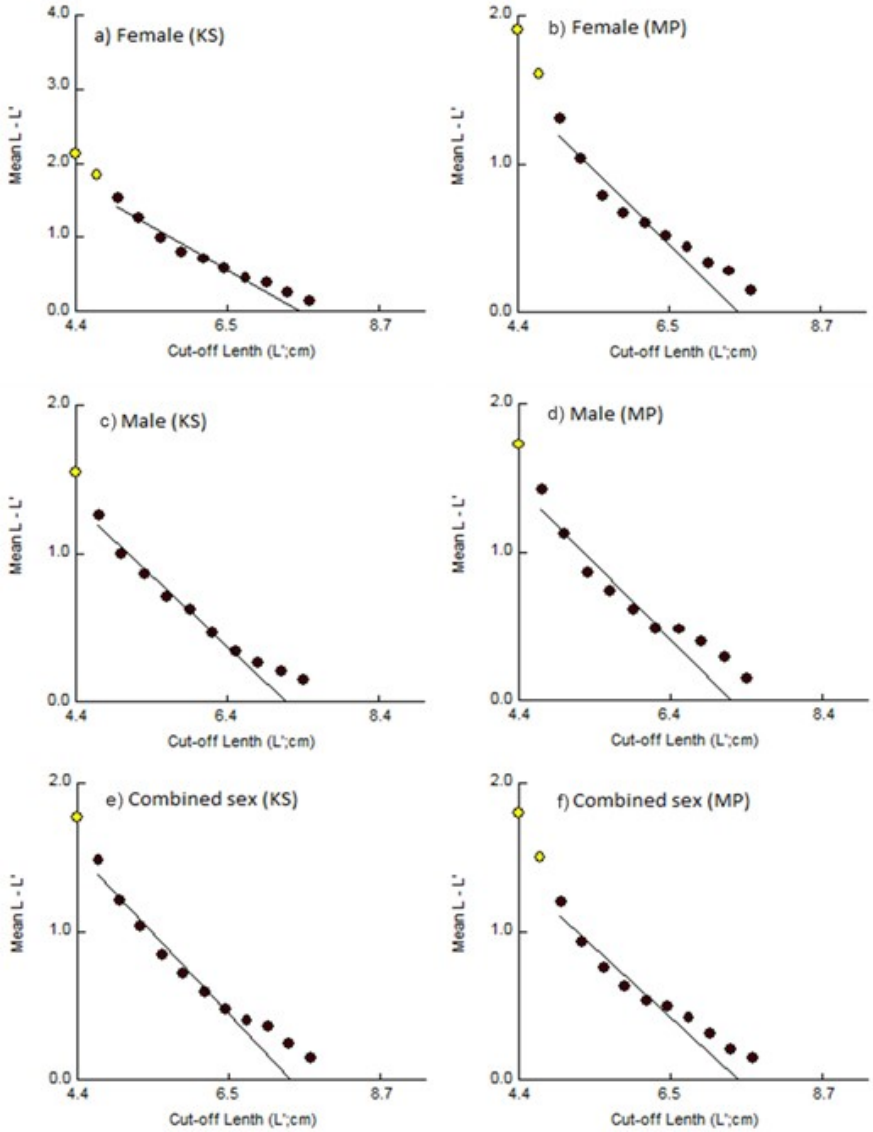

FIGURE 2 Length-based growth pattern of Powell-Wetherall plot for *Devario devario* at the Khansama (KS) and Mohanpur (MP) stations for female (a–b), male (c–d) and combined sexes (e–f) in the Atrai River, Dinajpur, Bangladesh.

3.4.2 Patterns of recruitment

The highest probable percentages of recruitment for *D. devario* were found in July (18.28% to 21.21%), followed by August (17.67% to 20.78%) for females. For males, the maximum values of this factor recorded in August (24.04%) to September (23.33%), followed by September (22.37%) to October (17.20%) for males, and in August (26.42%) to September (23.20%), followed by July (24.89%) to August (22.34%) for combined sexes (Figure 3). Therefore, the values signified that the peak recruitment period was from July to October, suggesting one major peak to recruit the young individuals of *D. devario* as a year-round phenomenon in their population. Divakar *et al.* (2017) found that the maximum recruitment percentage was observed in August (31.00%) for *Katsuwonus pelamis*, where the period remained between July and October. The annual recruitment pattern of *Sarotherodon melanotheron* found in the rainy season (April – July) and dry season (October – January) had maximum and minimum recruitment in June and February (Arizi *et al.* 2015), which is close to the present findings.

3.4.3 Fish mortality

For the *D. devario* population (at 28.61 – 29.01°C water temperature), natural mortality (M) was calculated between 2.26 and 3.93 year^{-1} for females, 1.94 and 5.98

year^{-1} for males and 3.93 and 6.14 year^{-1} for combined sexes (Figure 4). Fishing mortality (F) varied from –0.87 to –1.04 year^{-1}, –0.97 and 1.09 year^{-1} and –0.23 and –0.05 year^{-1}, whereas total mortality (Z) recorded from 1.22 and 3.06 year^{-1}, 0.97 and 7.07 year^{-1} and 6.09 and 3.70 year^{-1} for female, male and combined sexes respectively (Figure 4). This data suggested that females showed higher fish mortality (M, F or Z) than males, indicating females faced more predators, competition and fishing pressure in this river. Moreover, higher natural mortality of *D. devario* than fishing mortality also suggested that they faced more predatory pressure, pollution, disease or death in this habitat than fishing pressure, resulting in an unbalanced condition of this fish stock. Zakeyuddin *et al.* (2017) also reported that natural mortality (2.40 year^{-1}) was higher than fishing mortality (0.35 year^{-1}) of *D. regina*, also indicating the presence of some predators. The exploitation level (E) ranged from –0.28 and –0.85 for females, –1.00 and 0.15 for males and –0.06 and –0.01 for combined sexes, which appears to be lower than the expected value (E = 0.50), suggesting no overexploitation close to the value of *D. regina* (Zakeyuddin *et al.* 2017). This study will help with the sustainable exploitation of the study species.

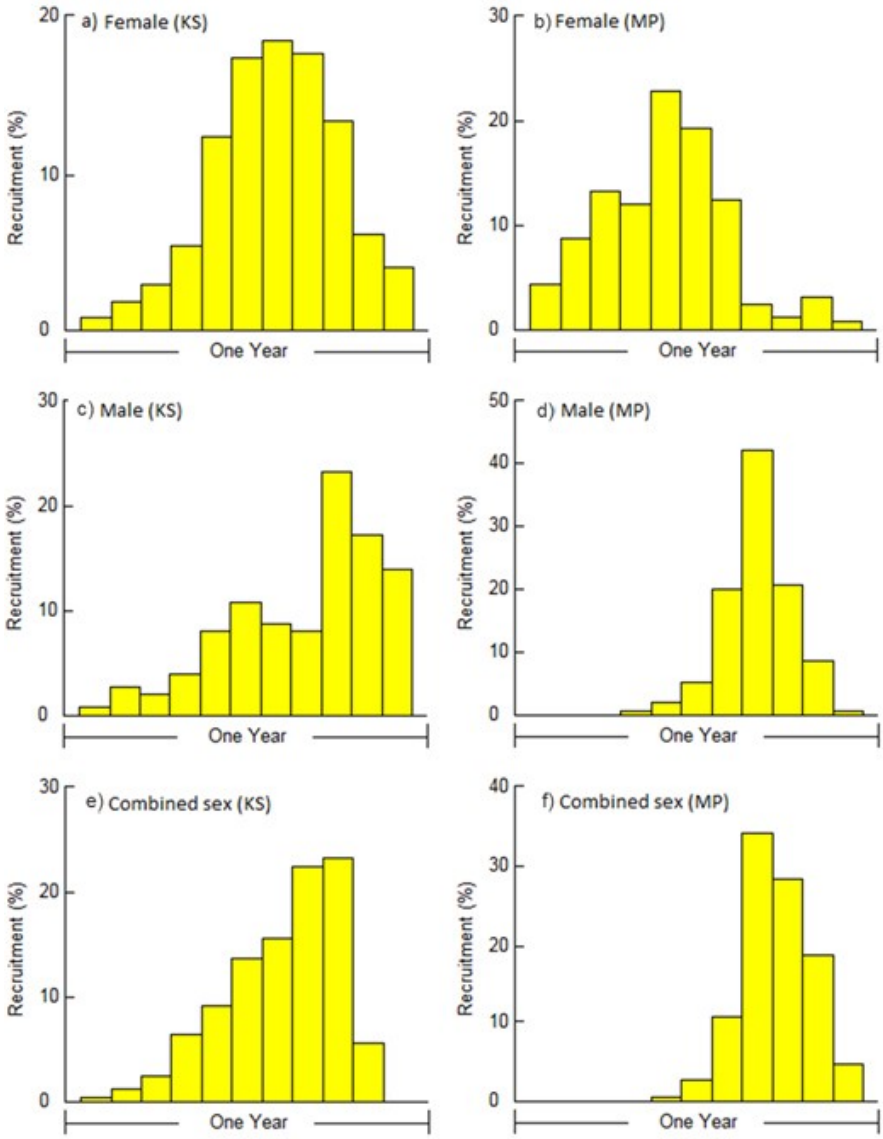

FIGURE 3 Length-based recruitment patterns for *Devario devario* at the Khansama (KS) and Mohanpur (MP) stations for female (a–b), male (c–d) and combined sexes (e–f) in the Atrai River, Dinajpur, Bangladesh.

3.4.4 Probability of capture

At first recruitment of *D. devario* from this river, length (cm) at first capture is based on the length-based frequency distribution calculated by the probability of capture (L_{50}). The lengths at which 25% (L_{25}), 50% (L_{50}) and 75% (L_{75}) fish specimens were retained using the fishing gear as 5.44 – 5.71, 5.74 – 6.10 and 6.04 – 6.42 cm for females; 5.27 – 5.45, 5.81 – 5.83 and 6.16 – 6.17 cm for males; and 5.29 – 5.72, 5.62 – 6.15 and 5.90 – 6.47 cm for combined sexes (Figure 5). Arizi *et al.* (2015) observed that the lengths at capture L_{25}, L_{50}, and L_{75} were 9.50, 10.13 and 10.50 for *Sarotherodon melanotheron* respec-

tively, which was higher than the present species might be due to different taxa. Thus, the probability of capture provides a realistic estimate of fish size in a fishing area, such as the Atrai River, aiding in sustainable capture by determining the minimum mesh size of fishing gear (Wehye *et al.* 2017).

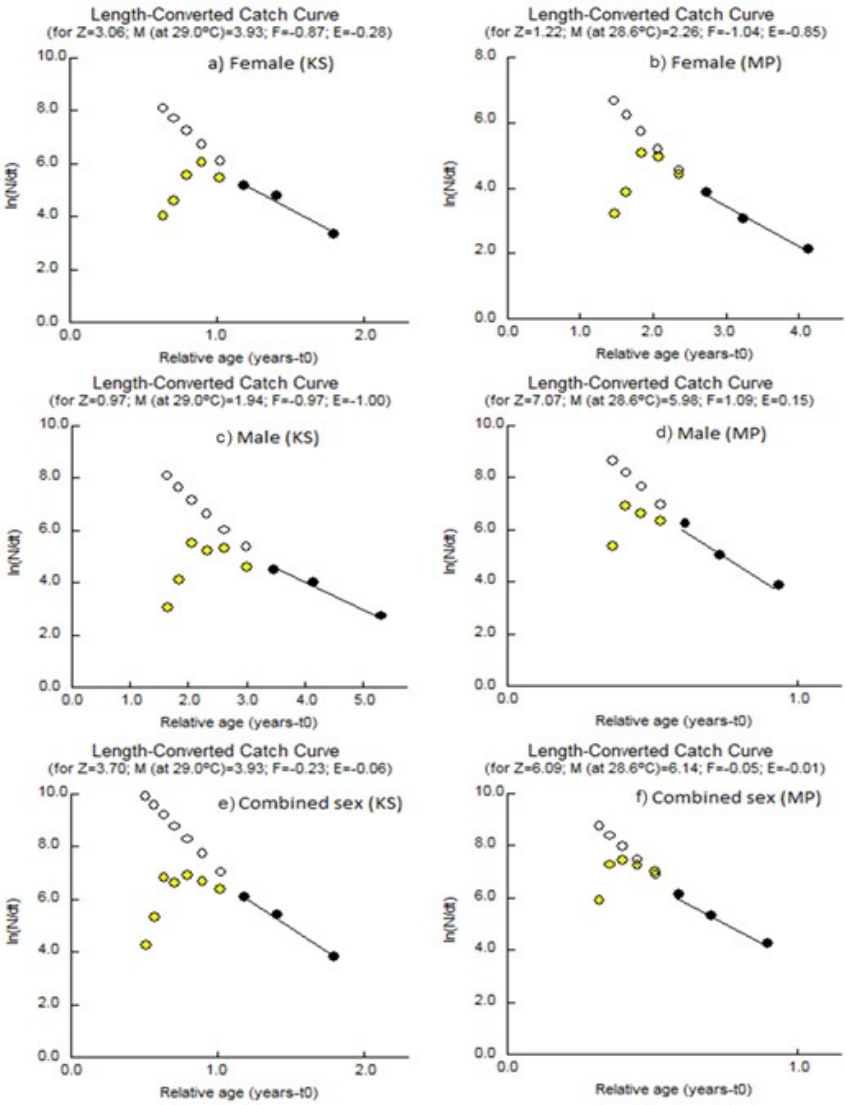

FIGURE 4 Estimation of mortality for *Devario devario* at the Khansama (KS) and Mohanpur (MP) stations for female (a–b), male (c–d) and combined sexes (e–f) in the Atrai River, Dinajpur, Bangladesh.

3.5.5 Reproductive biology

The gonad length (GL) of *D. devario* ranged from 0.14 ± 0.02 to 0.87 ± 0.03 cm, while the gonad weight (GW) recorded as 1.44 ± 0.11 to 1.98 ± 0.07 g peaked in April to May (Figure 6). Bithy *et al.* (2012) found that GL was 4.08 ± 0.53 to 4.45 ± 0.53 cm and GW as 4.72 ± 1.16 to 5.46 ± 0.84 g for *Puntius sophore*. Besides, the GSI of *D. devario* ranged from 32.75 ± 1.82 to 44.12 ± 273. Bithy *et al.* (2012) also found that the values of GSI of *P. sophore* varied from 17.53 to 52.14, with a peak value in July (52.14), suggesting that the variation in GIS of fish might be due to the degree of maturity of ova and spawning. The fecundity (F_e) of the present species was found to be 3253 ± 289 to 4831 ± 342 in the months of April to June, whereas the fecundity of *Chela fasciata* ranged from 2669 to 4437 (Divipala *et al.* 2013). The number of eggs in fish fluctuate due to ecological factors, of which temperature is considered the most likely indicator, as is the availability of food staff and water flow.

For *D. devario*, a cubic correlation was used to measure the relationship between fecundity (F_e) and TL. Whereas the values of "a" were found to be 14.81 to 55570, "b" was noted as -1.24 to 2.84 and "r^2" varied from 0.012 to 0.398, while these values were recorded as 194089, 4.457 and 0.702 for *A. mola* (Pal and Mahapatra 2016). Fecundity significantly correlated with TL (a = 0.0200, b = 2.893, and *r* = 0.864) for *A. mola* (Azadi and Mamun 2004). In a relationship between Fe and BW for the present species, values of "a" were 564.70 (May) to 3397.60 (June); "b" were 0.18 to 1.46; and "r^2" were 0.006 to 0.688, respectively, whereas 451.856, 1.657 and 0.754 for *A. mola* (Pal and Mahapatra 2016). According to Divipala *et al.* (2013), the values of "a", "b", and "r^2" for Fe and GL in this fish were recorded as 11020 to 2537.10,

-0.15 to 0.92 and 0.058 to 0.517 respectively, whereas for *Chela fasciata*, the values were 2365.92, 0.622 and 0.925. During the interrelation between F_e and GW in *D. devario*, the regression parameters "a", "b", and "r^2" were varied from 1378.50 (April) to 2435.90 (March); 0.47 to 1.93; and 0.048 to 0.536. In contrast, these values were also noted as 8241.381 (a), 1.016 (b), and 0.886 (r^2) for *A. mola* (Pal and Mahapatra 2016). Thus, the initial research data on *D. devario* will be useful for fishery management, stock prophecy, and reproduction to enhance their abundance in the Atrai River of Dinajpur, Bangladesh.

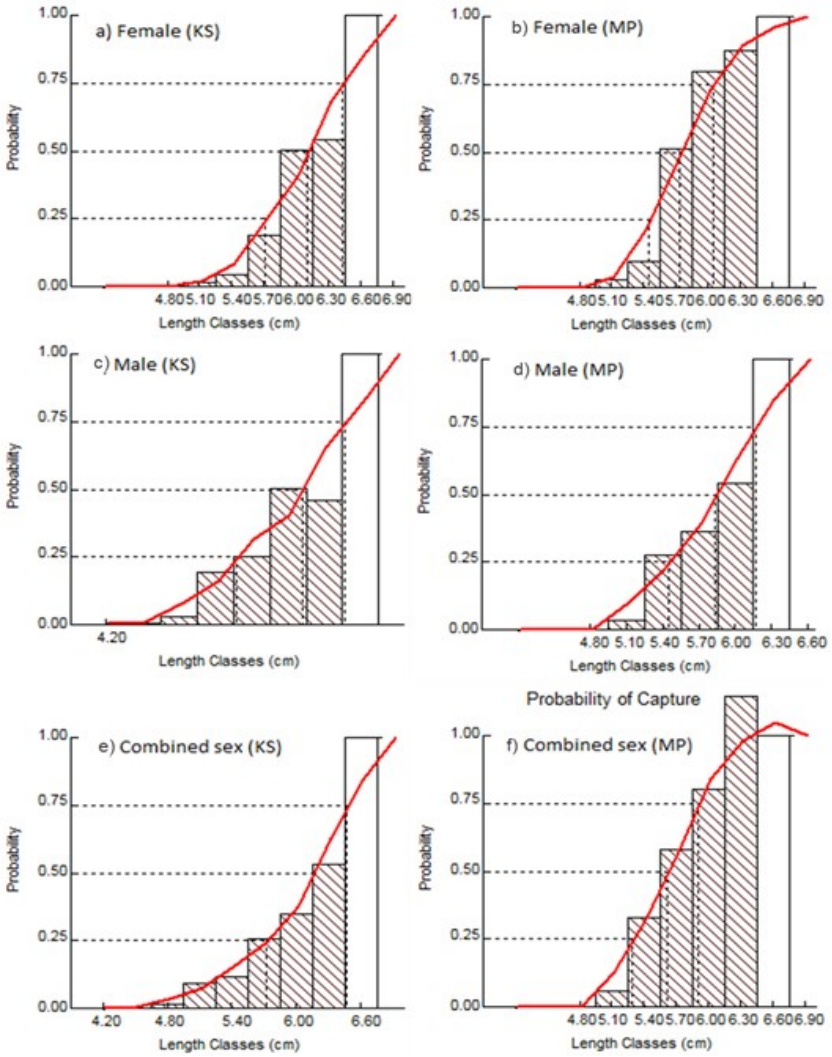

FIGURE 5 Probability of capture for *Devario devario* at the Khansama (KS) and Mohanpur (MP) stations for female (a–b), male (c–d) and combined sexes (e–f) in the Atrai River, Dinajpur, Bangladesh.

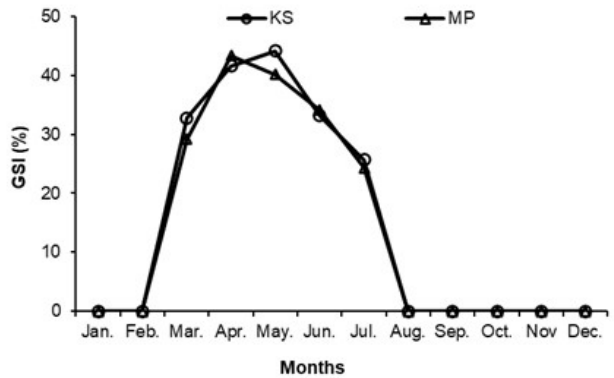

FIGURE 6 Monthly gonado-somatic index of gravid females of *Devario devario* at Khansama (KS) and Moohanpur (MP) in the Atrai River, Dinajpur, Bangladesh.

4 | CONCLUSIONS

Devario devario, a small indigenous species in Bangladesh, is a vital freshwater fish that fulfills nutritional requirements. A total of 1300 specimens were collected from the Atrai River in Dinajpur district. The species' body size ranged from 4.6 to 8.1 cm and 1.12 to 6.94 g. The study found strong relationships between TL vs. SL, FL vs. SL, FL vs. SL, HL vs. TL, HL vs. SL, and HL vs. FL among sexes. Growth population parameters showed growth rates of 0.78 to 1.8, 0.6 to 3.4, and 1.8 to 3.6 year^{-1} for female, male, and combined sexes, respectively. However, mortality rates were recorded for various sexes. The study aims to determine for effective and sustainable fishery management in the Atari River, considering condition factors and a reliable management and breeding tech-

nique in the future. This will help fishery managers, scientists, conservationists, and future researchers provide sustainable management strategies for conserving the stocks of this fish species.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

MMA: Conceptualization, Methodology, Data curation, Data analysis, Writing-original draft, preparation; HA: Data curation, Writing - review & editing; SSS: Data curation, Writing-review & editing; ATS: Data curation, Writing-review & editing; MRH: Data curation, Supervision; MRI: Conceptualization, Software, Data analysis, Writing-review & editing, Funding acquisition, Supervision. All authors have read and agreed to the published version of the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request to the corresponding author.

REFERENCES

Abowei JFN, Davies OA, Eli AA (2009) Study of length-weight relationship and condition factor of five fish species from Nkoro River, Niger Delta, Nigeria. Current Research Journal of Biological Science 1: 94–98.

Alex N, Justin DM, Cyrus R (2012) Length-weight relationship and condition factor of tilapia species grown in marine and freshwater ponds. Agriculture and Biology Journal of North America 3: 117–124.

Arizi EK, Aggrey-Fynn J, Obodai EA (2015) Growth, mortality and exploitation rates of *Sarotherodon melanotheron* in the Dominli Lagoon of Ghana. Momona Ethiopian Journal of Science 7: 258–274.

Azadi MA, Mamun A (2009) Population dynamics of the cyprinid fish, *Amblypharyngodon mola* (Hamilton) from the Kaptai Lake, Bangladesh. The Chittagong University Journal of Biological Science 4: 141–151.

Barnham C, Baxter A (1998) Condition factor 'K' for Salmonid fish. Fisheries Notes 1–3.

Bithy K, Miah MI, Haque MS, Hasan KR, Islam MF (2012) Estimation of the fecundity of Jat Puti, *Puntius sophore* (Hamilton). Journal of Environmental Science and Natural Resources 5: 295–300.

Chaklader MR, Siddik MAB, Nahar A (2015) Taxonomic diversity of paradise threadfin *Polynemus paradiseus* (Linnaeus 1758) inhabiting southern coastal rivers in Bangladesh. Sains Malaysiana 44: 1241–1248.

Divakar PH, Shirke SS, Kar AB (2017) Estimates of length-based population parameters of the Skipjack tuna, *Katsuwonus pelamis* (Linnaeus 1758) in the Andaman waters. Journal of Fisheries 5: 477–482.

Divipala I, Mercy TVA, Nair JR (2013) Reproductive biology of *Chela fasciata* Silas-an endemic ornamental barb of the Western Ghats of India. Indian Journal of Fisheries 60: 41–45.

Froese R (2006) Cube law, condition factor and weight-length relationships: history, meta- analysis and recommendations. Journal of Applied Ichthyology 22: 241–253.

Froese R, Thorson JT, Reyes RB Jr (2014) A Bayesian approach for estimating length-weight relationships in fishes. Journal of Applied Ichthyology 30: 78–85.

Fulton TW (1904) The rate of growth of fishes. Twenty-second Annual Report, Part III. Fisheries Board of Scotland, Edinburgh. pp. 141–241.

García CB, Duarte LO (2006) Length-based estimates of growth parameters and mortality rates of fish populations of the Caribbean Sea. Journal of Applied Ichthyology 22: 193–200.

Gayanilo Jr FC, Pauly D (1997) FAO-ICLARM Stock Assessment Tools (FiSAT) Reference Manual. FAO, Rome. 262 pp.

Ghorbani R, Hedayati A, Hashemi AR, Abolhasani MH, Haghi VA, Amini CM (2018) Population dynamics of *Carasobarbus luteus* in Shadegan International Wetland, Iran. Iranian Journal of Fisheries Sciences 17: 357–368.

Giannetto D, Franchi E, Pompei L, Lorenzoni M, Porcellotti S, Tancioni L (2012) Proposed empirical standard weight equation for brook chub *Squalius lucumonis*. North American Journal of Fisheries Management 32: 428–435.

Gislason H, Daan N, Rice JC, Pope JG (2010) Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries 11: 149–158.

Hanif MA, Siddik MAB, Chaklader MR (2015a) Fish diversity in the southern coastal waters of Bangladesh: present status, threats and conservation perspectives. Croatian Journal of Fisheries 73: 251–274.

Hanif MA, Siddik MAB, Chaklader MR, Mahmud S, Nahar A, Haque MS, Munilkumar S (2015b) Biodiversity and conservation of threatened freshwater fishes in Sandha River, Southwest Bangladesh. World Applied Sciences Journal 33: 1497–1510.

Islam MK, Das M (2006) Fecundity of gulsa *Mystus cavasius* (Hamilton) from the Bramaputra and Kongsa rivers. Journal of Bangladesh Agricultural University 4: 347–355.

Islam MR, Azom MG, Mamun M, Faridullah M (2017a) Length-weight relationship and condition factor of 13 fish species collected from the Atrai and Brahmaputra Rivers, Bangladesh. Journal of Biodiversity and Environmental Sciences 10: 123–133.

Islam MR, Mia MJ (2016) Length-weight and length-length relationships of five fish species in the Atrai River, Dinajpur, Bangladesh. Journal of Applied Ichthyology 32: 1371–1373.

Islam MR, Mia MJ, Sultana S (2019) Fish assemblage and structure with its hydrological parameters at Karatoya fish sanctuary, Panchagarh, Bangladesh. Iranian Journal of Fisheries Science 18: 140–162.

Islam MR, Mollah MFA (2012) Morphological observation and PG-induced breeding of *Glossogobius giuris* (Hamilton 1822). Journal of Science and Technology 11: 171–180.

Islam MR, Roy S, Mia MJ, Amin AKMR (2018) Length-length, length-weight relationships and condition factors for four freshwater fishes from the Atrai River, Dinajpur, Bangladesh. Journal of Applied Ichthyology 34: 200–202.

Islam, MR, Yeasmin M, Sadia S, Ali MS, Haque AR, Roy VC (2023) Small indigenous fish: a potential source of valuable nutrients in the context of Bangladesh. Hydrobiology 2: 212–234.

Kalita C, Choudhury H, Sarma D (2018) Length-weight relationships of three fish species from the lower Brahmaputra drainage in Assam, India. Journal of Applied Ichthyology 34: 1057–1058.

Kara A, Bayhan B (2008) Length-weight and length-length relationships of the bogue *Boops boops* (Linneaus, 1758) in Izmir Bay (Aegean Sea of Turkey). Belgian Journal of Zoology 138: 154–157.

Khan MA, Sabah (2013) Length-weight and length-length relationship for five fish species from Kashmir Valley. Journal of Applied Ichthyology 29: 283–284.

Koundal A, Dhanze R, Sharma I (2014) Length-weight relationship of five minor carps from Western Himalaya (H.P), India. Zoo's Print 29: 30–31.

Le Cren ED (1951) The length-weight relationships and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). Journal of Animal Ecology 20: 201–219.

Mekkawy IA, Hassan AA (2011) Some reproductive parameters of Synodontis schall (Bloch and Schneider, 1801) from the river Nile, Egypt. Journal of Fisheries and Aquatic Science 6: 456–471.

Memon KH, Liu Q, Kalhoro MA, Chang MS, Baochao L, Memon AM, Hyder S, Tabassum S (2016) Growth and mortality parameters of hairtail *Lepturacanthus savala* from Pakistan waters. Pakistan Journal of Zoology 48: 829–837.

Mia MJ, Naher J, Azom MG, Sabuz MSR, Islam MH, Islam MR (2019) Spatiotemporal variations in finfish assemblage and diversity indices in relation to ecological indicators of the Atrai River, Dinajpur, Bangladesh. Egyptian Journal of Aquatic Research 45: 175–182.

Moradinasab G, Daliri M, Ghorbani R, Paighambari SY, Davood R (2012) Length-weight and length-length relationships, relative condition factor and Fulton's condition factor of five cyprinid species in Anzali Wetland, Southwest of the Caspian Sea, Caspian. Journal of Environmental Science 10: 25–31.

Muchlisin ZA, Musman M, Azizah MNS (2010) Length-weight relationships and condition factors of two threatened fishes, *Rasbora tawarensis* and *Poropuntius tawarensis*, endemic to Lake Laut Tawar, Aceh Province, Indonesia. Journal of Applied Ichthyology 26: 949–953.

Munro JL, Pauly D (1983) A simple method for comparing the growth of fishes and invertebrates. ICLARM Fishbyte 1: 5–6.

Nadeem A, Kalhoro MA, Buzdar MA, Tariq S, Shafi M, Afzaal Z, Shah H, Saeed F, Haroon A, Ahmed I (2017) Growth, mortality and exploitation rate of *Sardinella longiceps* (Valenciennes, 1847) from Pakistan waters based on length frequency distribution data. Indian Journal of Geo Marine Science 46: 1693–1703.

Pal M, Mahapatra BK (2016) Fecundity and GSI of Mourala, *Amblypharyngodon mola* (Hamilton-Buchanan, 1822) from South Bengal district of West Bengal. International Journal of Fisheries and Aquatic Studies 4: 47–53.

Patiyal RS, Mir JI (2017) Length–weight relationships of 21 fish species from the upland Ganga River Basin tributaries of Central Indian Himalaya. Journal of Applied Ichthyology 33: 861–863.

Pauly D (1980) On the interrelationships between mortality, growth parameters, and mean environmental temperature in 175 fish stocks. Journal of the International Council for the Exploration of the Sea 39: 175–192.

Pauly D (1981) The relationships between gill surface area and growth performance in fish: a generalization of von Bertalanffy's theoryof growth. Meeresforschung 28:251–282.

Pauly D (1984) Fish population dynamics in tropical waters: a manual for use programmable calculators. ICLARM studies and reviews, Manila, Philippines. 325 pp.

Pauly D (1994). On the sex of fish and the gender of scientists: essays in fisheries science. Chapman and Hall, London. 250 pp.

Philips AE (2014) Comparison of some biological aspects between the two sexes of the European hake *Merluccius merluccius* from the Egyptian Mediterranean waters. Egyptian Journal of Aquatic Research 40: 309–315.

Rahman AKA (2005) Freshwater fishes of Bangladesh. Zoological Society of Bangladesh, Department of Zoology, University of Dhaka. Dhaka-1000. 263 pp.

Rypel AL, Richter TJ (2008) Empirical percentile standard weight equation for the blacktail redhorse. North American Journal of Fisheries Management 28: 1843–1846.

Siddik MAB, Hanif MA, Chaklader MR, Nahar A, Mahmud S (2015) Fishery biology of gangetic whiting *Sillag-*

inopsis panijus (Hamilton 1822) endemic to Ganges delta, Bangladesh. Egyptian Journal of Aquatic Research 41: 307–313.

Simon K, Mazlan A (2008) Length-weight and length-length relationships of archer and puffer fish species. The Open Fish Science Journal 1: 19–22.

Sokal RR, Rohlf FJ (1987) Introduction to Biostatistics. WH Freeman and Company, New York. 363 pp.

Sparre P, Venema SC (1998) Introduction to Tropical Fish Stock Assessment. Manual. FAO Fisheries Technical Paper 306, Review 1, FAO, Rome. 376 pp.

Sreelekshmi S, Benno PFG, Shijith BV (2017) Morphometric evaluation of an indigenous fish belong to genus *Devario* from three river systems of South Kerala. Journal of Biodiversity and Environmental Sciences 10: 106–114.

Stergiou KI (2000) Box 17. Using Fishbase to test life-history hypothesis. In: FishBase 2000: Concepts, Design and Data Sources (Ed. Froese R and Pauly D). Los Baños, Laguna, Philippines, ICLARM. 143 pp.

Tarkan AS, Gaygusuz Ö, Acipinar H, Gürsoy Ç, Özuluğ M (2006) Length-weight relationship of fishes from the Marmara region (NW-Turkey). Journal of Applied Ichthyology 22: 271–273.

Tracey SR, Lyle J, Haddon M (2007) Reproductive biology and per-recruit analyses of striped trumpeter (*Latris lineata*) from Tasmania, Australia: Implications for management. Fisheries Research 84: 358–368.

Victor RM, Sivakumar R, Mathialagan R (2014) Food and feeding habit and length-weight relationship of the Asian Striped Catfish *Mystus Vitattus* (Bloch, 1794) (Siluriformes: Bagridae) in the Vadavar River, Lower Anicut, Tamil Nadu. Indian Journal of Science 8: 55–64.

Wehye AS, Ofori-Danson PK, Lamptey AM (2017) Population dynamics of *Pseudotolithus senegalensis* and *Pseudotolithus typus* and their implications for management and conservation within the coastal waters of Liberia. Fisheries and Aquaculture Journal 8: 201.

Zakeyuddin MS, Isa MM, Rawi CSM, Sah ASRM, Ahmad AH (2017) Terrestrial insects as the main food for freshwater fish in Sungai Kerian Tributaries: an implication on habitat conservation. Sains Malaysiana 46: 833–843.

Zin T, Than AA, Naing TT (2011) Fecundity (Fe), gonadosomatic Index (GSI), hepatosomatic index (HSI), condition factor (K) and length weight relationship (LWR) in (*Channa orientalis*) Bloch and Schneider, 1801. University Research Journal 4: 47–62.

MR Islam https://orcid.org/0000-0003-4224-5156