# Size structure, weight-length relationship and condition factor of the endangered loach *Botia dario* from Bangladesh

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**Abstract**. *Botia dario* is one of the most important small indigenous species in Bangladesh, having both edible and ornamental values. Though once the fish was abundant in the natural water bodies of Bangladesh, now is categorized as “endangered” due to a considerable drop in population over past two decades. The study was conducted to explore the seasonal length frequency distribution, weight-length relationships and condition of *B. dario* using R programming environment. A total of 226 specimens were collected from August 2018 to July 2019 from open water bodies of northeastern Bangladesh. Four seasons, i.e., pre-monsoon (March-May), monsoon (June-August), post-monsoon (September-November), and winter (December-February) were considered to assess season-wise synthetic fitted model. The total length of *B. dario* was recorded minimum (4.6 cm) in post-monsoon and a maximum of 12.9 cm in winter. The empirical cumulative distribution function varied significantly between pre and post-monsoon as well as between monsoon and winter ($p < 0.001$). Gabelhouse length category of the double merged Table (quality- and quality+) showed a bold significant difference between two seasons ($p = 4.25e-09$). Coefficient of determination ($R^2$) values were recorded higher than 0.8 in all models suggesting that $\log_{10}(L_i)$ was responsible more than 80% to explain $\log_{10}(W_i)$. The interaction term of DVR (Dummy Variables) models fSeason x $\log_{10}(L_i)$ were insignificant in all combinations ($\gamma = 0$), indicating negligible difference in slopes between any two seasons. Significant differences were observed between the model intercepts ($\delta \neq 0$) of monsoon versus winter ($p < 0.001$) and post-monsoon versus winter ($p < 0.01$). In terms of weight-length residuals ($p = 0.0021$) and relative condition ($p = 0.01$), the conditions of *B. dario* in winter were found significantly lower than the year-round mean value. The season-specific synthetic models recorded in this study provide insight into the current status of the concerned species, which might attract policy makers and scientists to predict a prospective holistic model to save the species from extinction.

**Key Words**: dummy variables, empirical cumulative distribution function, Gabelhouse length category, relative condition, weight-length residuals.

**Introduction**. *Botia dario* (Hamilton, 1822), commonly known as queen loach or necktie loach, has an attractive view with golden yellow stripes on a black background. In Bangladesh, it is locally known as ‘Rani Mach’ or ‘Bou Mach’ and is principally regarded as table fish due to its excellent flesh quality (Hussain et al 2007) with remarkably higher amount of fat and minerals like calcium, phosphorus etc. contents (Hossain et al 1999). Due to its attractive color pattern, increasing demand for this fish originates among the aquarium fish aficionados (Gupta & Banerjee 2012), and Asian countries, notably India, has started to export it to different countries as ornamental fish (Gupta & Banerjee 2014). *B. dario* is one of the most important loaches widely distributed in South Asian countries, including Bangladesh, India, Nepal and Bhutan (Siddiqui 2007). The species is predominantly distributed in the greater Sylhet, Mymensingh, Dinajpur, Rangpur and Chittagong Hill Tracts regions in Bangladesh (Rahman & Ruma 2007; Ahmed et al 2013). Though, *B. dario* was previously abundant in all the open water bodies in Bangladesh, nowadays, availability and abundance of the species have been dropped substantially (Hossain et al 2015). IUCN (2015) has reported a sixty percent declination of the natural population of *B. dario* over the last 20 years due to different natural and anthropogenic causes like habitat loss and degradation, overexploitation of broods, juveniles and lack of proper management (Hossain et al 2015). Considering the overall population status, *B. dario* has been categorized as "endangered" in Bangladesh (IUCN 2015) indicating the species facing a very high risk of extinction in the wild in Bangladesh in the near future.

Therefore, proper conservation and management strategies need to be established urgently to protect this species. In Bangladesh, *B. dario* can be conserved by two measures: (i) complete banning of fishing during the spawning season to protect brooders and allow sufficient recruits (Hossain & Alam 2015) and by demarking size-specific catch to save at least juveniles (Gupta 2016) and/or (ii) bring it to aquaculture purview as substitutes of natural conservation to reduce fishing pressure on the natural population (Mojumder et al 2020). Unfortunately, information on its basic biology and population structure are scanty; only a few are available on spawning season (Mojumder et al 2020) conservational view (Hossain et al 2015; Rahman 2015), sex ratio and fecundity (Hussain et al 2007) but authors failed to found any data on length frequency distribution of this species. However, for improving the status of the species (from 'endangered' to 'least concern') in Bangladesh for a data poor species like *B. dario*, it is imperative to identify the occupancy (area of occurrence), seasonality (period specific abundance) and size structure (length frequency distribution) of the species.

From the managerial point of view, the following example states the inference of a particular species seasonal length frequency distribution. The Protection and Conservation of Fish Act, 1950 (Bengal Act XVIII of 1950), an Act to protect and conserve the fish in Bangladesh: under section 3(3) "Such rules may – (d) prescribe the seasons during which the killing or catching of fishes of any prescribed species shall be prohibited; (e) prescribe a minimum size below which no fish of any prescribed species, shall be killed or sold;" which indicate the importance of seasonal size structures of an individual species, as sizes also indicate the stages of maturity and recruitment status. From 1950 to 2021 in several amendments of different rules and regulations that enforce by the Act the season (stated as period) and the size of different species were clarified (Protection and Conservation of Fish Rules, 1985. rule 13. sub-rule (4). 14 February 2021 (Amendments)). Proper applications of those regulations required keen/valuable insights of size structures of that population (Neumann et al 2012). Therefore, the size structures are widely used as management and conservation tools. In addition, Neumann & Allen (2007) have described that size structure is a snapshot of particular fish population. Le Cren (1951) truly concluded the importance and justifications of weight-length relationships for modeling, assessing and managing fish stock. On the other hand, Jellyman et al (2013) clarified further the importance of synthetic analysis of weight-length relationships. This relationship helps deducing length to weight, biomass, condition and even in some extends the comparisons of life history parameters. The degree of well-being or relative healthiness of the fish is expressed by 'coefficient of condition' also known as condition. Variations in the condition primarily reflect the degree of nourishment and the state of sexual maturity (Victor et al 2014). The values of condition may also vary with fish age and in some species with sex (Froese 2006). Blackwell et al (2000) stated four matrices of condition viz. Fulton's condition factor, weight-length residuals, relative condition and relative weight; which are most commonly used by fisheries scientists. Calculation of each matrix is weight and length based.

Developing an appropriate management tool is largely dependable on the seasonal size structure data of *B. dario* in its natural habitats, which can provide valuable insights into the population's dynamism. Therefore, the study focused on the seasonal length frequency distribution, weight-length relationships and condition of *B. dario* together with season specific synthetic regression model.

## Material and Method

***Site selection, specimen collection and recording of length and weight***. Sunamganj 'Beel' (a lake-like wetlands with static waters might have channel to connect to river) situated at the northeastern Bangladesh was selected as the sample collection site. Hamilton (1822) recorded the first specimen from the northern rivers of Bangladesh and then after, all other taxonomists (Talwar & Jhingran 1991; Rahman 2005; Rahman & Ruma 2007) described this region as native to *B. dario*. The 'Beel' is connected by the Kushiyara River with its tributaries and distributaries and in the monsoon the entire area goes under water. Therefore, the above-mentioned 'Beel' had been considered as one of the few existing natural grounds of this endangered loach. A total of 226 *B. dario* specimens were captured with the help of professional fishers using seine net from 3 different points of the 'Beel' (Dakshin Sunamganj, 24°55'52.0"N 91°26'53.2"E; Balaganj, 24°39'13.1"N 91°49'35.8"E and Raznogor, 24°39'08.9"N 91°49'55.1"E) during August 2018 to July 2019. Immediately after capturing the specimens were preserved with 10% formalin solution and transported to the laboratory of Fisheries and Marine Science Department, Noakhali Science and Technology University. Total length (TL) and weight (W) of individual fish specimen was measured using a digital slide caliper having ±0.01 mm accuracy (EAGems-B00Z5KETD4) and a digital balance having ±0.01 g accuracy (EK600Dual), respectively following the instructions of Jennings et al (2012). Four seasons i.e., pre-monsoon (March-May), monsoon (June-August), post-monsoon (September-November) and winter (December-February), were planned to assess the data and to construct season-wise synthetic fitted model.

***Size structure***. As the observed maximum total length was 12.9 cm (Table 1), following the suggestion of Neumann et al (2012) 0.5 cm interval was applied for the bin of the histograms. A modified version of hist function from FSA was applied to construct histograms for multiple seasons. "Stepped" empirical cumulative distribution function (ECDF; Neumann & Allen 2007) plots were constructed for comparing seasonal length frequency distributions (FSA; Ogle 2016) and Kolmogorov-Smirnov (K-S) two-sample test (Neumann & Allen 2007) were applied to determine whether ECDFs are statistically different or not (Hollander et al 2014). The ks.test function of FSA and ks.boot function of Matching (Sekhon 2011) were followed for the K-S two sample test. Proportional Size Distribution (PSD) (Guy et al 2007; Neumann et al 2012) is the percentage of fish which are longer than a certain limit and preferred by the anglers. Gabelhouse (1984) proposed a length-categorization system to assess fish stock. In that categorization all fish in the "longer" categories also belong to all "shorter" categories. Apart from the game fish some nongame fishes are recently included. In that list "Ruffe" has similarities with *B. dario* in terms of length. Hence, analysis of Gabelhouse length categories for *B. dario* was performed considering the limit values of "Ruffe" (Ogle 2016; FSA). mapvalues function from plyr (Wickham 2011) is used to reduce the number of levels followed by droplevels function. Then the chisq.test of FSA for new table objects were performed to check the significant differences among the categories.

***Weight-length relationships***. Weight-length relationship was established using the following formula for proposing season wise synthetic fitted model (Ogle 2016):

$$W_i = \alpha L_i^{\beta} 10^{\epsilon_i} \quad \text{Eq. (1)}$$

where α and β are parameters and $10^{\epsilon_i}$ is the error term for the *i*th fish. As prescribed by Ogle (2016), the error term is multiplicative rather additive when the variability around the line increases with increasing the length of the fish. This was the case for *B. dario*.

Logarithmic transformation makes the Eq. (1) as follows:

$$\log_{10}(W_i) = \log_{10}(\alpha) + \beta \log_{10}(L_i) + \epsilon_i \qquad \text{Eq. (2)}$$

Because the back-transformed log scale is commonly biased, a correction factor for allometric equations (Sprugel 1983) was multiplied with the back-transformed values. The correction factor is:

$$e^{\frac{(log_e(base)s_{Y|X})^2}{2}}$$

where $s_{(Y|X)}$ is the residual standard error and $\log_e(base)$ is used for logarithmic adjustment. Anova and summary functions from car (Fox & Weisberg 2018) were used to test the significance levels (type II test, two-tail test) of the fitted linear regression model. The assumptions of the linearity, normality and constant variance were checked for each model by residPlot function from FSA. Only one model with extracted residuals and fitted values was plotted to avoid unnecessary repetitions.

The DVR models are the extensions of the equation Eq. (2) where $\log_{10}(L_i)$ is a covariate, as the dummy variable(s) and the interactions between the dummy variable(s) and covariate. Thus, the new model modified as (Ogle 2016):

$$log_{10}(W_i) = log_{10}(\alpha) + \beta log_{10}(L_i) + \delta fSeason1 + \gamma fSeason1 * log_{10}(L_i) + \epsilon_i \quad \text{Eq. (3)}$$

where:

$$fSeason1 = \begin{cases} 1, & \text{if captured in } Season1 \\ 0, & \text{if NOT captured in } Season1 \end{cases}$$

Factor and DVR model significance of interaction variables were determined by Anova from car. For testing the predictors of the fitted models considering all four seasons with all possible combinations (likewise: fSeason1(pre-monsoon=1, if captured in pre-monsoon and 0, if NOT captured in pre-monsoon and so on) were applied. The predicted mean W with appropriate confidence intervals for a value of TL plotted with lw CompPreds function from FSA to visualize whether weight-length relationship differ among seasons.

***Condition of the fish***. Assumption for Fulton's condition factor (K) is isometric growth (shape does not change with increasing length) which is limited to the fishes of similar length of a given population. As *B. dario* showed an increasing variability of weight with length that violate the assumption of isometric growth, that is why authors decided not to address this matrix.

Weight-length residuals (residual for the *i*th fish, $e_i$) from the Eq. (2) were used to measure fish condition (Sutton et al 2000; Pope & Kruse 2007):

$$e_i = \log_{10}(W_i) - \left(\log_{10}(\alpha) + b log_{10}(L_i)\right) \quad \text{Eq. (4)}$$

The relative condition factor ($Kn_i$ for the *i*th fish; Le Cren 1951) was calculated following this formula:

$$Kn_i = \frac{W_i}{\widehat{W_i}} \quad \text{Eq. (5)}$$

where $\widehat{W}_i$ is the synthetic mean weight calculated from the observed fish length for the sampled population (Blackwell et al 2000). $W_i$ is the observed fish weight for ith fish.

The weight-length residuals and relative condition show similarities with perfect correlation (r = 1) except the mean value 0 and 1, respectively. The negative value in weight-length residual and less than 1 in relative condition suggested the same: below the average condition of that population mean. The function stat_compare_means from ggpubr (Kassambara 2020) with ggplot2 (Wickham 2016) were used to perform method ="anova" argument to detect global p-value and then method ="t.test", ref.group =".all." arguments for pairwise comparison between seasons and year round. The relative weight matrix is computed by the coefficients of the accepted standard weight equation. "Ruffee" standard coefficients have unacceptable dissimilarities with the calculated coefficients of *B. dario*, which disqualify this matrix from applying for condition.

***Statistical analyses***. Raw data were entered to conventional spreadsheet (MS Excel, 2016) and saved as .csv file extension. The CSV file act as data.frame for further data analyses using the R environment (R Core Team 2020). Descriptive statistics were computed through psych (Revelle 2020) package after data mutation using dplyr (Wickham et al 2021). FSA (Ogle et al 2021), Plotrix (Lemon 2006) and graphics (Core R) were used to plot and to modify figures for graphical outputs.

**Results**

***Length-weight of the collected B. dario***. Major part (48%) of the total collected samples were captured during the monsoon (Table 1). Total length (TL) and weight (W) of *B. dario* ranged from 4.6 to 12.9 cm and from 1.22 to 39.24 g, respectively. Mean TL and W were highest (8.72 cm and 10.14 g) in samples collected in pre-monsoon and lowest (7.35 cm and 5.94 g) in monsoon (Table 1).

Table 1

Descriptive statistics of total length and weight of wild *B. dario* captured from the northeastern Bangladesh

| *Parameters* | *Seasons* | *n* | *% (n)* | *Mean* | *SD* | *Median* | *Min.* | *Max.* | *Skew* | *Kurtosis* | *SE* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total length (cm) | PM | 43 | 19 | 8.72 | 1.46 | 8.30 | 6.50 | 12.10 | 0.74 | -0.48 | 0.22 |
| | M | 108 | 48 | 7.35 | 0.79 | 7.30 | 5.10 | 9.10 | -0.10 | 0.05 | 0.08 |
| | PoM | 35 | 15 | 7.63 | 1.18 | 7.80 | 4.60 | 9.50 | -0.71 | 0.05 | 0.20 |
| | Wi | 40 | 18 | 8.60 | 1.46 | 8.40 | 6.40 | 12.90 | 0.97 | 0.65 | 0.23 |
| | Total | 226 | 100 | 7.88 | 1.28 | 7.70 | 4.60 | 12.90 | 0.98 | 1.97 | 0.09 |
| Weight (g) | PM | 43 | 19 | 10.14 | 6.18 | 7.69 | 3.74 | 26.60 | 1.19 | 0.35 | 0.94 |
| | M | 108 | 48 | 5.94 | 2.18 | 5.48 | 1.87 | 12.43 | 0.66 | 0.15 | 0.21 |
| | PoM | 35 | 15 | 6.87 | 3.24 | 6.58 | 1.22 | 13.90 | 0.28 | -0.61 | 0.55 |
| | Wi | 40 | 18 | 8.98 | 6.37 | 7.70 | 2.32 | 39.24 | 2.85 | 10.43 | 1.01 |
| | Total | 226 | 100 | 7.42 | 4.58 | 6.41 | 1.22 | 39.24 | 2.81 | 12.36 | 0.30 |

(n - number of samples; % (n) - percentage of total (integer); SD - standard deviation; Min. - minimum; Max. - maximum; SE - standard error of mean; PM - pre-monsoon; M - monsoon; PoM - post-monsoon; Wi - winter).

***Size structure***. Length frequency distribution of *B. dario* population showed multi-modal and skewed pattern in all seasons except monsoon (Figure 1, values of skewness and kurtosis in Table 1). Winter and pre-monsoon showed a right skewed pattern while post-monsoon has left. *B. dario* were found nearly in same ranges in pre-monsoon and in winter while the specimens sampled in the rest two seasons were below TL 7.5 and 8 cm (Figure 2). Kolmogorov-Smirnov two sample tests noticed significant differences ($p < 0.001$) in ECDFs between pre-monsoon and monsoon and between monsoon and winter (Table 2).

Table 2

Season specific empirical cumulative distribution function (ECDF) for *B. dario* captured in August 2018 to July 2019 from Sunamganj 'Beel'

| *Season* | *p-value* | *Pre-monsoon* | *Monsoon* | *Post-monsoon* |
|---|---|---|---|---|
| Monsoon | Test | 1.87e-05 | | |
| | Adjusted | 1.12e-04 | | |
| | Bootstrapped (n = 5000) | 0.00e+00 | | |
| Post-monsoon | Test | 6.65e-02 | 1.21e-01 | |
| | Adjusted | 2.66e-01 | 2.66e-01 | |
| | Bootstrapped (n = 5000) | 3.74e-02 | 6.98e-02 | |
| Winter | Test | 9.90e-01 | 1.87e-05 | 8.79e-02 |
| | Adjusted | 9.90e-01 | 1.12e-04 | 2.66e-01 |
| | Bootstrapped (n = 5000) | 9.20e-01 | 0.00e+00 | 5.50e-02 |

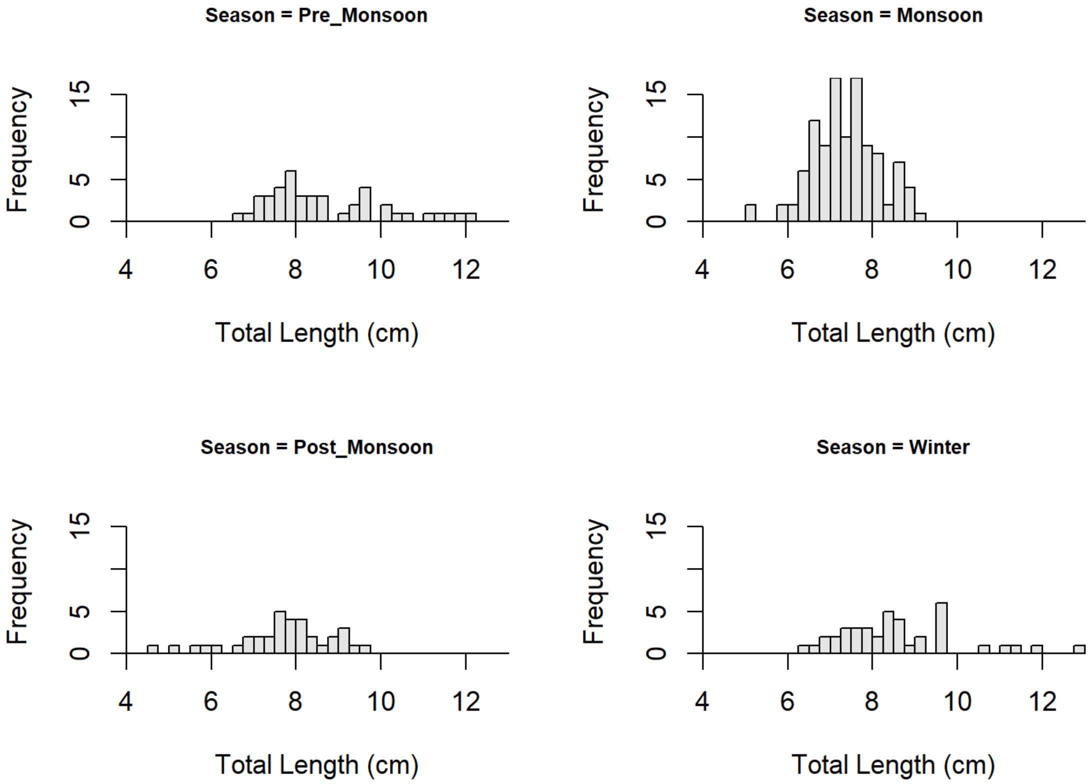


Figure 1. Seasonal length frequency histograms for *B. dario* sampled from Sunamganj Beel in August 2018 to July 2019.

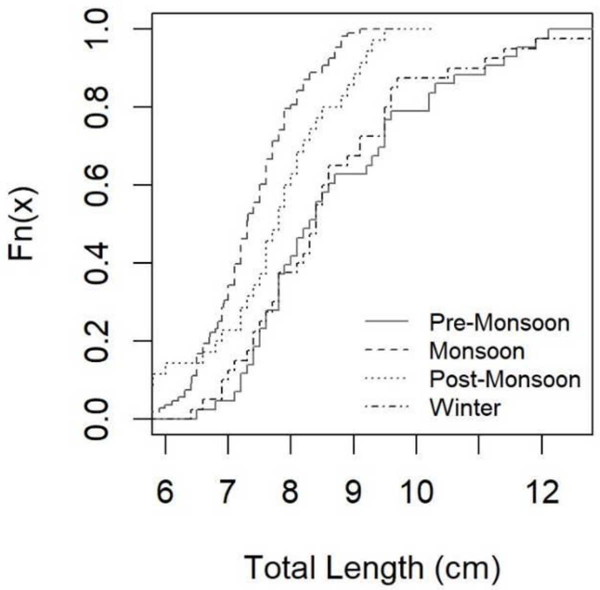


Figure 2. Season specific empirical cumulative distribution function (ECDF) for *B. dario* captured in August 2018 to July 2019 from Sunamganj Beel.

Gabelhouse length category year-round RCS (reverse cumulative sum) values suggested that the quality individuals showed around 15%, on the other hand, the stock represented about 98% (Table 3). Here, only post-monsoon appeared similar with the year-round proportion. However, winter and pre-monsoon exhibited proportional pattern similarities whereas, monsoon represented poor proportion of quality individuals than other seasons. The chi-square test of the double merged table (quality- and quality+) showed strong significant difference at least between two seasons (p = 4.25e-09).

Table 3

Gabelhouse length category (GLC) of *B. dario* by season. Reverse cumulative sum (RCS) shown only for entire year. Proportion (rounded) shown once by season. Only frequencies were used for merging between categories. GLC memorable (14 cm) and trophy (17.5 cm) were omitted from the column as there were no individual belong that category

| *Season* | *Parameter* | *Sub-stock* | *Stock* | *Quality* | *Preferred* | *Total* |
|---|---|---|---|---|---|---|
| | Ruffe (TL) (GLC) | 0 | 5.5 | 9 | 12 | |
| Year-round | Frequency | 4 | 187 | 33 | 2 | 226 |
| | Proportion | 1.77 | 82.74 | 14.6 | 0.88 | 99.99 |
| | RCS | 100 | 98.23 | 15.49 | 0.88 | |
| | GLC | sub-stock | stock | quality | preferred | |
| Pre-monsoon | Frequency | 0 | 27 | 15 | 1 | 43 |
| Monsoon | Frequency | 2 | 105 | 1 | 0 | 108 |
| Post-monsoon | Frequency | 2 | 28 | 5 | 0 | 35 |
| Winter | Frequency | 0 | 27 | 12 | 1 | 40 |
| | GLC | sub-stock | stock | quality | preferred | |
| Pre-monsoon | Proportion | 0 | 63 | 35 | 2 | 100 |
| Monsoon | Proportion | 2 | 97 | 1 | 0 | 100 |
| Post-monsoon | Proportion | 6 | 80 | 14 | 0 | 100 |
| Winter | Proportion | 0 | 68 | 30 | 2 | 100 |
| | GLC | sub-stock | stock | quality+ | | |
| Pre-monsoon | Frequency | 0 | 27 | 16 | | 43 |
| Monsoon | Frequency | 2 | 105 | 1 | | 108 |
| Post-monsoon | Frequency | 2 | 28 | 5 | | 35 |
| Winter | Frequency | 0 | 27 | 13 | | 40 |
| | GLC | | quality- | quality+ | | |
| Pre-monsoon | Frequency | | 27 | 16 | | 43 |
| Monsoon | Frequency | | 107 | 1 | | 108 |
| Post-monsoon | Frequency | | 30 | 5 | | 35 |
| Winter | Frequency | | 27 | 13 | | 40 |

***Weight-length relationships***. In all synthetic regression model including the year-round (Figure not shown) had big F-values with very small p-value (Pr(>F)), signifying the model with both an intercept and $\log_{10}(L_i)$ described more clearly of the variability in $\log_{10}(W_i)$ than a model with just an intercept (Table 4, Figure 3). Thus, $\log_{10}(L_i)$ significantly interpret $\log_{10}(W_i)$. The results corresponding t-test statistics and p-values (Pr(>|t|), the two-tailed test) recorded high significant differences between the slope of the linear regression model and the hypothesized value zero. The p-value in the Pr(>|t|) $\log_{10}(L_i)$ coefficient) row found very small which indicated that the slope was significantly dissimilar than zero and there was a significant relationship between $\log_{10}(W_i)$ and $\log_{10}(L_i)$. These significant relationships were evident in all models in all seasons and year-round as well. Coefficient of determination values were more than 0.8 in all synthetic model suggests that $\log_{10}(L_i)$ was responsible for more than 80% to explain $\log_{10}(W_i)$. The extracted residuals and fitted values from all regression models were plotted and conformed that those linear regression did not violate the assumptions of the linearity, normality, and constant variance (Figure 4, plot for pre-monsoon model is shown). Although, there were two outliers present in the residuals and fitted values of monsoon model but the plots ratify those outliers had no effect on altering the assumptions. Moreover, performing the test again after removing two outliers, no detectable change in p-value was observed.

Table 4

Estimated parameters of the synthetic linear regression model (Eq. (2))

| *Parameter* | *Pre-monsoon* | *Monsoon* | *Post-monsoon* | *Winter* | *Year round* |
|---|---|---|---|---|---|
| α (intercept coefficient) | -2.042851 | -1.954283 | -2.085073 | -2.024993 | -1.885511 |
| LCI (2.5 %) | -2.398716 | -2.210846 | -2.397542 | -2.451792 | -2.028474 |
| UCI (97.5 %) | -1.686986 | -1.69772 | -1.772603 | -1.598194 | -1.742547 |
| β ($log_{10}(L_i)$ coefficient) | 3.189359 | 3.123321 | 3.263568 | 3.131129 | 3.026433 |
| LCI (2.5 %) | 2.809709 | 2.826792 | 2.908516 | 2.672767 | 2.866427 |
| UCI (97.5 %) | 3.569009 | 3.419851 | 3.61862 | 3.58949 | 3.18644 |
| $e^{\frac{(log_e(base)s_{Y\|X})^2}{2}}$ (cf) | 1.019399 | 1.014419 | 1.015078 | 1.026318 | 1.018484 |
| F value (df) | 287.84(1,41) | 436.08(1,106) | 349.72(1,33) | 191.24(1,38) | 1389.3(1,224) |
| Pr (>F) | < 2.2e-16*** | < 2.2e-16*** | < 2.2e-16*** | < 2.2e-16*** | < 2.2e-16*** |
| t value (intercept coefficient) | -11.59 | -15.1 | -13.58 | -9.605 | -25.99 |
| Pr (>\|t\|) (intercept coefficient) | 1.61e-14*** | < 2e-16*** | 4.64e-15*** | 1.03e-11*** | < 2e-16*** |
| t value ($log_{10}(L_i)$ coefficient) | 16.97 | 20.88 | 18.7 | 13.829 | 37.27 |
| Pr (>\|t\|) ($log_{10}(L_i)$ coefficient) | < 2e-16*** | < 2e-16*** | < 2e-16*** | < 2e-16*** | < 2e-16*** |
| Residual standard error (df) | 0.08513(41) | 0.07349 (106) | 0.07514 (33) | 0.09899 (38) | 0.08312 (224) |
| Multiple R-squared | 0.8753 | 0.8045 | 0.9138 | 0.8342 | 0.8612 |
| Adjusted R-squared | 0.8723 | 0.8026 | 0.9112 | 0.8299 | 0.8605 |

LCI = lower confidence interval; UCI = upper confidence interval; df = degrees of freedom; cf = correction factor *** indicate significance differences at p < 0.001.

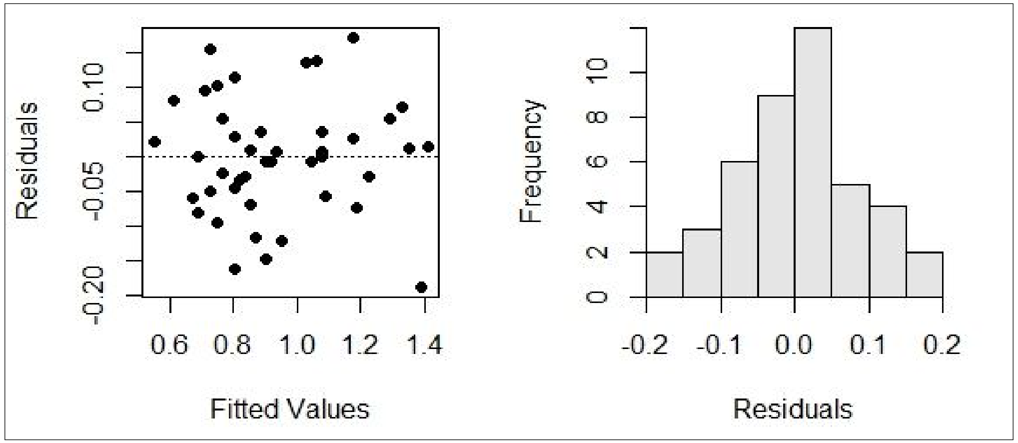


Figure 4. Residual plot (Left) and histogram of residuals (Right) from the regression model to the log-transformed weights and lengths of *B. dario* of pre-monsoon.

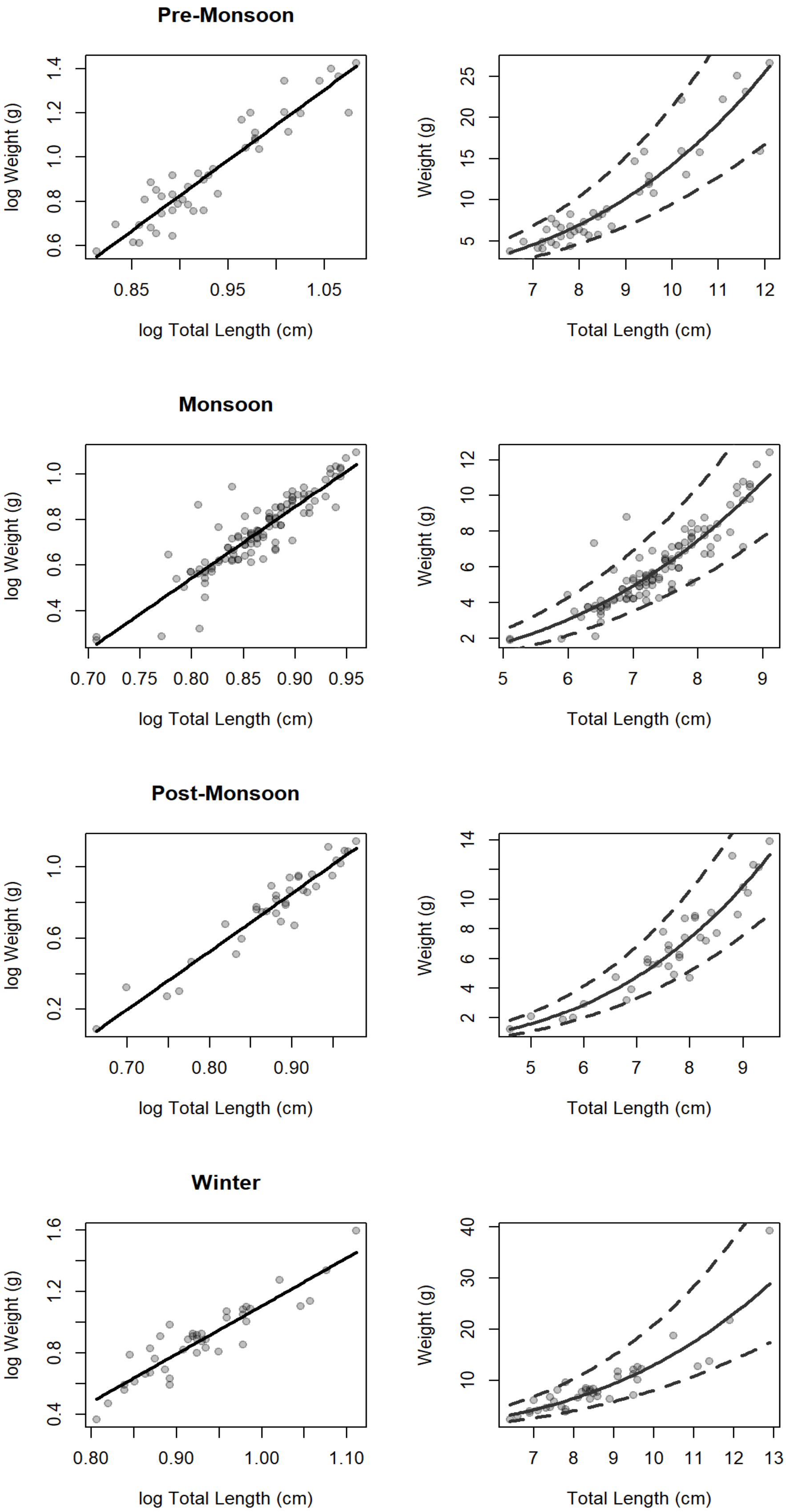


Figure 3. The $\log_{10}$ - $\log_{10}$ transformed *B. dario* weight-length relationships with the best-fit line overlaid (Left) and weight-length relationships with the best-fit synthetic model (solid line) and 95% confidence interval (dashed lines) superimposed.

The interaction term, *f*Season1 * $\log_{10}(L_i)$ among the parameters in Eq. (3) were insignificant in each and every combination indicating γ = 0, then there was no significant difference in slopes between any of the two capture seasons DVR models (Table 5, Figure 5). In addition, both the *f*Season1 and *f*Season1 * $\log_{10}(L_i)$ variables were found insignificant suggesting neither the intercepts nor the slopes vary significantly. Thus, any of the lines (model) among four combinations might be used for seasonal combinations. However, significant differences were found between the model intercepts (δ ≠ 0) of monsoon versus winter ($p < 0.001$) and post-monsoon versus winter ($p < 0.01$). In the model intercepts, both monsoon and post-monsoon differed significantly with winter. The synthetic weights of each quartile plotted in the Figure 6 also strengthened the aforementioned result and the relationship was more prominent in the 75$^{th}$ percentile.

Table 5

Estimated p-value matrices between DVR models for Eq. (3) (*** for p<0.001 and ** for p < 0.01 level of significance)

| *Season* | *p-value* | *Pre-monsoon* | *Monsoon* | *Post-monsoon* |
|---|---|---|---|---|
| Monsoon | *f*Season | 0.07369 | | |
| | $\log_{10}(L_i)$:*f*Season | 0.77535 | | |
| Post-monsoon | *f*Season | 0.2139 | 0.5533 | |
| | $\log_{10}(L_i)$:*f*Season | 0.7753 | 0.5398 | |
| Winter | *f*Season | 0.07607 | 0.0002542 *** | 0.008172 ** |
| | $\log_{10}(L_i)$:*f*Season | 0.84281 | 0.9749281 | 0.648343 |

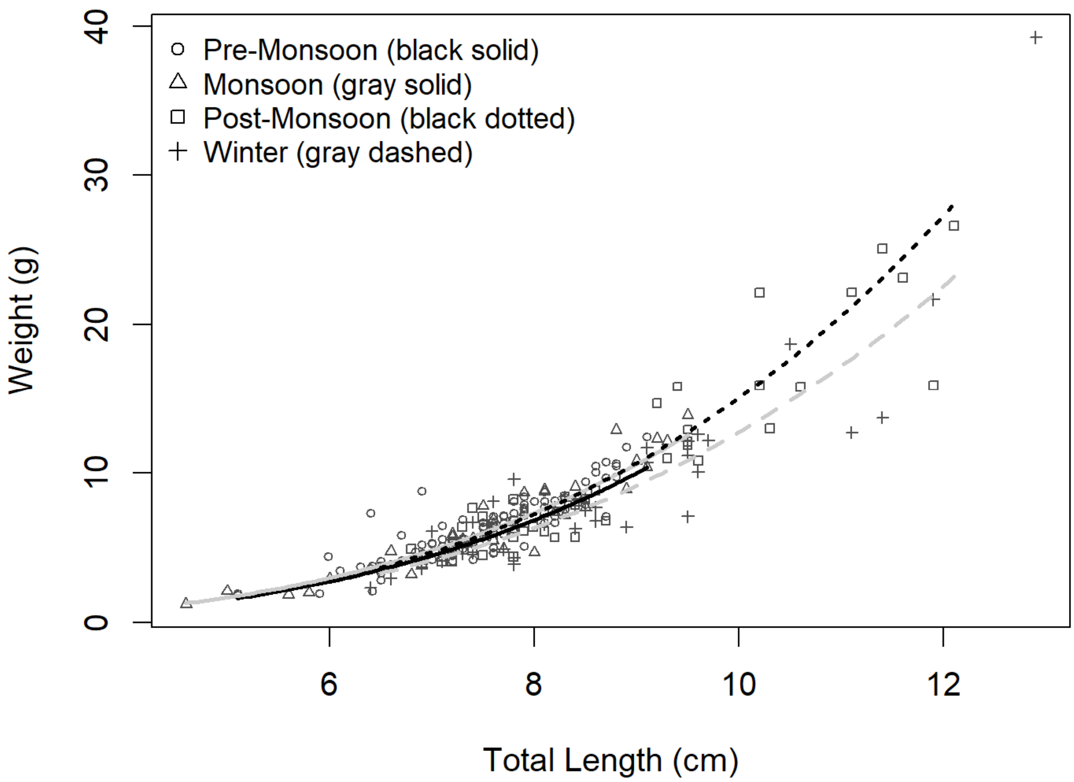


Figure 5. Relationships of weight-length synthetic model fits of four seasons for *B. dario* captured in August 2018 to July 2019 from Sunamganj Beel. Black dotted line (post-monsoon) overlapped gray solid line (monsoon) just after 6 cm to 9 cm more and extends further.

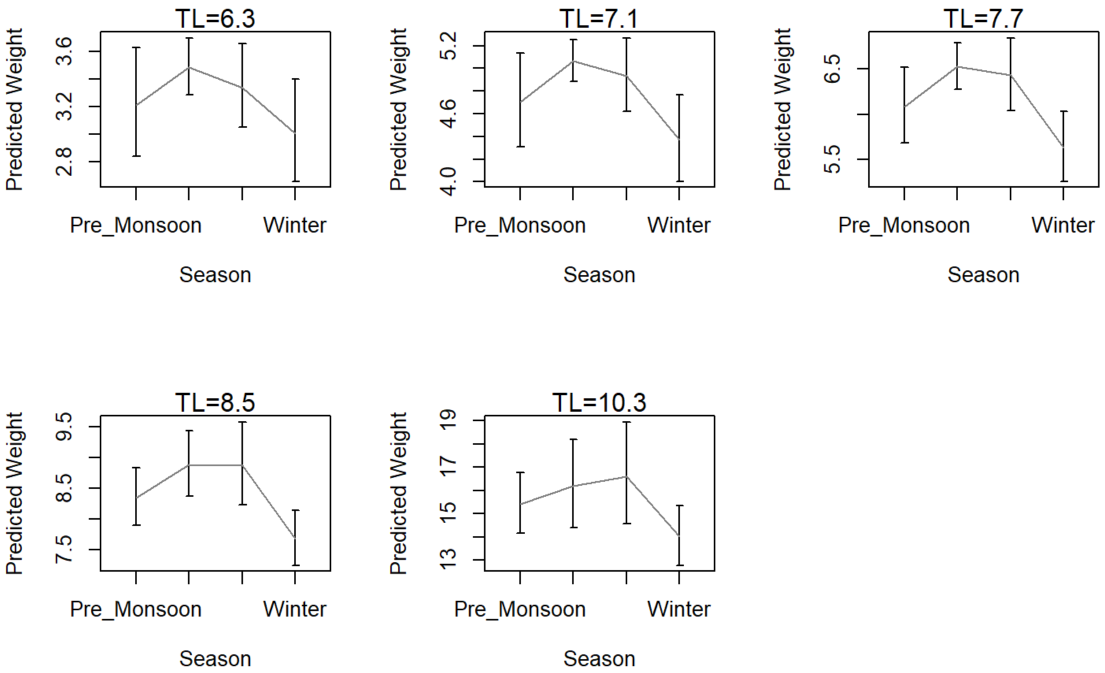


Figure 6. Synthetic weights (g) for *B. dario* with 95% confidence intervals, at the 5th, 25th, 50th, 75th, and 95th percentiles of total lengths (TL, cm) captured in. Scales differ in Y-axis as TL progress through the quartiles.

***Condition of B. dario***. Condition of *B. dario* varied with season and was significantly lower in winter (p = 0.0021) than the year-round mean (Figure 7). Similar results were observed for the other matrix (relative condition factor) of condition (p = 0.01) (Figure 8).

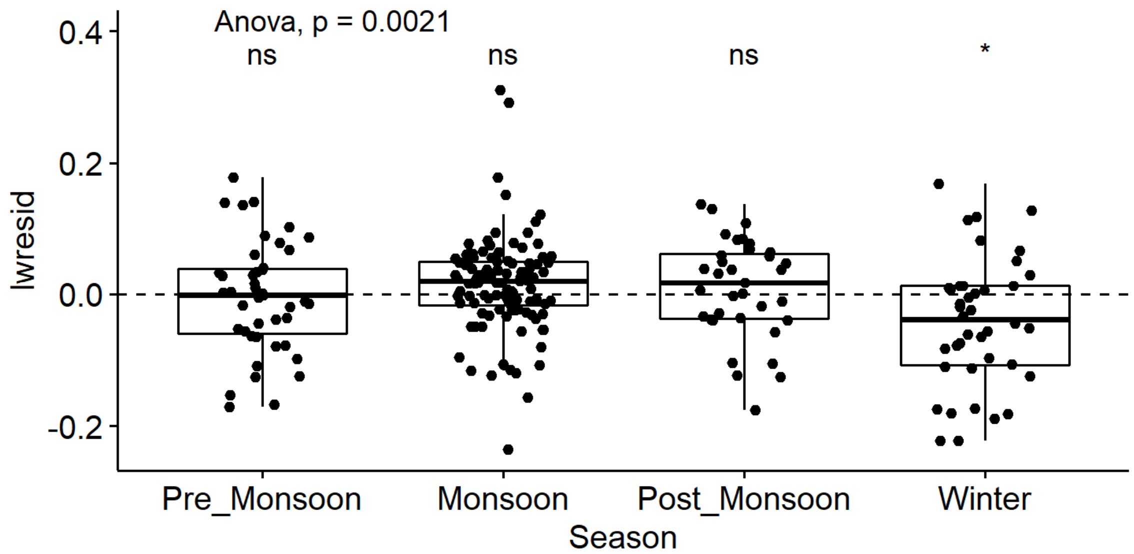


Figure 7. Comparison of Weight-length residuals (lwresid) with year-round sample mean (*denotes significant difference (here p = 0.0021) and ns = not significant).

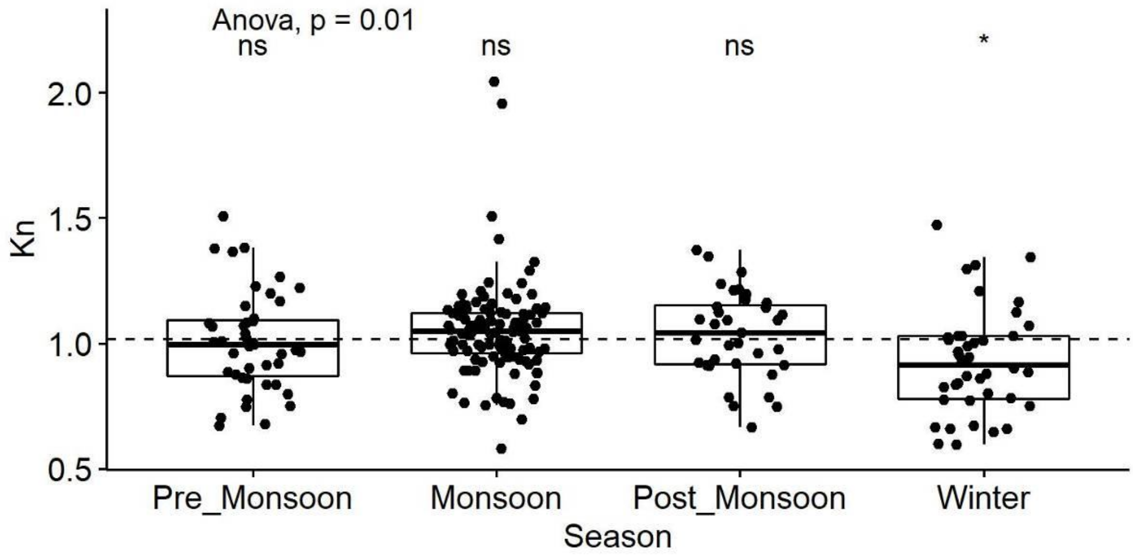


Figure 8. Comparison of relative condition factor (Kn) with year-round sample mean (*denotes significant difference (here p = 0.01) and ns = not significant).

**Discussion**. *B. dario* is a very popular food fish in Bangladeshi cuisine. Abundance and availability of the species showed a declining trend over the last decades (hence being considered as endangered) and unfortunately, till now no conservation action has been taken specific to save this valuable species in the natural habitats of Bangladesh. Again, there are scanty of information available on the population structure of the species and authors failed to get year-round information on the size structure of *B. dario*.

Over several decades the spatiotemporal models are based on the seasonal length frequency data which is very crucial to develop a model. Hamilton (1822) recorded the first specimen of this species and mentioned, "The *Dario* (Dari) is found in the northern rivers of Bengal, and grows to two or three inches in length." From the findings of the present study, it can be inferred that he (Hamilton) collected his specimen during monsoon or post-monsoon as the mean and median was found nearest to his record (Table 1). Apart from the first record, Rahman (1989) found the highest length of 15.1 cm while Hossain et al (2017) reported a range from 5.59 to 12.87 cm which are comparable to the size structure of this study (4.60-12.90 cm). Again, the weight range of *B. dario* found in present research (1.22-39.24 g) had some deviation with the range (3.4-27.87 g) reported by Hossain et al (2017); this might be associated with habitat condition and availability of appropriate foods. Sampling sites of the present work was 'Beel', which was comparatively much more productive than the river 'Ganges' from where Hossain et al (2017) collected samples. Besides, measuring lengths are usually very accurate, while measuring weight can differ noticeably; exclusively those taken in the field (Gutreuter & Krzoska 1994). Total length of *B. dario* recorded from Kishorganj and Pabna district of Bangladesh were 5.8-13.9 cm and 5.5-10.5 cm, respectively; and the same from India (Assam) were 5.2-12.3 cm (Santos 2014). The records from Kishorganj and Assam were similar to total length recorded in the present study during pre-monsoon and winter, while the records from 'Pabna' were close to monsoon and post-monsoon.

From the length-frequency histograms (Figure 1) and descriptive statistics (Table 1) it can be inferred that monsoon is the spawning season of *B. dario* as because, the season demonstrated uni-modal histogram having highest percentage of total capture with the lowest standard deviation. Similarly, the winter and pre-monsoon could be treated as the seasons for brood nourishment. The assumption has also been supported by the findings of Mojumder et al (2020) who reported comparatively higher gonadosomatic index values of *B. dario* from April to June. The possible outliers detected from the winter season should be protected to reduce recruitment overfishing. These consequences were found prominent through the ECDFs' strong significant differences (Figure 2, Table 2).

Although the authors chose the "Ruffe" standard of GLC for *B. dario*, some arguments might arise specifically for the maximum total length variation ("Ruffe" has 20.5 cm while *B. dario* has only 12.9 cm). This might lead to form a bias result to data analysis. But still that was the closest value to select "Ruffe" as standard. Apart from the analysis bias, this idea might help future analyst to make a flexible tool for adjusting the minimum and maximum length to create the species-specific standard for the GLC. Extensive investigations have been made on the length-weight relationship of many commercial and economically important species from tropical waters in the world. However, very limited information is available on the weight-length relationships of *B. dario* (Rahman 1989; Choudhury et al 2012; Haque & Biswas 2014; Hossain et al 2017). In Bangladesh, Hossain et al (2017) have studied in detail the length-weight relationships of this species from the Ganges River in northwestern Bangladesh. But in these reports virtually there were no substantial information on seasonal variation of length-weight relationships. Weight-length relationships are of great considerable importance in fishery research especially for study of fish population dynamics and stock condition (Bagenal & Tesch 1978). These relationships are useful to estimate the condition matrices to assess the general well-being of the fish or type of somatic growth, whether isometric or allometric. The present study recorded the growth coefficient (b) of *B. dario* from Sunamganj 'Beel' was near 3 indicating isometric growth pattern of the species whereas, Hossain et al (2017) reported negative allometric growth pattern (b < 3.00) from the Ganges River. The 'b' value of a fish species is greatly influenced by seasonal fluctuations in water quality parameters, food availability, feeding rate, gonad development, spawning period and other physiological factors (Bagenal & Tesch 1978; Le Cren 1951). The findings of Haque & Biswas (2014) also reinforced the seasonal differences of 'b' value who reported a range of 'b' value (2.02 to 3.45) fluctuated with seasons. Besides, 'b' values might change seasonally or even daily as well as between habitats (Gonçalves et al 1997). Therefore, it can safely be assumed that *B. dario* population from Sunamganj 'Beel' was in somewhat better condition than that of the Ganges River in Bangladesh.

Condition matrices are also getting popularity to explain the well-being of aquatic organisms like growth coefficients. The 'K' (Fulton's condition factor) value has been interpreted as "the higher the value, the better the condition of the fish". Though 'K' value highly species-specific but it can be generalized that 'K' value less than one indicates the fish is in poor health condition and more than one indicates the general wellbeing of fish (Goswami et al 2008). Observed 'K' value of *B. dario* varied seasonally having minimum in winter (1.3) and a mean of 1.4 considering all the four seasons. The result is much similar with the weight-length residuals (lwresid, $e_i$; Figure 7) and relative condition factor ($Kn_i$; Figure 8). Haque & Biswas (2014) reported that 'K' value of *B. dario* varied seasonally from 1.03 to 1.11 for males and from 0.96 to 1.25 for females which is similar to the findings of the present study. Certain factors like sex, stages of maturity, food abundance, data pulling, sorting into classes etc. have significant influence on the 'K' value of fish (Gayanilo & Pauly 1997). Therefore, the present findings suggested that *B. dario* had better fitness in warm periods as compared with cold ones (winter); this might be associated with an increase in food availability and feeding activity due to rise of temperature.

**Conclusions**. The present study dealt with the weight-length relationship, size and overall health condition of the endangered *B. dario* in the natural stocks of Bangladesh. The growth pattern of the species based on the weight-length relationships showed positive allometric pattern (> 3) throughout the year, indicating water quality parameters and food availability in the habitats were sufficient to support its population. Condition of *B. dario* exhibits a gradual decrease in winter season and onset of spawning period; indicating less feeding activity due to cold temperature and development of gonads at the expense of somatic weight. However, the abundance of the fish was alarming and intimidating, especially during winter. The most probable cause underlying these contradictory results could be higher anthropogenic interventions by recruitment overfishing. The seasonal data explored in the present study might be useful to the interested researchers and policymakers as a baseline secondary source for predicting a holistic model to formulate any conservation plan to save and/or restore the natural stocks of *B. dario*.

**Conflict of interest**. The authors declare that there is no conflict of interest.

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