Research article

Estimation of life history parameters for river catfish *Eutropiichthys vacha*: insights from multi-models for sustainable management

Dalia Khatun a, Md. Yeamin Hossain a,*, Obaidur Rahman a, Md. Firose Hossain b

a Department of Fisheries, University of Rajshahi, Rajshahi 6205, Bangladesh
b Department of Genetic Engineering and Biotechnology, University of Rajshahi, Rajshahi 6205, Bangladesh

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**ABSTRACT**

The river catfish, *Eutropiichthys vacha* is a vital protein source for rural communities and has high commercial value, but understanding its life history and management strategies reveals major inadequacies and ambiguities in the riverine ecosystems. Consequently, this study employs multi-models to analyze the life history parameters of *E. vacha* in the Ganges River (northwestern Bangladesh) from January to December, 2020. The total length (TL) and body weight (BW) of 382 individuals (male = 170, female = 192) were measured by a measuring board and a digital weighing balance, respectively. The overall sex ratio (male: female) was 1.0:1.13 and did not oscillate statistically from the standard 1:1 ratio (p > 0.05). The TL varied from 6.7-19.2 cm for males and 6.3-19.0 cm for females. The length-frequency distributions (LFDs) revealed females outnumbered in 8.0-9.9 cm TL whereas males in 7.0-7.9 cm TL. The slope (b) of the length-weight relationship (TL vs BW) for both sexes (b = 2.87) was substantially lower than isometry, specifying negative allometric growth pattern for *E. vacha*. Sex-specific relative (*K*) and Fulton’s (*KF*) condition analysis revealed better state of well-being of males than females. Only *K* reflected significant correlation with both BW and TL, hence making it ideal condition for predicting the fitness of *E. vacha* in this river. Moreover, the relative weight (WR) suggests an imbalanced habitat for females with higher abundance of predators but suitable for males. The form factor (*a3.0*) was 0.0062 and 0.0065, whereas the size at first maturity (*Lm*) and mean natural mortality (*Mn*) were 11.38 and 11.27 cm TL and 1.29 and 1.28 year⁻¹ for the respective sexes. Besides, the calculated mean optimum catchable length (*Lopt*) was 13.58 and 13.09 cm TL for each sex. These findings will be crucial for further studies and to recommend appropriate strategy for the sustainable management of *E. vacha* in the Ganges River and adjacent watersheds.

1. Introduction

Catfish (order Siluriformes) are the third-largest teleost order after Cypriniformes and Perciformes, with around 4100 species, accounting for about 12% of all teleosts (Eschmeyer and Fong, 2014; Wilson and Reeder, 2005). It gets its name from the whisker-like barbels around their mouths (Talwar and Jhingran, 1991). Catfish have a cosmopolitan distribution and can be found in inland or coastal waterways on all continents, even in Antarctica where fossils have been found (Grande and Eastman, 1986). It is economically significant as a food fish, ornamental fish, and sport fish (Jin et al., 2016). Catfish are a very prominent freshwater fish fauna which is abundantly found in Bangladesh (Rahman, 2005). The immense river systems and inland waters of Bangladesh contain 250 to 266 freshwater fish species (Rahman, 2005; Siddiqui et al., 2007), among which 55 species are classified as catfish (Rahman, 2005), though this number is also stated as 60 in some literature (Sarker et al., 2008). The Batchwa vacha, *Eutropiichthys vacha* (Hamilton, 1822) is a fresh- to brackish- water silurid catfish of the family Schilbeidae under the most diverse order, Siluriformes. It is a pelagic, potamodromous species (Riede, 2004) with voracious feeding habits, mostly feeding on small fishes and insects (Talwar and Jhingran, 1991). This fish is regarded as one of the representative and abundant catfish of the genus *Eutropiichthys* in the Ganges River, although *E. mura* is also available in small quantities (IUCN Bangladesh, 2015). This catfish is generally familiar as Bacha, Kangon, Cherki, and Challi in Bangladesh, India, Nepal, and Pakistan, respectively (Froese and Pauly, 2021). In Bangladesh, it is mostly recognized as a freshwater fish, mostly inhabiting major rivers and their tributaries, haors, and beels all over the country, but is sometimes also found in coastal rivers and Kaptai Lake (Rahman, 2005; Chowdhury, 2007; Kostori et al., 2011; Bashar et al., 2005).

* Corresponding author.
E-mail address: yeamin2222@yahoo.com (Md.Y. Hossain).

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This catfish has a broad spatial distribution that encompasses Bangladesh, Bhutan, India, Myanmar, Nepal, Pakistan, and Thailand (Menon, 1999; Riede, 2004; Talwar and Jhingran, 1991). Due to its excellent flesh quality, it is highly popular and sought-after consumer food fish (Hasan et al., 2002; Soomro et al., 2007) and has minimal commercial value in the aquarium industry (Abbas, 2010). Moreover, it is a native commercial target fish that is primarily targeted by small-scale and large-scale fishers as a vital source of subsistence (Craig et al., 2004; Hossain et al., 2012). The previous conservation status of E. vacha was critically endangered (IUCN Bangladesh, 2000), but currently this species has been assessed as least concern in Bangladesh (IUCN Bangladesh, 2015). However, the wild population is still declining due to over-exploitation, and habitat demolition (IUCN Bangladesh, 2015). Hossain et al. (2017, unpublished) also confirmed the declining trend for this species and mentioned some manmade causes such as overfishing, use of destructive fishing gear (i.e., Current Jali) and construction of Farrakka barrage as a major causative factor. Moreover, Khatun et al. (2019) also mentioned how the changing climate may possibly affect the reproduction of E. vacha in future in the Ganges River of northwestern Bangladesh. Therefore, this species should be subjected to continuous monitoring for the sustainability in its natural habitat.

The life history features of any fish species in a particular habitat determine its long-term sustainability (Das et al., 2019; Kumar et al., 2014; Prasad et al., 2012). Ample information on life history traits, such as sex ratio and size structure, length–weight relationships, growth, conditions, reproduction, and mortality, is crucial for proper planning and management of an exploited stock (Khatun et al., 2022; Gosavi et al., 2019), particularly when the species is a vital constituent of the commercial fisheries and located at the bottom of the upper food chain (Das et al., 2017; Kumar et al., 2014). Besides, habitat health and the condition of fish can also be delineated from this information (Hossain et al., 2021). Sex ratio (SR) and size structure (length–frequency distribution, LFD) provide the fundamental details for assessing the reproductive potentiality of fish populations (Vazzoler, 1996). The study of LFDs reveals the dynamic correlations between the growth, recruitment, and mortality rate along with breeding phenology, stock status, and habitat condition of riverine fishes (Neuman and Allen, 2001; Ranjan et al., 2005). Length–weight relationships (LWRs) and length–length relationships (LLRs) are important tools in fisheries management because they can distinguish the well-being of fishes belonging to intra- or inter-stock for a specific species (King, 2007). Knowledge of LWRs is fundamental for fisheries management and environmental monitoring schemes in a certain geographical territory (Froese, 2006; Renjithkumar et al., 2021). LWRs are an extensively utilized tool for the estimation of fishery biomass and yield from the length data (Garcia et al., 1998; Froese, 2006; Baitha et al., 2018), and also offer vital information for modeling of aquatic biota (Christensen and Walters, 2004). It can provide insight about the overall condition of a fish species, regarding its growth and survival (Le Cren, 1951; Christensen and Walters, 2004) as well as comparative life histories among diverse topographical grounds (Le Cren, 1951; Hossain et al., 2009, 2012; Azad et al., 2018). Besides, LLRs are also essential in fisheries management for relative growth studies where one length type is considered (Hossain et al., 2009; Wang et al., 2015). Moreover, condition factors are regarded as critical tools for assessing the health of fish species as well as the overall aquatic community (Muchlisin et al., 2010) and estimating potential variances among different stocks of identical species (King, 2007). Furthermore, relative weight (WR) is one of the most well-known indexes of fish which can ascertain the prey-predator relationship in a certain water body (Hossain et al., 2021). The size at sexual maturity (Lm) is a vital management parameter which can detect the basic reasons for the variation in the maturity size of fishes (Templeman, 1987; Sabbir et al., 2021).

Multi-model inference is a procedure that employs multiple models to estimate parameters instead of just one best model, which has several theoretical and practical benefits (Burnham and Anderson, 2002). Selection of a single model can substantially affect the reliability of inferences, since uncertainty in model selection is often considered to be zero, and thus accuracy is likely overestimated (Katsanevakis, 2006). When more than one model is supported by the data, it might be helpful to model-average the predicted response variable across models in order to draw conclusions that are stronger than those drawn from a single model (Katsanevakis, 2014). In this study, we concentrate on estimating natural mortality (M0) and optimum catchable length (Lopt) using multi-models, both of which are vital for population management. The estimation of M0 often represents the current condition of a fish stock and helps to set the management policies accordingly (Brodziak et al., 2011). Lopt is also fundamental in fisheries management policy which specifies the significance of fishing gear selectivity (Mawa et al., 2021).

A good number of studies have been reported on various aspects of E. vacha form the Ganges River and other water bodies (Table 1). Although Hossain et al. (2013) reported some parameters of life history including SR, LFD, LWRs, LLRs, condition factors, and form factor (α20) of this species from the Jamuna River in northern Bangladesh, the information on Lm, M0, and Lopt is lacking. Nonetheless, to the best of the author’s knowledge, detailed study on life history utilizing multi-models has not been conducted for this major fishery to date, which is crucial for their proper management and implementation of conservation policy. Therefore, this study is intended to focus on the estimation of life history parameters including sex ratio, length-frequency distributions (LFDs), length-weight relationships (LWRs), conditions (allometric, Ks; Fulton’s, Kc; relative, Krr; relative weight, Ws), and first sexual maturity (Lm), natural mortality (M0), and optimum catchable length (Lopt) of E. vacha using a number of individuals with various body sizes, which will be useful in management strategy evaluations to support this catfish in the Ganges River in northwestern Bangladesh.

Table 1. Available works on different aspects of Eutropiichthys vacha (Hamilton, 1822) along with their locations and references.

| Aspects | Location/Water body | References |
|---------|--------------------|------------|
| Length-weight and length-length relationship | Ganges River, Bangladesh | Hossain et al. (2009) |
| Padma River, Bangladesh | Hossain (2010) |
| Atrai and Brahmaputra River, Bangladesh | Islam et al. (2017) |
| Betwa and Gomti River, India | Sani et al. (2010) |
| Indus River, Pakistan | Soomro et al. (2012) |
| Sex ratio and size structure | Ganges River, Bangladesh | Khatun et al. (2018) |
| Ganga River, India | Tripathi et al. (2015) |
| Morphometric and meristic | Kaptai Lake, Meghna River and Tanguar haor, Bangladesh | Purvej et al. (2014) |
| Condition factor | Ganges River, Bangladesh | Khatun et al. (2020) |
| Atrai and Brahmaputra River, Bangladesh | Islam et al. (2017) |
| Ganges River, Bangladesh | Hossain (2010) |
| Life history traits | Jamuna River, Bangladesh | Hossain et al. (2013) |
| Sexual maturity, reproduction and feeding habit | Kaptai Lake, Bangladesh | Azadi et al. (1990) |
| Ganges River, Bangladesh | Hossain et al. (2012) |
| Ganges River, Bangladesh | Khatun et al. (2019) |
| India | Qasim and Qayyum (1961) |
| Kar et al. (2006) |
| Indus River, Pakistan | Soomro et al. (2012) |
| Population parameters and exploitation status | Kaptai Lake, Bangladesh | Banhar et al. (2021) |
| Ganga River, India | Tripathi et al. (2015) |
| Indus River, Pakistan | Memon et al. (2017) |
2. Materials and methods

2.1. Study site and fish sampling

This study was conducted in the Ganges River (locally renowned as the Padma River in Bangladesh), situated in the northwestern part of Bangladesh. Geographically, this river is located between 24°22’N latitude, and 88°35’E longitude (Figure 1). It is well known for having the richest freshwater fish fauna in Bangladesh and serves as a vital feeding and breeding ground for riverine fishes in northwestern Bangladesh (Jones et al., 2003), as well as being home to 26 catfish species (Rahman et al., 2012).

In total, 362 individuals (170 males and 192 females) of E. vacha were collected during this study from the various landing points of the Ganges River in the Rajshahi district (Godagari, Paba, and Charghat; Figure 1). All the specimens used in this study originated from the occasional catches of commercial fishers, collected randomly from January to December 2020 using gill net with a mesh size of 1.8–2.2 cm and cast net with 1.5–2.0 cm mesh size. The standard taxonomic identification key given by Talwar and Jhingran (1991) was utilized for the identification of fish species. A random sampling method was followed for the assessment of length and weight to circumvent any prejudice in size. After collection, ice was used to immediately chill the specimens and carried to the laboratory in a cooling box for morphometric analysis.

2.2. Fish measurement

Before laboratory examination, all specimens of E. vacha were thawed with water. To avoid anomalies in morphometric measures caused by fixation, the morphometric measurements (length and weight) were done on the same day of sampling. The total length (TL), fork length (FL), and standard length (SL) of every specimen were measured by a measuring board, and whole body weight (BW) was recorded using a digital weighing scale with 0.01g precision. For precise weight measurement, specimens were allowed to air dry and wiped with blotting paper to eradicate excess moisture from the surface of the fish. Besides, fish were sexed visually by morphometric differences and microscopically by gonad analysis (Khatun et al., 2019).

2.3. Sex ratio (SR) and length-frequency distribution (LFDs)

A chi-square test was used to examine whether there was any disparity in sex ratio from the standard anticipated value of 1:1 (male: female). The length class and the frequency of each length class were assessed according to the estimates of TL. In this study, 1 cm interval of TL was followed during the construction of the length-frequency distribution for both male and female E. vacha.

### Table 2. Number of males, females, and sex ratio (male: female = 1:1) of Eutropiichthys vacha (Hamilton, 1822) from the Ganges River, northwestern Bangladesh.

| Length class (TL, cm) | Number of specimens | Sex ratio (Male/Female) | $\chi^2$ (df = 1) | Significance |
|-----------------------|---------------------|-------------------------|-------------------|-------------|
|                       | Male | Female | Total |                        |             |
| 6.00-6.99              | 2    | 4      | 6     | 1:2.00                   | 0.67        | ns          |
| 7.00-7.99              | 16   | 6      | 22    | 1:0.38                    | 4.55        | *           |
| 8.00-8.99              | 32   | 39     | 71    | 1:1.22                    | 0.69        | ns          |
| 9.00-9.99              | 39   | 55     | 94    | 1:1.41                    | 2.72        | ns          |
| 10.00-10.99            | 20   | 32     | 52    | 1:1.60                    | 2.77        | ns          |
| 11.00-11.99            | 6    | 6      | 12    | 1:1.00                    | 0.00        | ns          |
| 12.00-12.99            | 10   | 8      | 18    | 1:0.80                    | 0.22        | ns          |
| 13.00-13.99            | 6    | 1      | 7     | 1:0.17                    | 3.57        | ns          |
| 14.00-14.99            | 7    | 8      | 15    | 1:1.14                    | 0.07        | ns          |
| 15.00-15.99            | 8    | 7      | 15    | 1:0.88                    | 0.07        | ns          |
| 16.00-16.99            | 7    | 8      | 15    | 1:1.14                    | 0.07        | ns          |
| 17.00-17.99            | 9    | 9      | 18    | 1:1.00                    | 0.00        | ns          |
| 18.00-18.99            | 6    | 8      | 14    | 1:1.33                    | 0.29        | ns          |
| 19.00-19.99            | 2    | 1      | 3     | 1:0.50                    | 0.33        | ns          |
| Overall                | 170  | 192    | 362   | 1:1.13                    | 1.34        | ns          |

TL, total length; df, degree of freedom; ns, not significant; *, significant at 5% level ($\chi^2 < 1, 0.05 = 3.84$).
2.4. Length-weight and length-length relationships (LWRs and LLRs)

Regression analysis of length-weight data was used to compute the LWRs of *E. vacha* using Le Cren’s (1951) power equation as:

\[
BW = a \times (TL)^b
\]

where BW is the fish body weight (g), TL is the total length (cm), *a* and *b* is the intercept and slope of the regression, respectively. Linear regression analyses were used to obtain the *a* and *b* parameters based on natural logarithms:

\[
\ln(W) = \ln(a) + b \ln(L)
\]

In addition, the 95% confidence limits of *a* and *b*, as well as the coefficient of determination (*r^2*) were computed according to the regression model’s fit (Pervaiz et al., 2012). From the dataset, strong outliers were eliminated after fitting log-log plots of *W* and *L* data via regression analyses (Froese, 2006). To validate whether the growth pattern was isometric or (positive/negative) allometric, a two-tailed t-test was performed to examine the significant divergence from the isometric value of *b* = 3 (Sokal and Rohlf, 1987). In addition, linear regression analysis was used to estimate LLRs such as TL vs. FL, TL vs. SL, and SL vs. FL without log-transformation (Khatun et al., 2018).

2.5. Condition factors

The allometric condition factor (*K_A*) was computed by the equation:

\[
K_A = \frac{W}{L^b}\text{ (Tesch, 1968)},
\]

where *W* is the BW in g, *L* is the TL in cm, and *b* is the LWRs parameter. Fulton’s condition factor (*K_F*) was determined based on

| Characteristics | *n* | Min | Max | Mean ± SD | 95% CL |
|-----------------|-----|-----|-----|-----------|--------|
| **Male** | | | | | |
| Total length (cm) | 170 | 6.7 | 19.2 | 11.167 ± 3.331 | 10.663–11.671 |
| Fork length (cm) | 5.9 | 16.6 | 9.806 ± 2.879 | 9.371–10.242 |
| Standard length (cm) | 5.3 | 15.2 | 8.902 ± 2.672 | 8.489–9.307 |
| Body weight (g) | 1.8 | 43.87 | 11.992 ± 10.911 | 10.340–0.606 |
| **Female** | | | | | |
| Total length (cm) | 192 | 6.3 | 19.0 | 11.021 ± 3.151 | 10.573–11.470 |
| Fork length (cm) | 5.5 | 16.6 | 9.678 ± 2.694 | 9.295–10.062 |
| Standard length (cm) | 4.9 | 15.1 | 8.777 ± 2.448 | 8.429–9.126 |
| Body weight (g) | 1.86 | 45.65 | 11.913 ± 10.963 | 10.353–13.474 |
| **Combined** | | | | | |
| Total length (cm) | 362 | 6.3 | 19.2 | 11.090 ± 3.233 | 10.756–11.424 |
| Fork length (cm) | 5.5 | 16.6 | 9.738 ± 3.779 | 9.451–10.026 |
| Standard length (cm) | 4.9 | 15.2 | 8.836 ± 2.553 | 8.572–9.100 |
| Body weight (g) | 1.8 | 45.65 | 11.950 ± 10.923 | 10.821–13.079 |

*n*, sample size; Min, minimum; Max, maximum; SD, standard deviation; CL, confidence limit.

**Figure 2.** The length-frequency distribution of male and female *Eutropiichthys vacha* (Hamilton, 1822) in the Ganges River, northwestern Bangladesh.
Fulton (1904) equation as: \( K_F = \frac{100}{C^2 W/L^3} \), where \( W \) and \( L \) indicate the same as in \( K_A \). To get the \( K_F \) closer to unit, a scaling factor of 100 was utilized. Moreover, the equation of Le Cren (1951) was applied for the assessment of the relative condition factor (\( K_R \)) of \( E. vacha \) as: \( K_R = \frac{W}{a/C^2 L^b} \), where \( W \) and \( L \) are defined above, and \( a \) and \( b \) are LWRs parameters. The relative weight (\( W_R \)) was calculated from Froese (2006) algorithm as: \( W_R = \frac{W/WS}{C^2 100} \), where \( W \) denotes an individual’s weight and \( WS \) denotes the expected standard weight for that same individual as computed by \( WS = a/C^2 L^b \) (the \( a \) and \( b \) variables were retained from the TL vs. BW relationship).

### 2.6. Form factor (\( a_{3.0} \)) and size at first sexual maturity (\( L_m \))

The estimation of \( a_{3.0} \) of \( E. vacha \) method was done following the Froese (2006) equation as: \( a_{3.0} = 10^{b/s} \), where \( a \) and \( b \) are described above, and \( s \) is the slope of regression of \( \ln a \) vs. \( b \). In this study, the \( a_{3.0} \) was estimated using an average slope \( S = -1.358 \). Besides, the \( L_m \) was estimated by the empirical model given by Binohlan and Froese (2009) as: \( \log (L_m) = -0.1189 + 0.9157 \times \log (L_{max}) \), where \( L_{max} \) signifies maximum TL.
2.7. Natural mortality (MW)

The MW was computed by the Peterson and Wroblewski (1984) model as $MW = 1.92 \cdot \frac{C_0}{W^{0.25}}$, where MW is the natural mortality at body mass $W$, and $W = a \cdot L^b$, where $L$, $a$ and $b$ are described earlier. Besides, MW was also assessed using two other models given by Hoenig (1983) as: $\exp (1.46 - 1.01 \ln [L_m])$ and Jensen (1996) as: $\frac{1.65}{L_m}$ to compare the appropriateness of these three models.

2.8. Optimum catchable length (Lopt)

The Lopt was assessed using two empirical models to compare the reliability of the estimated value; the first one according to Froese and Binohlan (2000) as $\log L_{opt} = 1.0421 \times \log (L_m) - 0.2742$ and the second one based on the formula of Beverton (1992) as $L_{opt} = \frac{3}{(3 + M/K)}$, where $L_m$ is the asymptotic length calculated as: $\log L_m = 0.044 + 0.9841 \times \log (L_{max})$ (Froese and Binohlan, 2000). M is natural mortality and K is the growth co-efficient determined by the equation: $K = 3/L_{max}$ (Pauly and Munro, 1984). The $L_{opt}$ range was also calculated from the percentage of fish between $L_m$ and $L_{opt} + 10\%$ larger sizes, and the percentage of fish above this $L_{opt}$ range was designated as mega-spawners (modified from Froese, 2004).

2.9. Statistical analyses

GraphPad Prism version 6.5 (GraphPad Software for Windows, San Diego, California, USA) was used to perform statistical analysis on the data. Prior to analysis, the datasets were checked for homogeneity and normality. The comparison of the mean relative weight $(WR)$ with 100 was done using Wilcoxon sign rank test (Anderson and Neumann, 1996). Besides, the correlation between the body measurements (e.g., TL, and BW) with condition factors $(K_A, K_F, K_R, and WR)$ was determined by Spearman rank test. Moreover, the LWRs were compared between the sexes by analysis of covariance (ANCOVA). The significance level of all statistical analyses was determined to be 5% ($p < 0.05$).

3. Results

3.1. Sex ratio (SR) and length-frequency distributions (LFDs)

In this study, 47% of the 362 sampled individuals of *E. vacha* were males and 53% were females, with the total sex ratio not differing significantly from the typical 1:1 ratio ($df = 1, \chi^2 = 1.34, p > 0.05$) (Table 2). However, the length class based distinction in sex ratio revealed a dominance of females in the 8.00–9.99 cm TL size groups, while males in the 7.00–7.99 cm TL range, although no statistically substantial differences ($p > 0.05$) was observed.

Table 3 demonstrates the descriptive statistics of length and weight measurements of *E. vacha* as well as their 95% confidence limit (CL). The smallest and largest individuals measured in this study were 6.3 cm and 19.2 cm TL, respectively, with BW spanning between 1.80 to 45.65 g, irrespective of sex. According to LFDs, the 8.00–9.99 cm TL size group
was proportionately dominating for both males and females (representing 42% and 49% of the total population, respectively) in the Ganges River (Figure 2). The data of TL and BW of both sexes did not pass the normality test and thus non-parametric Mann-Whitney U-Test was used for comparison between sexes. LFD revealed no significant difference in TL between sexes (U = 16106, p = 0.830), and BW also exhibited similar findings (U = 15639, p = 0.494). Figure 3 represents the changes of TL of E. vacha from the available literatures of Bangladesh during pre and post IUCN Bangladesh (2015) assessment.

3.2. Length-weight and length-length relationships (LWRs and LLRs)

Table 4 and Figure 4 represents the findings of the LWRs of E. vacha, including sample sizes (n), values for regression parameters (a and b) of LWRs, as well as their corresponding 95% confidence limits, coefficients of correlation ($r^2$), and growth type. The estimated $b$ values derived from the LWRs were significantly lower than 3.0 ($b < 3.00, p < 0.001$), specifying negative allometric growth (A-) for both males and females, as well as combined sexes. This denotes that the length grows faster than the weight for this species in the Ganges River. Statistically, a highly significant correlation ($p < 0.001$) was observed for all LWRs with the $r^2$ values $> 0.975$. Also, significant sex differences in LWRs were revealed by ANCOVA ($p = 0.012$) for the studied species.

Furthermore, Table 5 depicts the LLRs (TL vs. SL, TL vs. FL, and SL vs. FL), together with the calculated parameters (a and b) and their respective 95% CI, and the coefficient of determination ($r^2$). In this study, all LLRs were highly significant ($p < 0.001$), with the $r^2$ value exceeding 0.995.

3.3. Condition factors

Normality of all four studied condition factors between sexes were tested. However none of them were normally distributed, hence non-parametric Mann-Whitney U-test were employed to find significant differences between the sexes. The $K_f$ values varied from 0.0073 – 0.0141 for males and 0.0066 – 0.0112 for females (Table 6), and Mann-Whitney U-test showed significant differences of $K_f$ between the sexes ($p < 0.0001$). The $K_f$ ranged from 0.5253 – 1.0439 for males and 0.5527–0.9413 for females and the calculated range of $K_f$ was 0.7747–1.4961 and 0.3920–0.6654 for both sexes, respectively (Table 6). Similar to $K_f$, Mann-Whitney U-test stated significant distinction between males and females ($p < 0.0001$) for both $K_r$ and $K_f$. The calculated $W_f$ for males was 77.4737–149.6149 and for females it was 75.6792–128.155(155 (Table 6). The relationships of condition factors ($K_n$, $K_f$, $K_r$, and $W_f$) with TL and BW which are given in Table 7, were also non-normally distributed, consequently non-parametric spearman rank (rs) test was employed. Among the calculated four condition factors in this study, only $K_f$ showed significant correlation with both TL ($r_f = -0.2040, p = 0.0076$ for males and $r_f = -0.2166, p = 0.0026$ for females) and BW ($r_f = -0.2409, p = 0.0026$ for males and $r_f = -0.3204, p < 0.001$ for females). Figure 5 illustrates the relationship between TL and $W_f$ of E. vacha. The $W_f$ of females in this study showed statistically significant deviations from 100 ($p < 0.0001$), whereas males showed an insignificant deviation ($p = 0.8447$), as demonstrated by the non-parametric Wilcoxon sign rank test due to the failure of the dataset to pass the normality test.

## Table 5. The estimated parameters of the length-length relationships ($y = a + b \times x$) of *Eutropiichthys vacha* (Hamilton, 1822) from the Ganges River, northwestern Bangladesh.

| Equation | Sex | Regression parameters | 95% CL of a | 95% CL of b | $r^2$ |
|----------|-----|-----------------------|-------------|-------------|-------|
| TL = a + b × FL | M | -0.1686 | 1.1559 | -0.2468 to -0.0904 | 1.1483–1.1636 | 0.998 |
| TL = a + b × SL | F | 0.0973 | 1.2435 | -0.0306 to 0.2252 | 1.2297–1.2572 | 0.995 |
| SL = a + b × FL | F | -0.1776 | 0.9259 | -0.2752 to -0.0799 | 0.9164–0.9355 | 0.995 |
| SL = a + b × SL | F | -0.2880 | 1.1685 | -0.3702 to -0.2058 | 1.1603–1.1767 | 0.998 |
| TL = a + b × FL | C | 0.2546 | 1.2847 | -0.3560 to -0.1531 | 1.2736–1.2958 | 0.996 |
| TL = a + b × FL | C | 0.0072 | 0.9076 | -0.0790 to -0.0646 | 0.9065–0.9148 | 0.997 |
| TL = a + b × FL | C | -0.2281 | 1.1622 | -0.2850 to -0.1712 | 1.1566–1.1678 | 0.998 |
| TL = a + b × SL | F | -0.0742 | 1.2635 | -0.1571 to 0.0087 | 1.2545–1.2725 | 0.995 |
| SL = a + b × FL | F | -0.0928 | 0.9169 | -0.1532 to -0.0325 | 0.9109–0.9228 | 0.996 |

TL, total length; FL, fork length; SL, standard length; M, male; F, female; C, combined sex; a, intercept; b, slope; CL, confidence limit for mean values; $r^2$, coefficient of determination.

## Table 6. Allometric ($K_n$), Fulton’s ($K_f$), and relative condition factors ($K_r$) and relative weight ($W_f$) of *Eutropiichthys vacha* (Hamilton, 1822) from the Ganges River, northwestern Bangladesh.

| Condition factors | Sex | n | Min | Max | Mean ± SD | 95% CL |
|-------------------|-----|---|-----|-----|-----------|--------|
| $K_n$             | M   | 170 | 0.0073 | 0.0141 | 0.0095 ± 0.0012 | 0.0093–0.0097 |
| $K_f$             | F   | 192 | 0.5253 | 1.0439 | 0.6944 ± 0.0950 | 0.6801–0.7088 |
| $K_r$             | F   | 192 | 0.7747 | 1.4961 | 1.0107 ± 1.3050 | 0.9910–1.3050 |
| $W_r$             | F   | 192 | 77.4737 | 149.6149 | 101.0725 ± 13.0476 | 99.0970–101.0480 |
| $K_n$             | C   | 362 | 0.0073 | 0.0141 | 0.0098 ± 0.0012 | 0.0097–0.0099 |
| $K_f$             | C   | 362 | 0.5252 | 1.0439 | 0.7118 ± 0.0938 | 0.7021–0.7215 |
| $K_r$             | C   | 362 | 0.7552 | 1.4577 | 1.0091 ± 0.1257 | 0.9961–1.0221 |
| $W_r$             | C   | 362 | 75.5236 | 145.7732 | 100.9848 ± 12.5698 | 99.6092–102.2076 |

$K_n$, allometric condition factor; $K_f$, Fulton’s condition factor; $K_r$, relative condition factor; $W_r$, relative weight; M, male; F, female; C, combined sex; n, sample size; Min, minimum; Max, maximum; SD, standard deviation; CL, confidence limit for mean values.
Development of conservation strategies for wild fishes in the inland waters greatly relies on the documentation and regular upgradation of life history traits (Chowdhury et al., 2021). As fisheries management is a dependent field, concrete data on demography parameters (i.e., growth, mortality, recruitment, etc.) are vital prerequisites for the implementation of proper management policies (Raghavan et al., 2018; Gosavi et al., 2019). E. vacha is currently listed as least concern, but still facing different threats which may lead it to revert to its previous condition (critically endangered) if proper management measures cannot be implemented. Hence, detailed investigation of life history parameters might act as a key solution to manage this species sustainably in its natural habitats. Therefore, this study emphasized the estimation of life history parameters of E. vacha comprising SR, LFDs, LWRs, LIRs, condition factors (Ks, Kf, Kr and Wk), Lm, MW, and Lopt using multi-models from the Ganges River in NW Bangladesh.

The majority of aquatic (fish and shellfish) species are unlikely to depart from a typical male-to-female ratio of 1:1. However, this ratio may be significantly prejudiced in many finfish and prawn populations or even within the same population at different time period (Oliveira et al., 2012; Khatun et al., 2018), depending on a number of variables such as reproductive behavior, population adaptability, food accessibility, and environmental circumstances (Brykov et al., 2008; Vandeputte et al., 2012). During this study, out of 362 studied specimens of E. vacha, the male to female sex ratio was 1:1.13, with females outnumbering males. In contrast to males, reproductive success of females is typically influenced by resource availability and environmental factors rather than the quantity of mating partners. Consequently, reproductive success of males throughout the lifespan being restricted by the accessibility to females, which might be a reason of imbalance in the number of individuals of each sex in the studied population (Forsgren et al., 2008). Similar to this study, Khatun et al. (2018) from the Ganges River, Bangladesh (male: female = 1:0.1:1.13) and Tripathi et al. (2015) from the Ganga River, India (male: female = 1:0.1:61) found female-dominated populations, whereas the male dominance observed in the Indus River population of Pakistan (male: females = 1:1.6: 1.0) reported by Soomro et al. (2012). The total sex ratio in the current investigation did not deviate significantly from the typical 1:1 ratio (df = 1, χ² = 1.34, p < 0.05), which is consistent with the finding of Hossain et al. (2013) (df = 1, χ² = 2.57, p > 0.05) from the Jamuna River, northern Bangladesh.

The examined specimens of this study showed total length and weights ranging between 6.3 to 19.2 cm (Mean = 11.09 ± 3.23) and 1.80–45.65 g (Mean = 11.950 ± 10.923), respectively, throughout the whole year. The length of the largest individuals (Lmax) known from a population has strong correlation with asymptotic length (Lm) (Froese and Binohlan, 2000). The calculated Lmax of E. vacha in this study was 20.27 and 20.06 cm for male and female, respectively (Table 8). Since the Lm was calculated using empirical formula based on Lmax, Lm does not reveal any obvious trend during pre and post assessment of IUCN Bangladesh (2015) assessment for E. vacha from Bangladesh (Table 9).

Table 8 displays the calculated natural mortality based on three distinct models along with their mean value. The values of mortality estimated by Hoenig (1983) and Jensen (1996) in this study were comparatively higher than the estimates of the Peterson and Wroblewski (1984) model. However, the mean Mwr for the E. vacha population was calculated to be 1.29 year−1 for males and 1.28 year−1 for females (Table 8) in the Ganges River of NW Bangladesh. In addition, Figure 7 represents the relationship between the total length and natural mortality, which indicates that Mwr in the Ganges River was quite high for specimens below 6.00 cm TL, but it decreased as body size increased. The calculated Mwr for E. vacha from different water bodies around the world is shown in Table 9.

The calculated Lopt by two different models and their mean value are given in Table 8 and Figure 8. Also, the Lms, Lm, and Lopt were calculated based on Lmax using previous literature reported by several scientists from various water bodies on E. vacha is given in Table 9.
2006). Tesch (1971) stated that $b$ values near to 3 specify isometric growth while differences from 3 designate allometric growth, either positive ($>3$) or negative ($<3$) allometric. The $b$ values of all LWRs (TL vs. BW; FL vs. BW; SL vs. BW) in the current study were 2.85–2.91 for males and 2.87–2.93 for females, suggesting negative allometric growth pattern ($<3.00$) for both sexes which is indicative of a relatively slow growth rate and thinner bodies. For the female population, similar growth pattern was described by Hossain et al. (2013) ($b = 2.81$), Khatun et al. (2018) ($b = 2.78$) and Soomro et al. (2007) ($b = 2.96$). Khatun et al. (2018) reported a similar growth pattern ($b = 2.83$) in the male population of the Ganges River in Bangladesh. However, contrary to the present findings, Hussain et al. (2013) observed isometric growth ($b = 3.03$), while Soomro et al. (2007) showed positive allometric growth ($b = 3.16$) for male populations of E. vacha from the respective Jamuna River of Bangladesh, and the Indus River of Pakistan. While we are unable to provide a definitive explanation for the similarities and differences between our findings and the previous literatures, it is possible that the state of the species, and its geographic differences in population structure can be responsible (Jisr et al., 2018). Moreover, these distinctions may be derived due to several factors, including sex, season, maturity stages, and magnitude of stomach fullness (Ali et al., 2016; Ogunola et al., 2018; Czudaj et al., 2022). Thus, this observed variation might be assumed to be the impact of a single factor or a synergistic effect of multiple factors (Gosavi et al., 2019).

![Figure 5. The relationship between total length and relative weight of male and female Eutropiichthys vacha (Hamilton, 1822) in the Ganges River, northwestern Bangladesh.](image)

![Table 8. Estimation of form factor, size at first sexual maturity, asymptotic length, asymptotic weight, natural mortality and optimum catchable length of Eutropiichthys vacha in the Ganges River using different models based on maximum length and life history parameters.](table)
Despite the fact that most studies focused on a specific condition factor, we investigated four condition factors ($K_A$, $K_P$, $K_R$ and $W_G$) to assess the viability and habitat quality of *E. vacha* in the Ganges River. $K_R$ is a crucial condition factor which can reveal the physiological and nutritional status of an individual or a population. It is mostly interpreted with respect to energy reserves as well as with life history characteristics, such as reproduction and growth (Gubiani et al., 2020). Within the same sample or population, Froese (2006) suggested to use $K_R$ for comparison of the health status of males and females. Information on differences in food availability and the impact of physicochemical parameters on the life cycle of fish species is shown by the divergence of $K_R$ from 1, where $K_R > 1$ implying good general condition and $K_R < 1$ indicate opposite condition (Le Cren, 1951). The sex-wise analysis of maximum $K_R$ values in males (1.50) was higher than females (0.67) (Table 6), suggesting that
males are in better condition in comparison to females in the study area. This disparity could be attributed to the weight of food in the stomachs of the sexes (Ambily and Nandan, 2010). In the case of \( K_F \), male fishes likewise displayed higher values than female fishes (Table 6), indicating that overall, the general health of male fishes was better than female fishes. Hossain et al. (2013) reported the same result. This may be due to increased appetite and feeding intensity of male fishes than females (Subba et al., 2018). According to Barnham et al. (2003), the stage of development of reproductive organs has a significant impact on the \( K_F \), which in females drops quickly after the eggs are shed. In this study, females attains sexual maturity relatively faster than males (Table 8) which may also be responsible for lower \( K_F \) in females. The Spearman
rank correlation test revealed that only $K_F$ demonstrated a significant correlation with TL and BW for both sexes, compared to the other condition factors (Table 7). Therefore, this study suggested that $K_F$ could be used to assess the welfare of this fish in the Ganges River and its neighboring ecological community. The mean $W_K$ of both sexes tended to be 100 (Table 6), demonstrating the presence of prey and predator in this waterbody was balanced. However, the Wilcoxon signed rank test revealed that the $W_K$ for males ($p = 0.845$) indicated no noteworthy variations from 100, but a significant difference for females ($p < 0.0001$), signifying that the habitat was optimal for males but not for females, suggesting an imbalance in food accessibility comparative to predator signifying that the habitat was optimal for males but not for females, species have fairly limited or well-de

variations from 100, but a signifi

stant ($p = 0.0066$ and 0.0055), thus ruling out the likelihood of water body-wise Jamuna River reported by Hossain et al. (2013) for respective sexes River. Similar body shapes were also observed for the population of the Jamuna River reported by Hassain et al. (2013) for respective sexes ($0.0066$ and 0.0055), thus ruling out the likelihood of water body-wise differences of $a_{2.0}$ within the same country. The calculated $L_m$ of $E. vacha$ were 11.38 cm, and 11.27 cm in TL for males and females, accordingly which were smaller than the observed existence (Anderson and Neumann, 1996) for $E. vacha$ in the Ganges River. However, small percentage of mega-spawners represents the persistence of reproductive potential for $E. vacha$ in the Ganges River. However, small percentage of brood fish belonging to mega-spawners group in order to ensure the long-term sustainability of this fish every year in the Ganges River.

5. Conclusion and recommendations

In the Ganges River, multi-species fisheries are usually practiced with a substantial quantity of by-catch, thus suggesting management measures for single species are fairly cumbersome. Sex-specific analysis of condition factors in this study shows quite unfavorable environment for $E. vacha$ in the Ganges River. The calculated $L_m$ was lower than Lopt, hence recommending increased mesh size of fishing gear would be forthright, which will be useful to reduce fishing mortality, but the exploitation rate will be decreased as well which lead to financial losses to the fisherman. Therefore, this study suggests to capture fishes over $L_{opt}$ so that most of the individual get a chance to reproduce before being caught. This will reduce growth and recruitment overfishing and will ensure higher catches in the long run. However, this study emphasizes the need for a complete study about mortality and exploitation status of $E. vacha$ to get a better insight into the current stock condition in the Ganges River. We hope the outcomes of this study will be a functioning tool for fishery managers to initiate appropriate management approaches and regulations for the sustainable conservation of the lingering stocks of this species in the Ganges River and adjacent ecosystem.

Declarations

Author contribution statement

Dalia Khatun and Md. Yeamin Hossain: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Obaidur Rahman: Performed the experiments; Analyzed and interpreted the data.

Md. Firoze Hossain: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data will be made available on request.

Declaration of interest’s statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.
