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Population Parameters of the Stinging Catfish, *Heteropneustes fossilis* in a Semi-Enclosed Wetland Ecosystem: An Insight from the Arial Beel, Bangladesh

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ABSTRACT

Population parameters offer a comprehensive understanding of the population dynamics of fish species within their habitats. This study is the first of its kind to investigate multi-model biological parameters of *Heteropneustes fossilis* in a semi-enclosed freshwater wetland, specifically the Arial Beel in Bangladesh. The total length and body weight of the specimens ranged from 6.6 to 32.4cm and from 1.1 to 144g, respectively, with the recorded maximum total length representing a new record for *H. fossilis* in Bangladesh. The b value of the length–weight relationship was 2.93, indicating a negative allometric growth pattern, supported by a high coefficient of determination (r^2 = 0.98). Key growth parameters were estimated as follows: asymptotic length (L_∞) = 33.93 cm, growth coefficient (K) = 0.34 year^{-1}, growth performance index (Ø′) = 2.59, and longevity (t_{max}) = 8.88 years. The form factor ($a_{3.0}$) was calculated at 0.005. The size at sexual maturity (L_m) and optimum catchable length (L_{opt}) for the combined sexes of *H. fossilis* were 18.38cm and 22.44cm, respectively. The average relative condition factor (K_r) was 1.01, suggesting that the population is in good health within the beel environment. This study provides detailed insights into the growth and biological status of *H. fossilis* in an interconnected riverine and floodplain wetland ecosystem. Further research incorporating more samples and additional species is recommended to develop a comprehensive ecological profile of Arial Beel, with the aim of establishing it as a model wetland ecosystem for the sustainable management of freshwater resources.

INTRODUCTION

Global natural fish stocks are dwindling each year due to the adoption of modern fishing techniques in open waters, often without adequate measures to preserve fish populations and biodiversity in natural aquatic ecosystems. According to the **FAO (2020)**, world annual fish production from capture fisheries remains relatively the same after the late 1980s till date amidst, the global consumption rate of fish is increasing rapidly. Although fish production from aquaculture appears promising, the demand for captured fish from open natural water is higher at the consumer level due to their distinguished good taste and flavor.

Bangladesh is blessed with enormous natural water bodies and inland capture fisheries. Among natural inland water bodies in Bangladesh, beels play important roles as breeding and rearing grounds for indigenous fishes. Beels are natural depressions that become flooded during the rainy season and may completely or partially dry up during the summer months. There are numerous beels in Bangladesh among them Arial Beel is the third largest freshwater beel, covering an area of 14436 ha and located between 23°32´N to 23°71´N latitudes and 90°10´E to 90°37´E longitudes **(Roy *et al*., 2022)**. Although during monsoon, the Arial Beel is filled with water, in the summer season, only the deeper part of the beel (locally known as denga) contains water. Mainly, Dengas acts as a year-round reservoir of indigenous fish and after being flooded with rain water reserved fishes spread to the whole area. This beel is particularly famous for producing large-sized small indigenous species (SIS), especially *Anabas testudineus* and *H. fossilis*. The permanent ponds of the beel facilitate SIS reserve all year round and give them a good chance to grow their maximum length. There are at least 61 species of fish available in Arial Beel and most of them have high demand in the market and usually sell at high prices owing to their size and taste **(Roy *et al*., 2022)**. The high biodiversity of Arial Beel has important ecological roles. Therefore, proper fisheries management and biodiversity conservation are crucial for Arial Beel.

Heteropneustes fossilis Bloch (1974) or the Asian stinging catfish, is one of the popular catfish species of Bangladesh with huge market demand for its good taste and low-fat content. The geographical distribution of *H. fossilis* covers Bangladesh, India, Pakistan, Myanmar, Nepal, Sri Lanka, Thailand and Laos. The species is a common inhabitant of muddy water of ponds, rivers, ditches, lowlands, and swamps **(Froese & Pauly, 2018)**. This species is also recorded from different beels in Bangladesh like, Chalan Beel **(Galib *et al*., 2010)**, Gajner Beel **(Islam *et al*., 2021)** and Arial Beel. *Heterocephalus fossilis* is a fish with no scales and thin skin, having a flat head and a long body. Moreover, it is an air-breathing fish with the presence of a unique pair of accessory respiratory organs that serve as lungs. *H. fossilis* fish is a good source of protein, iron and zinc and is popular among the local people as it is considered as a suitable fish for patients.

H. fossilis is one of the dominant fish species in Arial Beel, which contributes significantly to the breeding and production of the species. In the natural environment, high fishing pressure and habitat demolition are the main threats for *H. fossilis*. Although the induced breeding of *H. fossilis* makes it possible to culture the fish commercially, the demand for wild *H. fossilis* at the consumer level is still high. Moreover, the high price difference between capture and culture *H. fossilis* makes it vulnerable in a natural waterbody and it has become prone to overexploitation. The information of biometric indices of any species in a particular water body can give valuable insights about a health condition, population structure, growth pattern, exploitation rate, reproduction, natural mortality, age, age at first maturity, condition factor, form factor, length-weight relationship and many others. All these life history traits data of a species help understand the present condition and future perspectives for species conservation and sustainability. For example, proper management of any natural water body, the length weight relationship (LWR) and length-length relationship (LLR) data can give very important insights and suggestions **(Dinh *et al*., 2022)**. LWR data are known to provide information about growth patterns, food obtainability, and water quality of the respective water body. Length Frequency Distribution (LFD) of any species in a particular water body gives valuable information about population structure, age and growth pattern. Growth pattern and LWR of fish helps understand the mortality and exploitation rate of the fish. For growth parameters, knowledge about growth performance index (Ø′), asymptotic length (L_∞), age at zero length (t_0), growth coefficient per year (K), life-span/longevity in year (t_{max}) is important **(Nadia *et al*., 2023)**. Moreover, LFD and growth parameter data of a fish species give valuable insights into the mortality parameters of the fish. Total mortality (Z), natural mortality (M) and fishing mortality (F) data are much needed to estimate the exploitation rate (E) of the fish.

Moreover, condition factors give insights about the well-being of the fish, surrounding water conditions and interaction between these in that particular habitat **(Dinh *et al*., 2022)**. The condition factor of fish influences age pattern, first age of maturity and optimum catchable length **(Famoofo & Abdul, 2020)**. Relative condition factor (K_r) gives insights into the well-being of fish related to food condition, spawning, habitat and water quality. At the same time, Fulton's condition factor (K_F) provides particular information about health conditions in different stages of the development cycle, such as the spawning season. This information benefits ecosystem modeling and fish population dynamics.

Although some studies have been carried out on *H. fossilis* from different water bodies around the world, such as in India (Ganga River, **Khan *et al*., 2012;** Chalakudy River, **Renjithkumar *et al*., 2021)**, Bangladesh (Nageshwari River, **Ferdaushy & Alam, 2015)** Atrai River and Brahmaputra River, **Islam *et al*., 2017;** Gajner Beel, **Hossain *et al*., 2017; Hasan *et al*., 2022)**; and Pakistan (Indus River, **Hossain *et al*., 2016)**, no research has been done yet in detail on the biological indices of *H. fossilis*, particularly in Arial Beel of Bangladesh. This study was the first to reveal the biological parameters of the species in Arial Beel. It aimed to estimate the length-weight relationship, condition factor, form factor, growth pattern, age at sexual maturity, and optimum catchable length of the commercially important catfish *H. fossilis*. The study also included a comparative analysis of the calculated values of different population parameters of this species in various waterbodies worldwide. The findings will contribute to the development of a proper management strategy for sustainable production and habitat restoration of *H. fossilis* in Arial Beel.

MATERIALS AND METHODS

1. Study region and sampling

Arial Beel, located between the Padma and Dhaleshwari rivers, was chosen for the study because it is an important breeding ground for a wide range of fish species (Fig. 1). Sampling was conducted from 21 July 2022 to 22 March 2023, a period of nine months, from artisanal fishers in Sreenagar Upazila Bazar, Arial Beel.

A total of 201 specimens of *H. fossilis* were collected utilizing a variety of traditional fishing apparatuses. For instance, cast nets with a mesh size ranging from 1 to 2cm, lift nets with a mesh size of less than 0.5cm, and gill nets with a mesh size between 1.5 and 2.5cm were employed. Subsequent to the collection process, the specimens were immediately placed in an icebox prior to their transportation to the laboratory for fixation in 10% neutral buffered formalin. The total length (TL) and standard length (SL) of each specimen were measured utilizing a wooden measuring board, achieving an accuracy of 0.01cm. A digital balance was employed to precisely ascertain the body weight (BW) with a sensitivity of 0.01g.

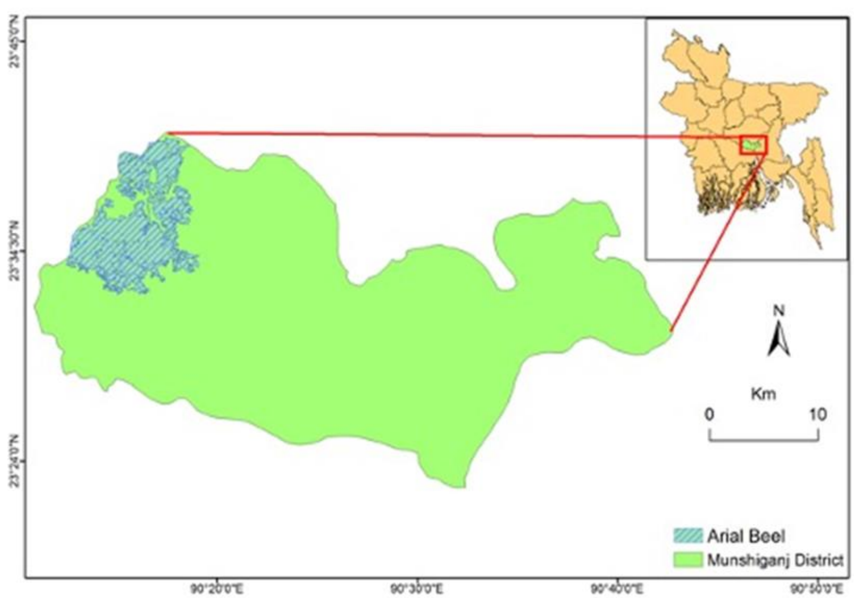

Fig. 1. The map indicating the sampling locations in Arial Beel, Munshiganj, Bangladesh

2. Population structure

Total length, standard length, and body weight were measured with their mean values at a 95% confidence interval. The length frequency distribution (LFD) for the *H. fossilis* population was plotted using 5.0cm class intervals of total length (TL) and standard length. The weight frequency distribution of this species was plotted using 10.0g class intervals.

3. Growth pattern

The formula, $W = a \times L^b$; where W represents total weight (g), L represents total length (cm), and a and b are regression parameters, was used to assess the link between length and weight **(Froese, 2006)**. Before regression, natural logarithms were used to eliminate obvious outliers at a 95% confidence level: $\ln(W) = \ln(a) + b \ln(L)$, and the highest deviation was avoided in the analysis. As a result, the t-test was applied to assess the significant deviation from the isometric value (b = 3 for LWR and b=1 for LLR).

The calculated allometric coefficient (b) values of TL vs. BW in LWR were utilized to identify fish species growth patterns. Allometric growth can be positive (when b > isometric value) or negative (when b < isometric value).

4. Growth parameters

The von Bertalanffy (VBG) model was used to explain the growth parameters (L_t, mean length at age t; t, age in years; and t_0, hypothetical age at zero length). The length basis formula utilized was $L_t = L_\infty [(1\text{-exp}\{-K(t\text{-}t_0)\}]$. Furthermore, the growth parameter and asymptotic length (L), were calculated based on the maximum recorded length using the following relationship: $\log(L_\infty) = 0.044+0.9841\times\log(L_{max})$. The rest of the growth parameters were checked using formulas from **Pauly and Munro (1984)**. The age at zero length was calculated using the relationship $\log(-t_0) = -0.392-0.275 \log L_\infty - 1.038 \log K$ **(Pauly, 1980)**, and the growth coefficient (K) was calculated using the equation $K = \ln(1+L_m/L_\infty)\ t_m$ **(Beverton, 1992)**. In addition, the asymptotic weight (W_∞) was computed through $W_\infty = a \times L_\infty\ b$, and the growth performance index was determined through $Ø' = \log10K+2\ \log10L_\infty$. Finally, lifespan or longevity was determined using the equation $t_{max} = 3/K$.

5. Form factor

The form factor ($a_{3.0}$) was estimated using the following formula of **Froese (2006)**: $a_{3.0} = 10^{\log a\text{-}\ s\ (b\text{-}3)}$, where a and b are the regression parameters of LWRs and s is the regression slope of ln a vs. b. During this study, a mean slope S = -1.358, was picked as a proxy since a lack of LWR data for this species.

6. Condition factors (CFs)

Four condition factors—allometric condition factor (K_a), Fulton's condition factor (K_x), relative condition factor (K_r), and relative weight (W_r)—were assessed in this study to evaluate the health and environmental status of *Heteropneustes fossilis* in the Arial Beel. The allometric condition factor (K_a) was calculated using Tesch's equation: $K_a = W / L^b$, where *W* represents body weight (BW), *L* denotes total length (TL), and *b* is the exponent from the length–weight relationship (LWR).

Fulton's condition factor (K_x) was determined using the formula: $K_x = 100 \times (W / L^3)$, where *W* represents BW and *L* denotes TL. The constant 100 is used to bring the value of K_x closer to unity.

The relative condition factor (K_r) was computed using Le Cren's equation: $K_r = W / (a \times L^b)$, where *a* and *b* are constants from the LWR, and *W* and *L* represent BW and TL, respectively.

Lastly, the relative weight (W_r) was estimated using the equation: $W_r = (W / W_s) \times 100$, where *W* is the observed BW and W_s is the standard weight, calculated as $W_s = a \times L^b$.

7. Size at sexual maturity (L_m) and optimum catchable length (L_{opt})

The size at sexual maturity (L_m) for *H. fossilis* was ascertained utilizing the formula formulated by **Binohlan and Froese (2006)**: $\log (L_m) = - 0.1189 + 0.9157 \times \log (L_{max})$, wherein L_{max} represents the maximal total length (TL) of *H. fossilis* and L_m denotes the size at sexual maturity in TL. The equation employed for assessing the age at maturity (t_m) was t_m (50%) = $(1/1) \times \ln (1\ L_m/L_\infty)$. The optimal length ($L_{opt}$) was evaluated through two distinct empirical models to compare the reliability of the estimated value; the first model is based on the work of **Froese and Binohlan (2000)** expressed as $\log L_{opt} = 1.0421*\log (L_\infty)- 0.2742$. Additionally, the **Beverton (1992)** model was implemented to assess $L_{opt} = L_\infty\ [3/ (3 + M/K)]$; where L_∞ signifies the projected asymptotic length, as articulated by $\log (L_\infty) = 0.044 + 0.9841 \times \log (L_{max})$ in which M connotes natural mortality, and K is the growth coefficient, with $K = \ln (1 + L_m/L_\infty)\ t_m$ **(Pauly & Munro, 1984)**. A trio of fisheries indicators is utilized in the present investigation for stock management. (i) The percentage of mature individuals within the catch, with a target of 100%; (ii) The proportion of specimens exhibiting optimal length in the catch, with 100% as the aim, ± 10% of the optimal length derived from specimen frequency, with 100% as the aim; and (iii) An additional 10% of L_{opt} of mega-spawners from stock structure, with a target of 0% **(Froese, 2004)**.

8. Mortality

Natural mortality was estimated by using the formula of $\ln M = -0.0152 - 0.279\ln[L_\infty] + 0.6543\ln[K] + 0.463\ln[T]$, **(Pauly, 1980)**; $M = \exp(1.46 - 1.01\ln[L_m])$ **(Hoenig, 1983)**; $M = -\ln[0.01]/t_{max}$ **(King, 1995)**, and $M=1.60K$ and; $M=1.65/L_m$ **(Jensen, 1996)**. Here, 27 ℃ temperature was considered for Arial Beel, Bangladesh. In the present study, multiple empirical relationships were employed to gather more precise data and examine their suitability and similarity in tropical water bodies for catfish.

9. Statistical analysis

The data set was analyzed using Microsoft Excel and IBM SPSS statistics 21. Analysis of Covariance (ANCOVA) was performed to assess significant differences in slopes and intercepts across the relationships. A linear regression model was employed to investigate the LLR (SL vs. TL). The correlations among variables were tested and plotted using the "Performance Analytics" packages in R, version 4.0.5 **(R Development Core Team, 2021)**. All the analyses were done at a 5% (P<0.05) significance level.

RESULTS

1. Population structure

Explanatory data for length (cm) and weight (g) measurements, together with their 95% confidence intervals (CI), are depicted in Table (1). The smallest and the largest individuals were 6.60 and 32.40cm in TL, respectively, while the SL varies from 6.00 and 29.60cm. BW ranges from 1.20 to 144.00g. The total length (TL) size groups of 15.00–19.99cm (37.31%) and 20.00–24.99cm (17.91%) were numerically dominant, together accounting for more than half (55.22%) of the total population. In terms of body weight, the 10–20g group was the most abundant (26.87%), followed by the 1.0–10g group (15.92%) and the 20–30 g group (12.44%) (Fig. 2).

Table 1. Explanatory statistics for the length (cm) and weight (g) measurements of *Heteropneustes fossilis* in the Arial Beel, Bangladesh.

Measurement	n	Minimum	Maximum	Mean ± SD	CI $_{95\%}$
Total Length (cm)		6.60	32.40	18.85± 6.73	17.91 to 19.79
Standard Length (cm)	201	6.00	29.60	17.06± 6.16	16.20 to 17.92
Body Weight (g)		1.20	144.00	43.56 ± 39.70	38.03 to 49.10

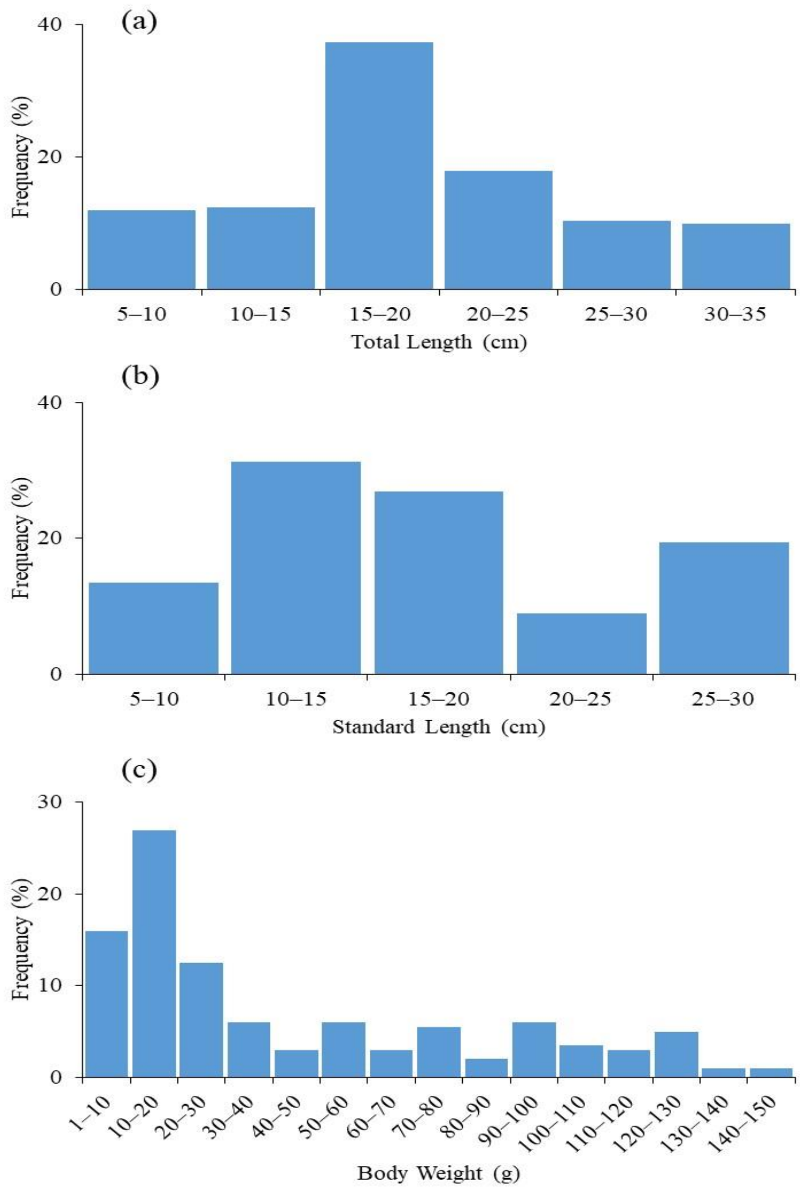

Fig. 2. Frequency of (a) total length, (b) standard length and (c) body weight of *Heteropneustes fossilis* in the Arial Beel

2. Growth pattern

The regression parameters, 95% CL of a and b, and the coefficient of determination (r^2) and growth pattern (GP) of *H. fossilis* are represented in Table (2). The acquired allometric coefficient (b) between TL and BW indicates a negative allometric growth pattern of this species (b<3.00; *P*<0.0001) (Fig. 3). In addition, the b value between SL and TL likewise indicates the negative allometric growth pattern (b<1). Both LWR and LLR were highly significant (*P*<0.0001), with r^2 values being 0.98 and 0.99, respectively. The relationship between TL and SL, and TL and BW of *H. fossilis* in Arial Beel are shown in Fig. (3).

Table 2. Descriptive statistic of length-weight and length-length relationships of *Heteropneustes fossilis* in the Arial Beel

Formula	n	Regression variables		a (±95%CI)	b (±95% CI)	r^2	GP
		a	b				
BW = a× TL^b	201	0.006	2.93	0.005 to 0.007	2.87 to 2.98	0.98	-A***
TL = a + b × SL		-0.175	0.91	-0.324 to -0.027	0.91 to 0.92	0.99	-A***

Notes: ***n*:** sample size, a and b: parameters in the length-weight relationship, CL: confidence limit, r^2: coefficient of determination, GP: growth pattern, -A: negative allometric growth. *** denotes <0.001, respectively.

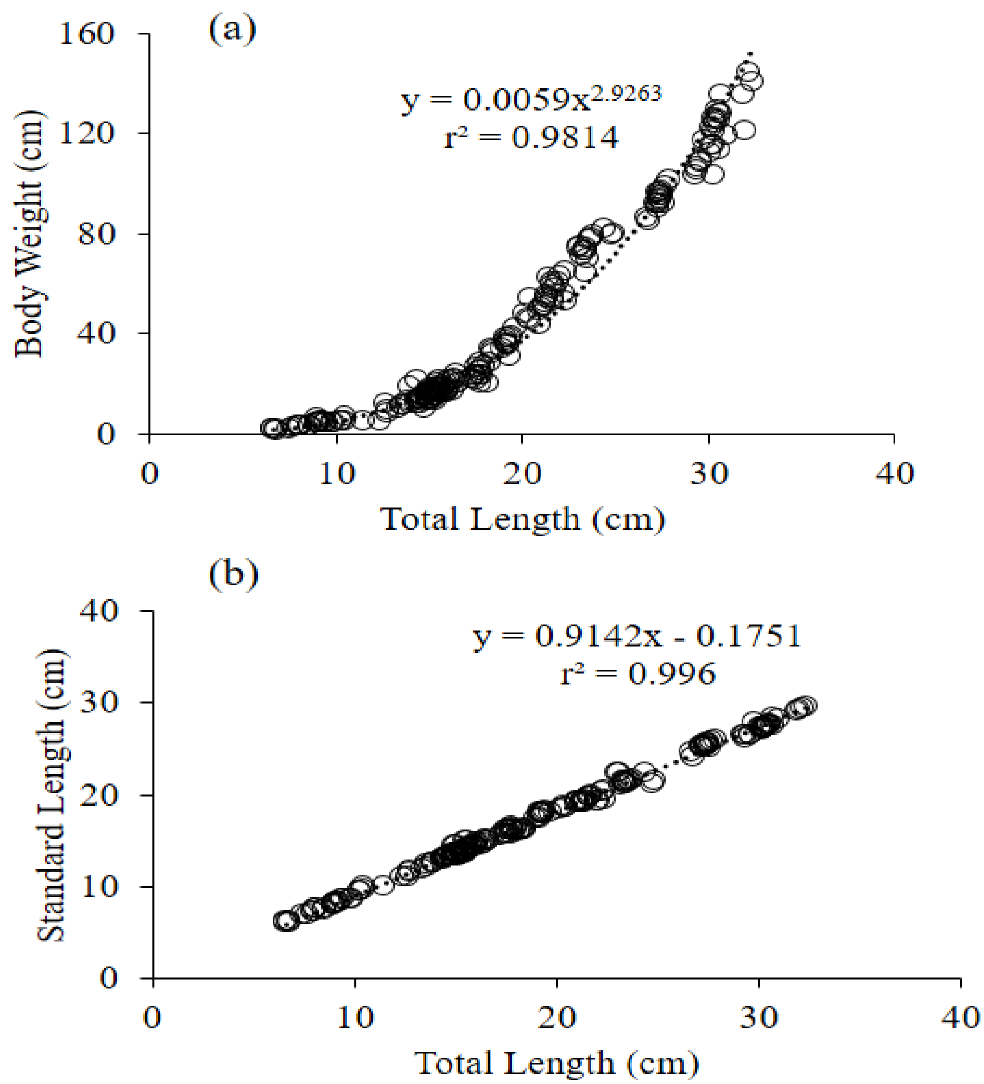

Fig. 3. Relationship between (a) total length and body weight, and (b) total length and standard length of *Heteropneustes fossilis* in the Arial Beel

3. Growth parameters

The growth parameters of the *Heteropneustes fossilis* population from the Arial Beel are summarized in Table (3). The estimated values for asymptotic length (L_∞), asymptotic weight (W_∞), and theoretical age at zero length (t_0) were 33.93cm, 177.68g, and –0.47 years, respectively, with a growth coefficient (K) of 0.34. Since a K value greater than 1 typically indicates rapid growth, the K value observed in this study suggests a relatively slow growth rate for *H. fossilis* in this environment.

Table (3) also shows that the maximum age (t_{max}) and age at first maturity (t_m) were estimated at 8.88 years and 0.78 years, respectively. The size at sexual maturity (L_m) was calculated as 18.38cm TL. Additionally, comparative analysis was conducted using growth data for *H. fossilis* from various water bodies around the world, allowing researchers to evaluate how the population from Arial Beel aligns with global growth trends (Table 5).

Table 3. Growth reproduction and mortality parameters of *Heteropneustes fossilis* in the Arial Beel

Parameter	Value
Asymptotic length in cm (L_∞)	33.93 cm
Asymptotic weight in g (W_∞)	177.68 g
Growth coefficient per year (K)	0.34
Age at zero length in cm (t_0)	0.47 cm
Growth performance index (Ø′)	2.59
Life-Span/Longevity in year (t_{max})	8.88 years
Size at sexual maturity in cm (L_m)	18.38 cm
Age at maturity in year (t_m)	0.78 year
Natural mortality per year (M*)	0.52 year^{-1}
Optimum catchable length (L_{opt})	22.44 cm

NB: * Indicates the value acquired by the formula of King, 1995.

4. Condition factors (CFs) and prey-predator status

Table (4) represents the average value of allometric (K_A), Fulton's, relative condition factor (K_r) and relative weight (W_R) with minimum and maximum values. The mean K_A was 0.006 (0.001) and the lowest and highest K_A were 0.003 and 0.01, respectively. The average K_F was 0.48 (0.078), with minimum and maximum K_F being 0.26 and 0.82, respectively (Table 4). The mean K_r was 1.01 (0.16), with a minimum of 0.54 and a maximum of 1.64. The mean W_R was 100.64 (15.69), with the lowest and highest W_R being 53.51 and 164.02, respectively. Pearson correlation among TL, SL, W, various condition factors (i.e. K_A, K_F, K_r) and W_R are shown in Fig. (4). TL and SL were significantly positively related with weight (r = 0.96, Fig. 4). K_F showed a significant negative correlation with TL and SL (r = -0.19, -0.18, respectively). K_F was significantly positively correlated with K_r and W_R (r = 0.98) (Fig. 4). In addition, the relationship of relative weight (W_R) with total length (TL) is shown in Fig. (5). The highest relative weight gain was observed in 21–24 followed by 24–27 and 18–21cm TL.

Table 4. Statistics for condition factor (CF) measurements, including 95% confidence intervals (CI) and the correlation estimates between CFs and total length (TL) of *Heteropneustes fossilis* in the Arial Beel, Bangladesh

CFs	Minimum	Maximum	Mean ± SD	CI 95%

K_A	0.003	0.01	0.006±0.001	0.0058 to 0.0061
K_F	0.26	0.82	0.481±0.078	0.470 to 0.492
K_r	0.54	1.64	1.006±0.157	0.985 to 1.028
W_R	53.51	164.02	100.638±15.686	98.456 to102.819

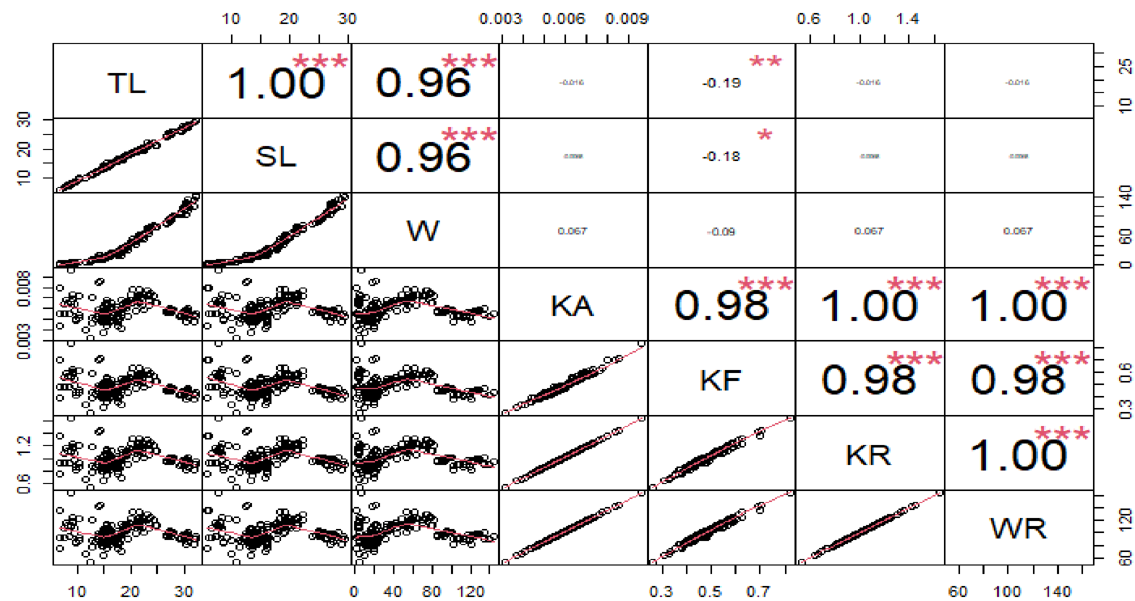

Fig. 4. Pearson correlations among total length, standard length, body weight, allometric (K_A), Fulton's (K_F), relative (K_r) condition factor, and relative weight (W_R) of *Heteropneustes fossilis* in the Arial Beel. Note: *,** and *** denote *P*<0.05, <0.01 and <0.001, respectively

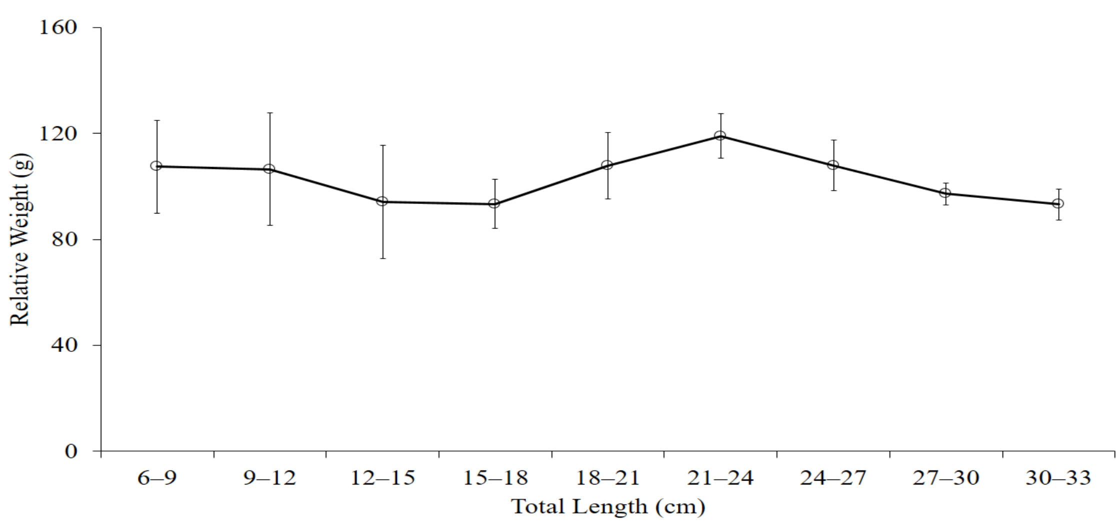

Fig. 5. Relationship between total length and relative weight of *Heteropneustes fossilis* in the Arial Beel

5. Form factor

The value of $a_{3.0}$ was noted as 0.005 for combined sexes of *H. fossilis* in the Arial Beel. Furthermore, using existing data, $a_{3.0}$ of *H. fossilis* obtained from different waters around the world was calculated and denoted in Table (5).

6. Size at sexual maturity and optimum catchable length

The size at sexual maturity (L_m) for the *Heteropneustes fossilis* population in the Arial Beel, Bangladesh, was estimated at 18.38 cm total length (TL), with the corresponding age at maturity (t_m) calculated as 0.78 years. The optimum catchable length (L_{opt}) was determined to be 20.93 cm TL based on the empirical model of **Froese and Binohlan (2000)**, and 22.44cm TL using the model proposed by **Beverton (1992)** (Table 5). Across global water bodies, L_{opt} values calculated using **Beverton's (1992)** empirical relationship were consistently slightly higher than those derived from **Froese and Binohlan (2000)**.

In this study, the researchers also calculated and compared maximum length (L_{max}), size at maturity (L_m), age at maturity (t_m), and optimum length (L_{opt}) for *H. fossilis* using existing data from various aquatic systems worldwide, providing a comparative framework for evaluating the growth and maturity patterns of the Arial Beel population (Table 5).

7. Natural mortality

The natural mortality rate (M) of *Heteropneustes fossilis* in the Arial Beel was estimated using several established empirical models. The calculated values were 0.83, 0.52, 0.54, 2.12, and 0.47 per year, derived using the formulas proposed by **Pauly (1980)**, **Hoenig (1983)**, **King (1995)** and **Jensen (1996)**, respectively. These estimates reflect methodological differences among the models. Additionally, natural mortality rates for *H. fossilis* from various global water bodies were compiled for comparison and are presented in Table (5). The observed variation in natural mortality values across different habitats ranged from 0.47 to 2.12 per year, highlighting ecological and environmental influences on population dynamics.

Table 5. Calculated asymptotic length, size at sexual maturity, age at maturity, natural mortality and optimum catchable length of *Heteropneustes fossilis* obtained from different water bodies around the world

Water body	Sex	Regression parameter		L_{max} (cm)	Lα	$a_{3.0}$	L_m (cm)	t_m (y)	M (y^{-1})					L_{opt}		References
		a	B				Max L based		$\ln M = -0.0152 - 0.279\ln[L_\infty] + 0.6543\ln[K] + 0.463\ln[T]$ **(Pauly, 1980)**	$M^*_w = -\ln(0.01)/t_{max}$ **(King, 1995)**	$M = 1.60K$ **(Jensen,1996)**	$M = 1.65/t_m$ **(Jensen,1996)**	M= Exp (1.46–1.01 Ln [t_{max}] **(Hoenig 1983)**	L_{opt} = antilog {1.0421 * log(L_∞) - 0.2742} **(Froese and Binohlan, 2000)**	$L_{opt} = L_\infty$ {3/ (3 + M*/K)} **(Beverton, 1992)**	
Bangladesh																
Arial Beel, Munshiganj	C	0.006	2.926	32.4	33.93	0.005	18.38	0.78	0.83	0.52	0.54	2.12	0.48	20.93	22.44	**Present study**
Gajner Beel	C	0.004	3.07	24.10	25.35	0.005	14.02	0.81	0.93	0.54	0.57	2.05	0.50	15.45	16.77	**Hasan *et al.*, 2022**
Gajner beel floodplain, Pabna,	C	0.006	3.01	16.50	17.46	0.006	9.91	0.83	1.08	0.58	0.60	1.97	0.53	10.48	11.55	**Hossain *et al.*, 2017**
Gajner beel floodplain, Pabna,	C	0.004	3.08	26.80	28.15	0.005	15.45	0.8	0.90	0.54	0.56	2.07	0.49	17.23	18.52	**Rahman *et al.*, 2019**
Atrai River and Brahmaputra River	C	0.008	2.86	13.70	14.54	0.005	8.36	0.86	1.16	0.60	0.62	1.93	0.55	8.66	9.62	**Islam *et al.*, 2017**

Nageshwari	C	0.047	2.68	15.50	16.42	0.017	9.36	0.84	1.10	0.58	0.61	1.96	0.54	9.83	10.87	**Ferdaushy and Alam, 2015**
								India								
Ganga River	C	0.004	3.14	31.00	32.48	0.006	17.65	0.78	0.85	0.52	0.55	2.11	0.48	20.00	21.49	**Khan *et al*., 2012**
Deepar Beel, Assam,				19.10	20.16		11.33	0.83	1.02	0.57	0.59	2.0	0.52	12.17	13.36	**Das *et al*., 2015**
Chalakudy River, Western Ghats	C	0.007	2.94	41.2	42.98	0.006	22.90	0.76	0.76	0.50	0.52	0.07	0.46	26.78	28.43	**Renjithkumar *et al*., 2021**
								Pakistan								
Indus River	C	-1.45	2.13	13.00	13.81		7.96	0.86	1.18	0.56	0.63	1.92	0.55	8.20	9.33	**Hossain *et al*., 2016**

*Indicates a particular parameter in the equation

DISCUSSION

In this study area, the largest recorded length of *H. fossilis* was 32.4cm, which is consistent with data from other parts of the world. The maximum length of the species found in the Ganga River, India was 31cm **(Khan *et al*., 2012)**, which is almost the same as the length recorded in this study. However, in other areas of Bangladesh, such as Gajner Beel, Atrai and Brahmaputra, and Nageshwari River, the maximum lengths found were lower (26.80cm, 13.70cm, and 15.50cm, respectively), and in Pakistan (Indus River), the maximum length recorded was 13.00cm. The only exception was the species found in the Chalakudy River, India, which had a maximum length of 41.2cm **(Renjithkumar *et al*., 2021)** (Table 5).

The body weight of the recorded fish (1.20 to 144.00g) falls within the range of findings from other areas. For example, **Hasan *et al*. (2020)** found a minimum weight of 1.20 grams in Gajner Beel, Bangladesh, while **Renjithkumar *et al*. (2021)** recorded a maximum weight of 400 grams in Chalakudy River, India. The maximum body weight recorded is similar to the findings of *H. fossilis* in the Ganga River (146.55g), as reported by **Parvin *et al*. (2022)**. The recorded values were compared with the data of online FishBase **(Froese & Pauly, 2018)** and the findings of other scientific researches. Noteworthy, the maximum length observed in our study is comparatively higher than most of the previous findings. This might be due to Arial Beel's highly productive location at the convergence of two rivers and its nutrient-rich environment, receiving both chemical and organic nutrients from neighboring croplands.

The growth pattern of *H. fossilis* in this study was negative allometric ($b < 3$). This negative allometric pattern is consistent with previous observations on wetlands of Bangladesh such as the Nageshwari, Bangladesh **(Ferdaushy & Alam, 2015)**, Indus River, Pakistan **(Hossain *et al*., 2016)**, and Atrai River and Brahmaputra River, Bangladesh **(Islam *et al*., 2017)**. Negative allometric growth in fish has been associated with either environmental conditions or morphological characteristics of specific species. This suggests that larger specimens may have undergone a body shape change to become more elongated, or that smaller specimens had a higher nutritional status at the time of sampling. The growth pattern of fish would be greatly influenced by the sampling methodology and period **(Froese, 2006)**. The limitation of this study was restricted to 9 months rather than year-round; this study would suggest further year-round studies.

The growth parameters were determined to know the future yields and stock biomass of the water body as those are so crucial to assessing the health of a certain water body. In this current study, the calculated growth parameters L_∞, Ø′ and K were 33.93cm, 2.59 and 0.34 per year, respectively for *H. fossilis*. In this case, the estimated $L\infty$ was high compared with our largest specimen due to shortcomings of Von Bertalanffy growth model. The prime drawback of this growth model is the nonlinear growth pattern of fish at an early age, fish grow faster than their later age **(Etim *et al*., 2002)**. Therefore, it is suggested that to overcome the mentioned problem, the growth performance index (Ø′) could be the more accurate way to determine and compare the growth performance index where both L_∞ and K are considered **(Pauly & Munro, 1984)**.

The growth coefficient K describes the rate of achieving the maximum length of a species, however, it does not represent the absolute growth rate. Due to the K values for *H. fossillis* being less than 1, slower growth rates were found in the present study. Since a species or stock has varied growth rates across its life stages, **Etim *et al*. (2002)** claimed that a straight comparison between L_∞ and K does not produce an appropriate prediction. As a result, the growth performance index (Ø') is a more. Due to the varied growth rates of a species or stock across its life stages, **Etim *et al*. (2002)** argued that a direct comparison between L_∞ and K does not yield an accurate prediction. Consequently, the growth performance index (Ø') is a more comprehensive method for comparing the growth performance **(Pauly & Munro, 1984)**. Ø′ was calculated which was 2.59 based on body weight at harvest. A high-value performance index reflects to the better adaptation of fishes in avoiding predators by rapidly expanding their size and lowering their chance of becoming prey. Remarkably, this study represents the initial attempt to calculate the growth performance index of *H. fossilis*; hence, further comparisons with other results will be necessary. In addition, the assessed life span (t_{max}) was 8.88 years and the age at zero length (t_0) was 0.4741cm in the current study.

The $a_{3.0}$ indicator helps assess fish body shape differences between populations or species **(Froese, 2006)**. In the current study, the value of $a_{3.0}$ (0.005) designates the body shape *H. fossilis* in Arial Beel is elongated as it is within the range of 0.003–0.018, 5th–95th Percentile **(Froese, 2006).** The result is supported by **Islam *et al*. (2021)**, who found an $a_{3.0}$ value (0.0063) indicating an elongated body shape.

Four CFs (K_A, K_r, K_F, and W_R) were examined during this research endeavor, to elucidate the health status of fish populations and the condition of the aquatic environment, along with their interrelations. CFs serve as a quantifiable metric for evaluating the success of development, reproductive success, and survival rates; they provide a quantitative assessment of the overall well-being of fish, ultimately reflecting on the viability of both current and future populations **(Richter, 2007)**. In this study, the average value of the K_A was 0.006 (Table 2). The value is consistent with previous records such as those in Padma River of Bangladesh (0.002; 0.002-0.002) **(Parvin *et al*., 2019)** and Gajner Beel (0.002–0.0098) **(Hasan *et al*., 2020)**.

The range of K_F (mean 0.48, from 0.26 to 0.82) is consistent with previous findings in freshwater and wetlands of Bangladesh Gajner Beel (mean 0.48, from 0.33 to 0.72) **(Ferdaushy & Alam, 2015)** and Padma River, Bangladesh (mean 0.52, from 0.32 – 0.70) **(Parvin *et al*., 2019)**. Note that K_F serves as an index that illustrates the correlations between biotic and abiotic factors influencing the physiological states of fish. Additionally, it provides insights into the well-being of populations at various stages of their developmental cycles. **Hasan *et al*. (2022)** demonstrated that the K_F values exhibited a positive correlation with the spawning period of *H. fossilis*, which commenced in April, peaked in June, and concluded in August. The study, therefore, suggests further studies on the interrelationship between spawning seasons and condition factors of *H. fossilis* in Arial Beel.

The average value of the relative condition factor (K_r) for this species was 1.012 (min 0.538 – max 1.646). Its average value suggests a state of well-being for the species tested. The deviation of K_r from the value of 1 provides critical insights regarding variations in food availability and the impact of physicochemical characteristics on the life cycle of fish species **(Le Cren, 1951)**. Numerous factors contribute to the growth condition of fish, including reproductive cycles, food availability, as well as habitat and environmental influences **(Morato *et al.*, 2001)**. Since the rivers and wetlands of Bangladesh are rich in benthos organisms (i.e. oligochaeta, polychaeta, insect, bivalve and gastropoda, etc.) **(Khan *et al.*, 2007)**, these organisms support the growth of *H. fossilis*. The feeding habit is also further influenced by spawning season **(Lizama & Ambrosio, 2002; Jahan & Mahmud, 2025)** and water quality parameters (i.e. temperature; **De Giosa *et al.*, 2014**). It is observed, however, K_r is sometimes related positively and negatively related with temperature and spawning, respectively **(Lizama & Ambrosio, 2002; De Giosa *et al.*, 2014)**.

W_R is frequently employed as an index to assess the status of fish within their ecosystems **(Froese, 2006)**. It helps to estimate the conditions of prey-predator dynamics and ecosystem disturbances at the population level **(Rypel & Richter, 2008)**. Low W_R values (i.e., <100) for individuals or populations suggest underlying issues such as limited prey accessibility or elevated predator density. Conversely, high W_R values (i.e., >100) indicate an abundance of prey or diminished predator density **(Rypel & Richter, 2008)**. The average WR value for *H. fossilis* in this study was found to exceed 100, thereby implying that the Arial Beel ecosystem is conducive to the growth of *H. fossilis*, potentially owing to ample food resources and/or a lower prevalence of its predatory fish counterparts. The average value of W_R of *H. fossilis* were above 100 in this study, suggesting that the Arial Beel ecosystem is suitable for *H. fosssilis* growth, perhaps due to sufficient food abundance and/or lower abundance of its predatory fishes.

Effective management systems for fish protection depend on data about size at sexual maturity and optimal catchable length. In the current study, there was a slight difference between the estimated L_{opt} for *H. fossilis* in the Arial Beel, Bangladesh and it was 20.93 and 22.44cm TL **(Beverton, 1992; Froese & Binohlan, 2000)**. Considering the **Beverton (1992)** model, it is suggested that *H. fossilis* whose length is below 22cm should not be caught. In this study, it was observed that 56.72% of the caught fish were juveniles, whereas 23.88% of fish were mature, and the rest of the fish belonged to the mega spawner group (Fig. 6).

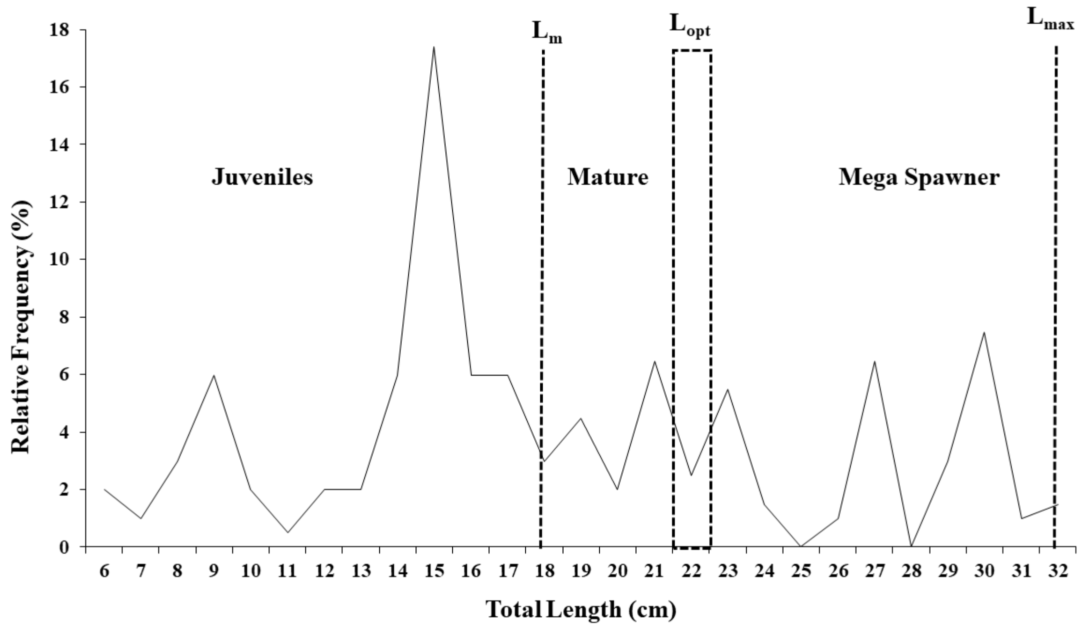

Fig. 6. Optimum catchable length of of *Heteropneustes fossilis* in Arial Beel (L_m, size at sexual maturity, L_{opt}, optimum catchable length, L_{max}, maximum length)

To achieve the catch of mature fish, initial mature individuals should not be caught before spawning. Besides, this is essential to protect mega-spawners from achieving vigour and more fecund fish **(Froese *et al*., 2016).** In this study, the L_{opt} (22.44) is larger than the maturity size (18.38). Therefore, fish should be allowed to grow up to 22.44 cm and not to be caught the fish less than 18 cm in any situation for sustainable stock management. On the other hand, upon juxtaposing this value with the computed L_m of alternative aquatic ecosystems, it becomes evident that the value exhibits a remarkable similarity to the derived values of the Ganga River and Chalakudy River, India **(Khan *et al*., 2012; Renjithkumar *et al*., 2021)**, however much higher than the Indus River, Pakistan **(Hossain *et al*., 2016)**. This may be the result of geographical variation.

The determination of mortality rates is of paramount importance for the accurate estimation of species abundance and the implementation of harvest restrictions aimed at optimizing yield **(Nadia *et al*., 2023)**. Natural mortality was calculated by using five different formulae and the values were compared with the species found in other water bodies. The range of natural mortality assessed by different empirical formulas varies from 0.52 to 2.12. The value calculated by the formulae of **Hoenig (1983); King (1995)**, and **Jensen (1996)** (based on K) varies slightly. However, it differs greatly from the empirical formula proposed by **Pauly (1980)** and **Jensen (1996)** (based on t_m). Natural mortality of *H. fossilis* was estimated at 1.09 year^{-1} and 0.93 year^{-1} in Gajner Beel and Padma River, Bangladesh **(Islam *et al*., 2021; Parvin *et al*., 2022)**. Although the estimation formula used in both cases was different than the current study however the obtained values were in the range of the current study, specifically similar to the value of **Pauly (1980)**.

CONCLUSION

The study revealed a detailed insight into the population parameters of *H. fossilis* from the Arial Beel wetland in northern Bangladesh, suggesting a fairly suitable condition for better growth. The recorded maximum length indicates good growth and well-being of the habitat. However, results from the optimum catchable length suggested more than half of the catch were juveniles giving a prior hint that there is a potential risk of overfishing, which should be taken into consideration for proper management. The population parameters found for *H. fossilis* in the study consider the Arial Beel as one of the sound ecosystems compared to other opened and semi-opened freshwater bodies in Bangladesh, which indicates the necessity for further research focus with larger and broad-scale data sets to recognize it as a model and healthy ecosystem in terms of sustainable management of the aquatic environment and freshwater resources.

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