Aquatic Resource Sciences

Journal homepage: www.journal.inrrd.com/ars

Original article

Temporal variations of sex ratio, size structure, growth pattern and physiological conditions of Stinging Catfish *Heteropneustes fossilis* in the Ganges River in relation to eco-hydrological parameters

Most. Farida Parvin[1,2], Md. Ashekur Rahman[2,3], Md. Mizanur Rahman[4], Sohag Molla[3], and Md. Yeamin Hossain[3]*

[3]*Institute of Environmental science (IES), University of Rajshahi, Rajshahi-6205, Bangladesh*
[2]*Institute of Natural Resources Research and Development, Rajshahi 6206, Bangladesh*
[3]*Department of Fisheries, University of Rajshahi, Rajshahi 6205, Bangladesh*
[4]*Department of Aquaculture, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh*

ARTICLE INFO

Article history
Received 14 January 2024
Revised 29 February 2024
Accepted 03 March 2024
Available online 05 March 2024

Keywords
Sex ratio
Size structure
Growth pattern
Physiological condition
Heteropneustes fossilis
Ganges River

ABSTRACT

Monthly variations of sex ratio, population structure, growth pattern and physiological conditions of *Heteropneustes fossilis* were studied from Ganges River, northwestern (NW) Bangladesh. Specimens of male (539) and female (622) were captured during January to December, 2019 by fishers. A measuring board and electronic balance were used to measure lengths and body weight for each specimen, respectively. Statistically, sex ratio varied from the estimated 1:1 ratio. Except in December, proportions of females were greater than males over the year. The ranges of total length were 8.5-22.2 cm and 8.9-28.7 cm for males and females, respectively. For both sexes, overall growth pattern was positive allometric and ANCOVA showed highly significant variation in length-weight relations. The length-length relationships were exceedingly significant with $r^2 \geq 0.984$. The maximum proportion of fatty fish was observed in June for both sexes where lowest in October for females and November for males. Percentage of fatty fishes was showed significant relation with environmental factors. These results will be helpful for advance research and provides sustainable management policy for *H. fossilis* in the Ganges River and adjoining water bodies.

Introduction

Catfish, the frequent name of a miscellaneous group of bony ray-finned fish under the order Siluriformes, inhabited in brackish inland coastal waters, but the largest part inhabit shallow and running water and are existed in Asia, America and Africa (Bruton 1996). Because of its enormous economical significant and aquarium purpose, it has momentous significance in different countries (Sarkar et al. 2017). Various reasons present for the increased interest in cultivating this type of fish, including its high growth rate, patience with the complicated environmental circumstance and acceptability of consumers as it is eaten fresh at all time. (Sarkar et al. 2017).

Heteropneustes fossilis (Bloch 1794) is a precious catfish of the order Siluriformes generally known as shinghi or shinghee in Bangladesh (Rahman et al. 2019). Adults exits in ditches, ponds, marshes, swamps, and sometimes in muddy rivers (Hasan et al. 2020; Halwart and Gupta 2004). This fish has significant commercial worth because of its exceptional taste, high medicinal significance with

*Corresponding author
Email address: hossainyeamin@gmail.com (Md. Yeamin Hossain)

high-quality protein, calcium and iron (Jayalal and Ramachandran 2012; Saha and Guha 1939). It is broadly distributed in Bangladesh, Laos, India, Pakistan, Nepal, Mayanmar, and Sri Lanka (Talwar and Jhingran 1991). *H. fossilis* is categorize at least concern both in Bangladesh (IUCN Bangladesh 2015) and worldwide (IUCN 2021).

Sex ratios are basic demographic characteristics of species that are strongly connected to species development (Veran and Beissinger 2009), mating structures, parental activities (Liker et al. 2014; McNamara et al. 2000), and sexual selection (Silva et al. 2010; Emlen and Oring 1977). At various phases of progress including fertilization (primary), birth (secondary), and adulthood sex ratios might be considered (Carmona-Isunja et al. 2017). Several ecophysiological allegations of sex ratios in adult life have been identified through theoretical and empirical investigations across various species on ecology, physiology, and life histories (Székely et al. 2014; Veran and Beissinger 2009). To estimate reproductive potential of fish populations, population size structures (length-frequency distribution, LFD) provide important evidence for determining spawning capacity of a fish species (Khatun et al. 2018; vazzoler 1996). The LFD assess the stock status, river health and fish spawning period in riverine fish (Ranjan et al. 2005) in addition to express the relations of the vigorous growth rates, fatality and recruitment (Neuman and Allen 2001). Information of length weight relationship (LWR) is frequently used for calculating the weight corresponding to a given length (Froese 2006) and observing the temporal variation in growth of fish and health indexes (Khatun et al. 2018). Moreover, it is important for the determination of the fish population's production and biomass. Physiological condition (i.e. fatty, ideal and lean) assists to recognize the health status of a specific species (Sutharshiny et al. 2013; Sivashanthini et al. 2013 and Thulasitha et al. 2013). Though development of fish is a complex progression affected by so many physiological, nutritional, and environmental parameters. On the other hand, temperature is documented as one of the most significant single abiotic factors affecting development, food ingestion, and food alteration of fish (Azaza et al. 2008).

However, several researches have been done on various aspects including length-length relationships (LLRs) (Ferdausy and Alam 2015) and length-weight relationships (LWRs) (Islam et al. 2021; Hasan et al. 2020; Rahman et al. 2019; Hossain et al. 2017; Muhammad et al. 2017; Das et al. 2015; Ferdaushy and Alam 2015; Khan et al. 2012) but to the best of our knowledge, there was no work on these aspects (except *Eutropiichthys vacha,* Khatun et al. 2018) of *H. fossilis* in the Ganges River. This research is therefore the first explanation on the temporal variation of the sex ratio (SR), Size structure (LFDs), growth pattern and physiological condition of *H. fossilis* in the Ganges River, northwestern Bangladesh, using monthly data for one year.

Materials and Methods

Study area and sampling

Our study was performed in the Ganges River (locally known as the Padma River in Bangladesh; Lat. 24° 35′ N; Long. 88° 64′ E), NW Bangladesh. In total, 1161 specimens (male = 539, female 622) of *H. fossilis* were collected from January to December 2019. Monthly 80-120 specimens were randomly collected from the fishers' catch landed at various points from Shampur and Bagha in Rajshahi and Najirgong, Sujanagar in Pabna of the Ganges River, northwestern part of Bangladesh (Figure 1). Gill net, cast net and square lift

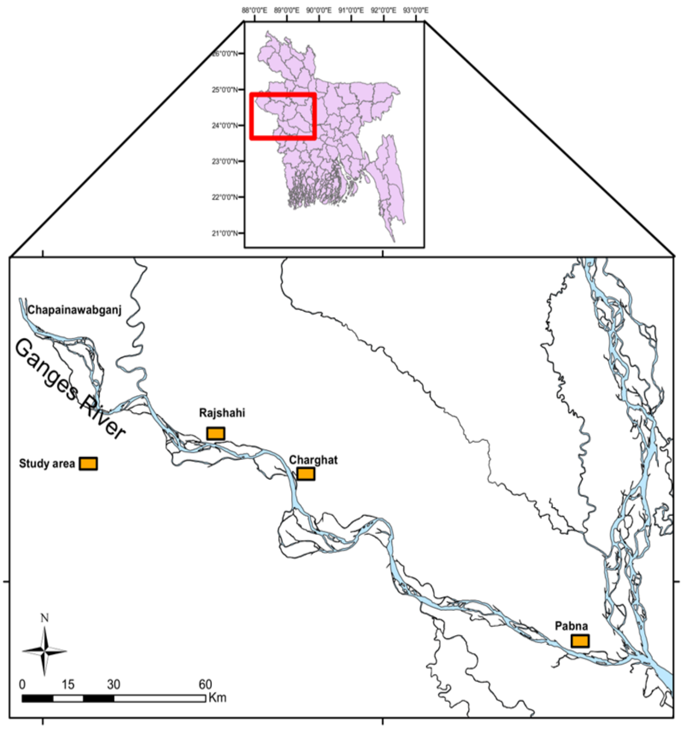

Fig. 1. The Study area of *Heteropneustes fossilis* in the Ganges River, northwestern Bangladesh

net was used by fishermen to catch the fish sample and sampling was done during day time. Samples were immediately chilled on the spot and on the arrival to laboratory fixed with 10% formalin solution.

Fish measurement

Sex classification of fish was completed by (i) morphometric and meristic characters and (ii) microscopic examination of the gonads. Every specimen was washed with water and kept dry in the air. To eliminate the excess humidity from the body surface for ensuring exact weight measurement blotting paper was used. For every specimen, total length (TL) and standard length (SL) were measured by measuring board and total body weight (BW) were taken to the nearest 0.01g accuracy by digital balance.

Size structure

For population size (length frequency distribution, LFD), 1 cm interval of TL was used for *H. fossilis*.

Growth pattern

LWR was used for estimating the growth pattern by applying the equation $W = a*L^b$ (Le Cren 1951). The regression parameters *a* and *b* were determined by: $ln(W) = ln (a) + b\ ln (TL)$. 95% confidence limits of *a* and *b* and the co-efficient of determination (r^2) were also determined. In regression analyses unfitted outliers were eliminated considering the method of Froese (2006). To confirm the growth whichever isometric or positive/negative allometric, t-test was applied and we checked deviation from the isometric value, where b=3 (Sokal and Rohlf, 1987) to clarify.

Physiological condition

Physiological state (i.e. fatty, ideal and lean) for each specimen of *H. fossilis* was calculated using the equation of King (2007) as $\hat{a} = W/(TL)^b$. If $\hat{a}$ is similar or near to the value of *a*, ideal condition is indicated, however deviation from *a* value (< *a* lean fish and > *a* fatty fish and) is suggestive to either lean or fatty fish.

Eco-hydrological parameters

Monthly ecological factors were documented from the sampling site, for assessing the effect of eco-hydrological features on physiological condition (fatty fish) of *H. fossilis*, using digital multi-meter. The recorded parameters were Temperature (ºC), pH, dissolve oxygen (mg/L) and TDS (mg/L). Additionally, the data of monthly rainfall (mm) were collected from meteorological station of Dhaka, Bangladesh.

Statistical analyses

Statistical analyses have been carried out by Microsoft ® Excel-add-in-DDXL and GraphPad Prism 6.5 software with 5% significance level. All data were checked for homogeneity of variance. In addition, a chi-square test for the determination of the sex-ratio divergence was employed as of the predictable value of 1:1 (male: female). A non-parametric test, Mann-Whitney U-test was applied to compare the mean values between sexes. Deviation of growth pattern between the sexes was determined by using ANCOVA. The influence of ecological parameters on physiological condition was done by Pearson correlation and canonical correspondence analysis (CCA).

Results

Sex ratio

During this study, out of the 1161 specimens (male = 539, female = 622; male: female = 1: 1.15) of *H. fossilis* in the Ganges River, 46% were males and 54% were females. Estimated average sex ratio (1:1.5) significantly varied from the predictable value of 1:1 (Table 1). Moreover, monthly deviation in sex ratio explained that maximum proportion occurred during October for both sexes. Throughout the year, females outnumbered the males and sex ratios varied from 1.0:0.91 in December to 1.0:1.42 in June. In addition, with length class the dissimilarity in sex ratio exhibited that the male: female ratio was almost same for the 10.00-11.99 cm and 14.00-15.99 cm TL class. On the other hand, males dominated somewhere from the 8.00-9.99 cm and 12.00-13.99 cm TL class and females for the 16.00-17.99 cm and 20.00-21.99 cm TL were significantly varied (Table 2)

Size structure

The size distribution of *H. fossilis* comprised TL ranging from 8.5-28.7 cm. The small and the large individuals were 8.5-22.2 cm TL for male and 8.9-28.7 cm TL for females (Fig. 2). Furthermore, Length-frequency distributions (LFDs) indicated that the13.00-13.99 cm TL length group was statistically prevailing and representing 15% and 21% of its population, respectively. In addition, Mann-Whitney U-test expressed considerable variance in the LFDs (U= 130986, p < 0.001) between sexes. Additionally, our findings revealed that BW of females (3.41-146.55g; 95% CL = 21.12-24.19g) was higher than that of males (3.12-61.81g; 95% CL = 14.79-16.46g),

Table 1. Monthly numbers of males, females and sex ratio (male: female = 1:1) of *Heteropneustes fossilis* (Bloch, 1794) in the Ganges River, north-western Bangladesh.

Months	Number of specimens			Sex ratio (Male: Female)	$\chi2$ (df =1)	Significance
	Male	Female	Total			
January	42	48	90	1: 1.14	0.40	ns
February	48	54	102	1: 1.13	0.35	ns
March	38	43	81	1: 1.13	0.31	ns
April	44	51	95	1: 1.16	0.52	ns
May	37	44	81	1: 1.19	0.60	ns
June	38	54	92	1: 1.42	2.78	ns
July	46	58	104	1: 1.26	1.38	ns
August	52	60	112	1: 1.15	0.57	ns
September	39	47	86	1: 1.21	0.74	ns
October	55	63	118	1: 1.15	0.54	ns
November	54	58	112	1: 1.07	0.14	ns
December	46	45	91	1: 0.91	0.18	ns
Overall	**539**	**622**	**1161**	**1: 1.15**	**5.93**	*

df, degree of freedom; ns, not significant; *significant at 5% level ($\chi^2 > \chi^2_{t1,\,0.05} = 3.84$).

Table 2. Sex ratios (male: female) across total length ranges for *Heteropneustes fossilis* (Bloch, 1794) in the Ganges River, north-western Bangladesh.

Length class TL, cm	Number of specimens			Sex ratio (Male: Female)	$\chi2$ (df =1)	Significance
	Male	Female	Total			
8.00-9.99	14	11	25	1: 0.79	0.36	ns
10.00-11.99	60	62	122	1: 1.03	0.03	ns
12.00-13.99	215	163	378	1: 0.79	7.15	*
14.00-15.99	148	169	317	1: 1.14	1.39	ns
16.00-17.99	53	107	160	1: 2.02	18.23	*
18.00-19.99	36	60	96	1: 1.67	6.00	*
20.00-21.99	12	23	35	1: 1.92	3.46	*
22.00-23.99	1	16	17	1: 16.00	13.24	*
24.00-25.99	0	6	6	1:0.00	6.00	*
26.00-27.99	0	3	3	1:0.00	3.00	ns
28.00-29.99	0	2	2	1:0.00	2.00	ns
Overall	**539**	**622**	**1161**	**1:1.15**	**5.93**	*

Notes: ns, not significant, *significant at 5% level ($\chi^2_{t\,1,\,0.05} = 3.84$)

and Mann-Whitney U-test expressed that there were significant dissimilarities in BW frequency between genders (Mann-Whitney U=128112, $p < 0.001$).

Growth pattern

The variation of coefficient *b* for TL and BW relationships designates positive allometric growth for males in nearly all of the twelve months except in April, June, October and December negative allometric growth was observed for males. Besides, isometric growth was found in February, March and July for males but in females it found February, June and December. Monthly expressive statistic measurements are represented in Table 3 and Fig. 3. All the *b* vales for the LWR illustrated in Table 4 that stated positive allometric growth (> 3.00) in males (95% CL of b = 3.14-3.27) and females (95% CL of b = 3.25-3.35). Monthly values of allometric growth for both sexes are presented in Table 4 and Fig. 4). All LWRs were significant to strongly significant (p <

0.001), with all r^2 values ≥ 0.935, and analysis of covariance (ANCOVA) result showed that there were very significant dissimilarities between males and females for the slopes (*b*) (*F*=7.2210, *df* = 1157, *p*= 0.0073). Furthermore, the relation of TL vs. SL of *H. fossilis* was highly significant ($p < 0.001$) and the r^2 value was >0.984.

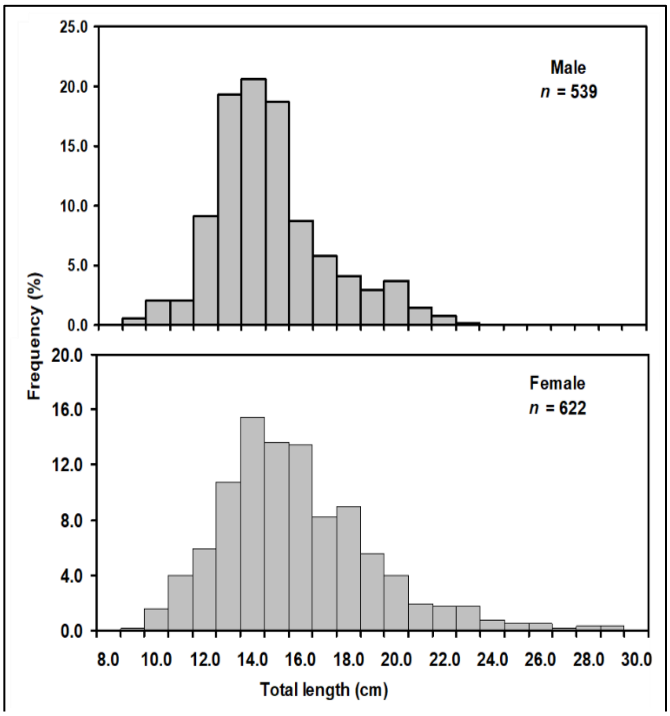

Fig. 2. Length-frequency distributions of *Heteropneustes fossilis* in the Ganges River of north-western Bangladesh

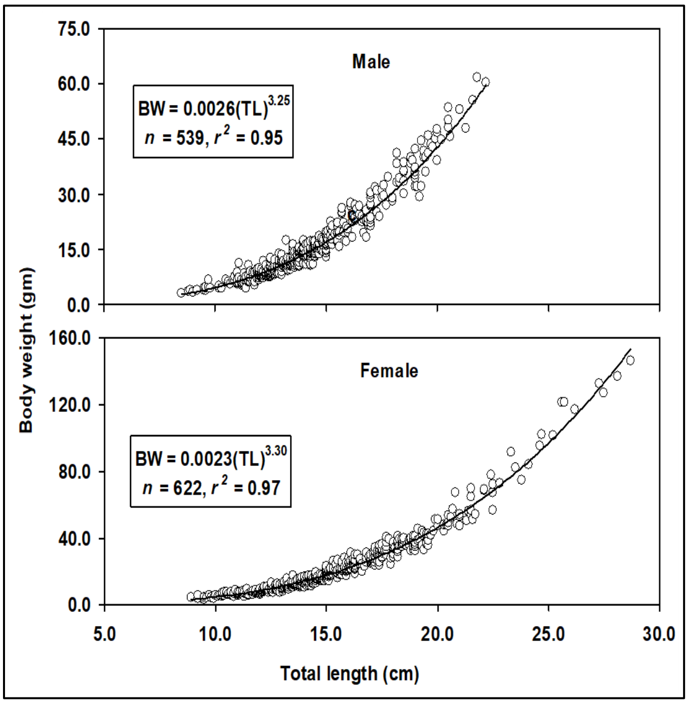

Fig. 3. Length-weight relationships of *Heteropneustes fossilis* in the Ganges River of north-western Bangladesh

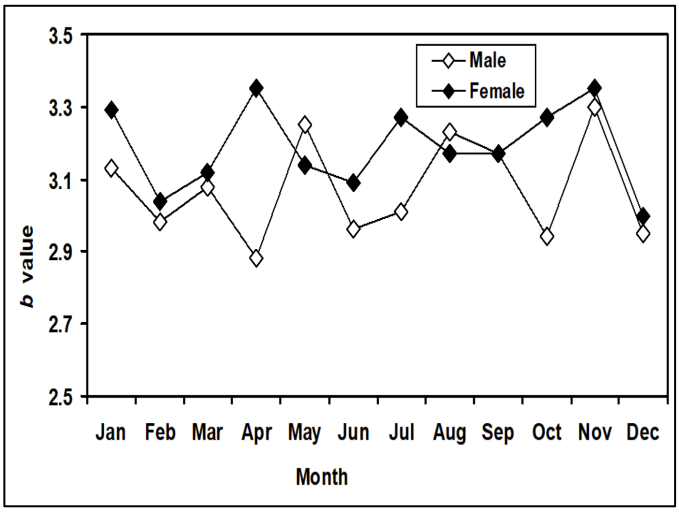

Fig. 4. Relationships between growth co-efficient (*b*) of *Heteropneustes fossilis* in the Ganges River, north-western Bangladesh

Physiological condition

The maximum fatty fish was obtained in June for males (39%) and females (48%). The percentages of fatty fish were found to upswing in April and remained until July for both sexes; then lessened in August before starting to escalate again after November. Monthly changes of physiological condition for both male and female *H. fossilis* are illustrated in Fig. 5. However, highest fatty fish was found (64% and 53%) in 8.0 - 10.0 cm and 22.0-24.0 cm TL (Fig. 6).

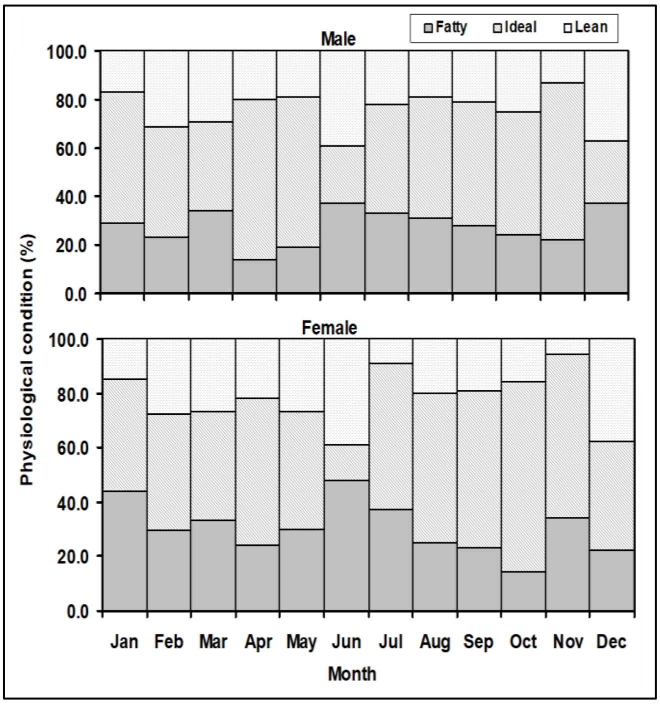

Fig. 5. Monthly changes of physiological status (i.e. ideal, fatty and lean) for *Heteropneustes fossilis* in the Ganges River, north-western Bangladesh

Table 3. Descriptive statistics on the total length (cm) and body weight (g) measurements of *Heteropneustes fossilis* (Bloch, 1794) in the Ganges River, north-western Bangladesh.

Month	Sex	n	TL (cm)				BW (g)			
			Min	Max	Mean ± SD	95% CL	Min	Max	Mean±SD	95% CL
January	**M**	42	9.5	19.3	13.35±1.93	12.75-13.95	3.86	32.17	10.91±5.48	9.20-12.62
	F	48	11	19.6	14.35±2.28	13.59-15.02	5.59	38.59	14.73±8.41	12.28-17.17
February	**M**	48	8.8	15.3	12.61±1.58	12.15-13.07	3.59	21.53	10.71±3.89	9.58-11.84
	F	54	9.2	17	13.22±1.75	12.74-13.68	3.95	25.48	12.53±4.89	11.19-13.86
March	**M**	38	9.7	22.2	14.86±3.26	13.79-15.93	5.6	60.36	19.59±15.02	14.65-24.52
	F	43	9.2	23.8	15.19±3.43	14.13-16.24	3.95	74.78	21.26±16.88	16.08-26.46
April	**M**	44	9.5	17	13.03±1.79	12.47-13.58	4.43	22.98	10.21±4.79	8.76-11.67
	F	51	10.1	17.5	13.5±2.10	12.91-14.09	5.15	28.45	12.56±6.53	10.61-14.50
May	**M**	37	12.2	21.3	15.29±2.35	14.50-16.07	7.67	47.88	18.61±9.62	15.40-21.82
	F	44	12.5	28.7	19.93±4.78	18.47-21.38	10.36	146.55	58.61±40.68	46.24-70.98
June	**M**	38	11	21	16.52±2.99	15.53-17.50	6.55	53.55	27.21±13.85	22.66-31.76
	F	54	10.3	23.5	16.99±3.71	15.98-18.01	5.07	91.3	33.51±20.94	27.79-39.22
July	**M**	46	11.5	19.8	15.34±1.98	14.75-15.92	10.33	42.76	20.88±8.45	18.37-23.39
	F	58	12.8	20.7	16.67±1.81	16.20-17.15	11.7	57.09	27.97±10.11	25.31-30.63
August	**M**	52	11.1	16.4	13.55±1.31	13.19-13.92	6.06	25.1	13.34±4.35	12.13-14.55
	F	60	9.2	18.9	14.80±2.41	14.18-15.43	3.95	41.18	19.79±9.92	17.23-22.36
September	**M**	39	12	19.6	14.94±1.85	14.35-15.54	9.44	45.87	19.77±9.02	16.84-22.68
	F	47	10.4	19.9	15.39±1.98	14.81-15.97	7.38	51.05	22.75±9.31	20.02-25.49
October	**M**	55	9.6	16	13.86±1.16	13.55-14.17	4.53	20.71	12.97±3.08	12.14-13.81
	F	63	10.4	16.1	14.04±1.16	13.75-14.33	5.38	21.82	13.50±3.67	12.57-14.42
November	**M**	54	10.2	21.8	13.78±2.40	13.13-14.44	4.64	61.81	14.99±10.98	12.00-17.97
	F	58	9.8	22.8	15.10±3.37	14.21-15.99	4.04	72.57	21.79±16.06	17.56-26.01
December	**M**	46	8.5	20.6	13.08±2.70	12.28-13.88	3.12	45.68	12.02±8.93	9.37-14.67
	F	42	8.9	21	14.5±3.31	13.46-15.53	3.41	47.06	18.33±12.33	14.49-22.17

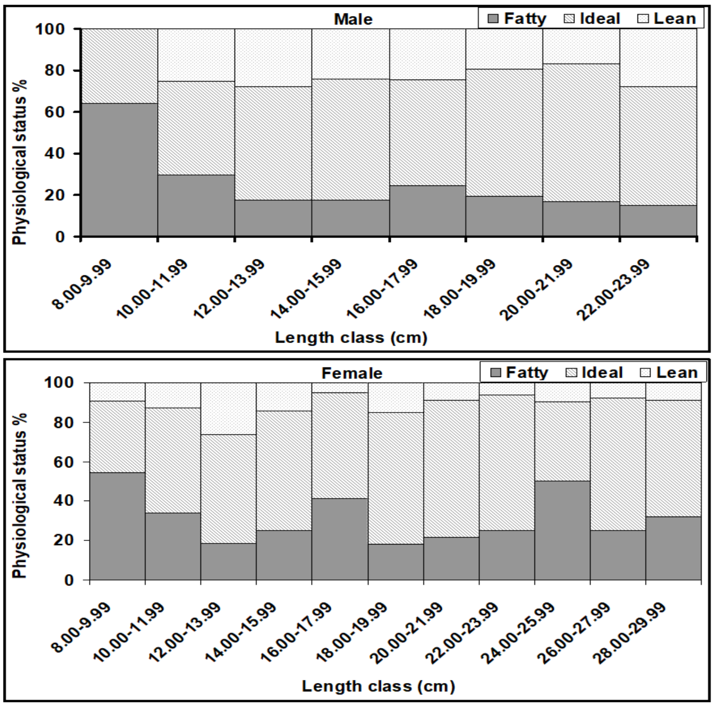

Fig.6. Length basis physiological status (i.e. ideal, fatty and lean) for *Heteropneustes fossilis* in the Ganges River, north-western Bangladesh

Eco-hydrological parameters

The fatty fishes are statistically highly correlated with Temperature, rainfall, DO and TDS but pH did not represent any significant correlation with the fatty fish (Table 5 and Fig. 7, 8).

Discussion

Data on variation of sex ratio, growth and physiology of *H. fossilis* scare in literature from Bangladesh and somewhere else. A sum of individual with various body sizes was gathered throughout the year using different fishing gear from the Ganges River during this study period. Sex ratio could not be altered with environmental stimuli, mostly temperature (Baroiller and D'Cotta 2001). Availability of food also facilitates female dominance in an environment rich in food (Msiska and CoastaPierce 1997). Sex ratio may also indicate other factors comprising thermal effects on sex development and also predatory influence on behavior, growth rate, mortality as well as longevity life span (Khatun et al. 2018; Hossain et al. 2016;

Table 4. Descriptive statistics and estimated parameters of the length-weight relationships ($W = a \times TL^b$) of *Heteropneustes fossilis* (Bloch, 1794) in the Ganges River, north-western Bangladesh.

Month	Sex	*n*	Regression parameters				r^2	GT
			a	*b*	95% CL of *a*	95% CL of *b*		
January	**M**	42	0.0030	3.13	0.0015-0.0059	2.87-3.40	0.935	+A
	F	48	0.0021	3.29	0.0013-0.0034	3.12-3.47	0.967	+A
February	**M**	48	0.0053	2.98	0.0032-0.0087	2.79-3.18	0.952	I
	F	54	0.0046	3.04	0.0029-0.0073	2.86-3.22	0.958	I
March	**M**	38	0.0040	3.08	0.0023-0.0071	2.87-3.29	0.961	I
	F	43	0.0038	3.12	0.0024-0.0062	2.93-3.28	0.968	+A
April	**M**	44	0.0082	2.88	0.0051-0.0131	2.69-3.08	0.956	-A
	F	51	0.0019	3.35	0.0012-0.0028	3.19-3.51	0.973	+A
May	**M**	37	0.0024	3.25	0.0012-0.0047	3.01-3.50	0.953	+A
	F	44	0.0041	3.14	0.0026-0.0064	2.97-3.30	0.975	+A
June	**M**	38	0.0083	2.96	0.0048-0.0143	2.79-3.16	0.961	-A
	F	54	0.0045	3.09	0.0029-0.0072	2.93-3.26	0.965	I
July	**M**	46	0.0053	3.01	0.0030-0.0094	2.80-3.22	0.951	I
	F	58	0.0027	3.27	0.0016-0.0046	3.08-3.44	0.959	+A
August	**M**	52	0.0040	3.23	0.0022-0.0073	2.99-3.47	0.935	+A
	F	60	0.0035	3.17	0.0023-0.0054	3.01-3.33	0.964	+A
September	**M**	39	0.0035	3.17	0.0019-0.0064	2.95-3.40	0.956	+A
	F	47	0.0037	3.17	0.0022-0.0063	2.98-3.36	0.960	+A
October	**M**	55	0.0056	2.94	0.0035-0.0088	2.77-3.11	0.956	-A
	F	63	0.0023	3.27	0.0014-0.0037	3.10-3.45	0.958	+A
November	**M**	54	0.0023	3.30	0.0015-0.0036	3.13-3.47	0.967	+A
	F	58	0.0020	3.35	0.0014-0.0029	3.22-3.48	0.979	+A
December	**M**	46	0.0053	2.95	0.0032-0.0088	2.75-3.15	0.954	-A
	F	42	0.0051	3.00	0.0033-0.0080	2.83-3.17	0.970	I

n, sample size; M, male; F, female; *a*, *b* are length-weight relationships parameter; CL, confidence limit; r^2, co-efficient of determination; GT, growth type; -A, negative allometric growth; I, isometric growth; + A, positive allometric growth.

Rahman et al. 2012). Divergence from the 1:1 sex ratio is unpredictable from many aquatic organisms, while some fishes and shellfishes may have a substantial skew in this ratio (Khatun et al. 2018; Mawa et al. 2022). In our study, the sex ratio of male and female was 1.0:1.15, indicating females prevailing over males which significantly varied from the expected value of 1:1. During this analysis, all the sex ratio significantly varied from the predicted value of 1:1 ($df = 1$, $\chi^2 = 4.85$, $p < 0.05$). Alam et al. (2018) found the sex ratio varied from 1:1 to 1:2.03 for *H. fossilis* which is closely similar with our study. On the other hand, an increase in sex ratio with body size has been documented for other species (Hossain et al. 2012).

In this study, the obtained highest length of *H. fossilis* was 28.7 cm which is smaller compare to 31.0 cm in TL (Khan et al. 2012) in the Ganges River, India but greater than 28.5 cm TL (Bhatt et al. 1977) reported from the Plain, Northern India, 26.8 cm TL (Rahman et al. 2019), 16.5 cm TL (Hossain et al. 2017) and 24.1 cm TL (Hasan et al. 2020) from Gajner *beel*, Bangladesh. Also, Ferdausy and Alam (2015) recorded the maximum length for *H. fossilis* as 15.5 cm from Nageshwari River, Bangladesh while Muhammad et al. (2017) reported TL = 13.0 cm in the Indus River, Pakistan and Das et al. (2017) reported TL = 18.6 cm from the Deeper *beel*, India. The observed value differs from all above results which could be attributed to dissimilarities in geographical position and ecological parameters, especially temperature of water and availability of food (Hossain and Ohtomi 2010; Sabbir et al. 2022).

Table 5. Relationships between eco-hydrological factors with percentage of fatty fish of *Heteropneustes fossilis* (Bloch, 1794) in the Ganges River, northwestern Bangladesh

Relationships	r_s/r_p values	95% CL of r_s	*P* values	Significance
Temperature *vs.* Fatty fish	0.8076	0.4353 – 0.9440	0.0015	**
Rainfall *vs.* Fatty fish	0.6651	0.1473 to0.8968	0.0183	*
pH *vs.* Fatty fish	0.1128	-0.4932 to 0.6450	0.7271	ns
DO *vs.* Fatty fish	-0.6334	-0.8855 to -0.0933	0.0270	*
TDS *vs.* Fatty fish	-0.5850	-0.8677 to -0.0166	0.0457	*

DO, dissolved oxygen (mg/l); TDS, Total dissolve solids; *b*, growth pattern; r_s, Spearman rank correlation values; CL, confidence limit; *P*, level of significance; *ns*, not significant; *significant; **highly significant

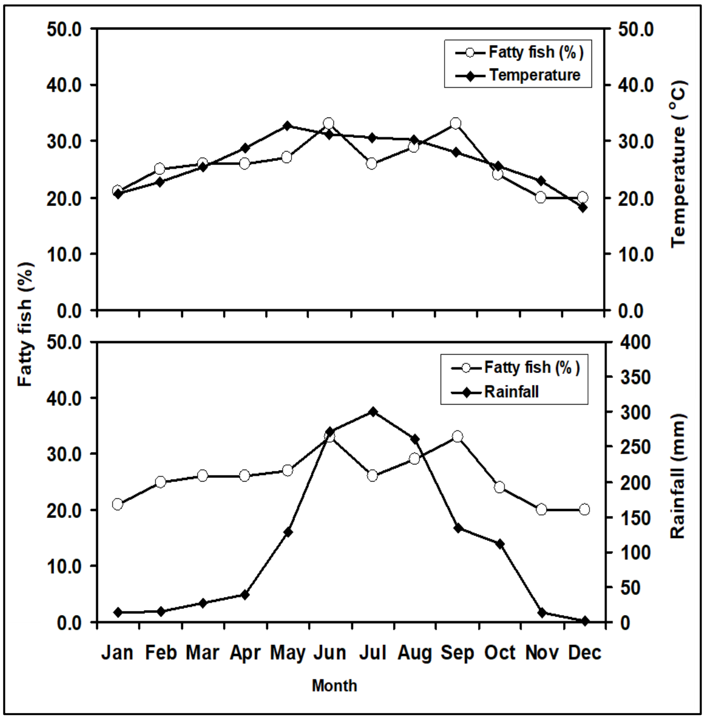

Fig. 7 Relationships between temperature and rainfall with Fatty fish (%) of *Heteropneustes fossilis* in the Ganges River, north-western Bangladesh

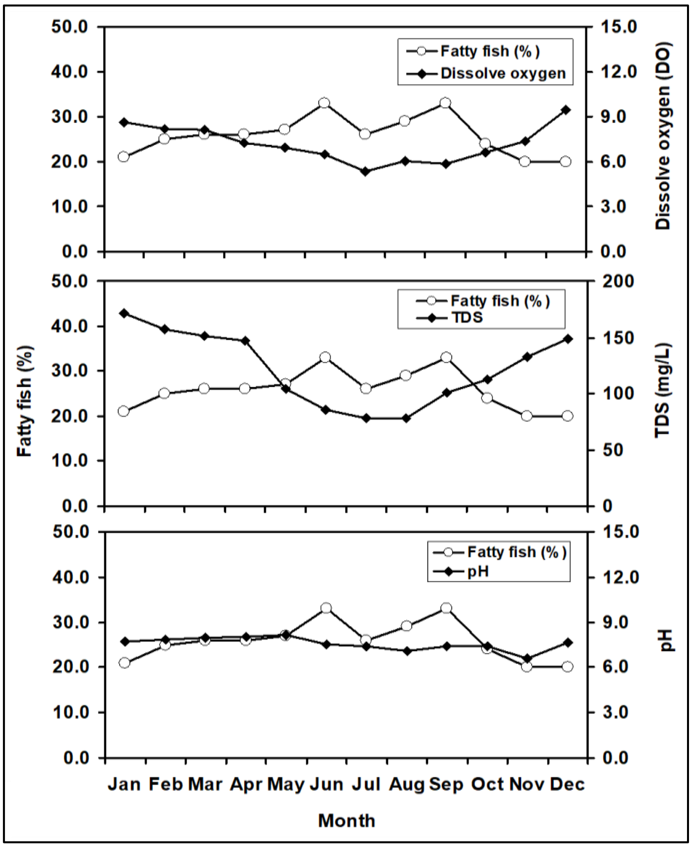

Fig. 8 Relationships between dissolve oxygen, total dissolve solids and pH with Fatty fish (%) of *Heteropneustes fossilis* in the Ganges River, north-western Bangladesh.

The growth exponent *b* may remain between 2.0-4.0; however, more satisfactory values are fluctuating from 2.5-3.5 (Carlander 1969; Froese 2006). This study exposed the *b* values of LWR continued within 2.88 - 3.35 ranges (*b* = 2.88 - 3.30 for males and *b* = 3.00 - 3.35 for females). In our study, all the *b* values of LWR specified positive allometric growth (> 3.00) in both sexes. According to Tesch (1971), *b* values near to 3.0 expressed that fish grow isometrically, larger than 3.0 indicating positive allometric and smaller than 3.0 revealed negative allometric. Similar finding was also reported by Khan et al. (2012) (*b*=3.14) from the Ganga River, India. However, isometric growth pattern was reported by Hossain et al. (2017) (*b*= 3.01), Rahman et al. (2019) (*b*=3.08) and Hasan *et al.* (2020) from the Gajner *Beel* Bangladesh. Besides, negative growth pattern was reported by Ferdausy and Alam (2015) (*b* = 2.68) from the Nageshwari River, Alam et al. (2018) (*b* = 2.26 and *b* = 2.38) from the Hilna *beel* and *beel* Kumari *beel*, Bangladesh and Muhammad et al. (2017) (*b* = 2.13) from the Indus river, Pakistan. However, the fluctuation in growth pattern occurs because of some factors such as sex, habitat availability, gonad ripeness, level of stomach fullness, seasonal effect, well-being of fish health, methods of preservation and deviations in the observed length class (Hossain et al. 2013, 2018; Mawa et al. 2022), which were not accounted in present study. In our research, sex-specific variations were found, specifically females having a larger slope than males. All the *b* values of LWR for females were greater than males, indicating females body weight raises faster compared to males.

Our study showed that, the maximum portion of fatty fish was found in June for both sexes considering the other months indicated the spawning period. The gradual increase of fatty fish followed until March - June, which specified mature fish existing. But this percentage reduced in May and June just after then peak spawning season occurred. This percentage begins to rise steadily in November, possibly signaling the start of the Ganges River's post-spawning recovery process, and continues until March. As this was the first study on physiological status of this species, it was not possible to compare with others.

On the other hand, the eco-hydrological parameters affect the proportion of fatty fish. Percentage of fatty fishes was showed significant relation with temperature, rainfall, DO and TDS. Habitat temperature controls the fish body growth rate, food consumption, and various body functions because of fish are poikilothermic animal (Handeland et al. 2008; Azevedo et al. 1998; Houlihan et al. 1993**)**. Throughout the study, the highest water temperature was observed in May (32.8^{o}C) and the minimum was in December (18.2^{o}C). The highest rainfall was found in July and no precipitation was occurred in the month of December. pH doesn’t show any relation with growth. DO is considered the most vital parameter due to its necessity for aerobic metabolism **(**Timmons et al. 2001**)**. DO and TDS also revealed correlation with growth. According to Biswas and Panigrahi (2015) desired level of DO is 5.0 to 15.0 mg/l. At least 3.0-5.0 mg/l DO is needed of for survive. Similarly, pH is also considered crucial for any aquatic ecosystem. In our study, the monthly DO level varied from 5.38 to 9.45 mg/l and TDS ranged from 78.23 to 157.54 mg/l indicating a suitable habitat for fresh water fisheries resources in the Ganges River of Bangladesh

Our study explicates the monthly dissimilarity of sex ratio, size structure, growth patter and relation of physiological condition with environmental factors of H. fossilis. The result of this study will improve the knowledge of fish biology and provide basic information for advanced studies. Thus, presented data would be reassuring to develop justifiable management policy for *H. fossilis* in the Ganges River and surrounding environment.

References

Alam MT, Hussain MA, Sultana S, Hasan MT, Mazlan AG, Simon KD & Mazumder SK (2018). Population growth and reproductive potential of five important fishes from the freshwater bodies of Bangladesh. Iranian Journal of Fisheries Sciences, 17(4), 657-674.

Azaza MS, Dhraïef MN & Kraïem MM (2008). Effects of water temperature on growth and sex ratio of juvenile Nile tilapia *Oreochromis niloticus* (Linnaeus) reared in geothermal waters in southern Tunisia. Journal of thermal Biology, 33(2), 98-105.

Azevedo PA, Cho CY, Leeson S & Bureau DP (1998). Effects of feeding level and water temperature on growth, nutrient and energy utilization and waste outputs of rainbow trout (*Oncorhynchus mykiss*). Aquatic Living Resources, 11(4), 227-238.

Baroiller JF & d'Cotta H (2001). Environment and sex determination in farmed fish. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 130(4), 399-409.

Bhatt VS, Dalal SG & Abidi SAH (1977). Fecundity of the freshwater catfishes *Mystus seenghala* (Sykes), *Mystus cavasius* (Ham), *Wallagonia attu* (Bloch) and *Heteropneustes fossilis* (Bloch) from the plains of Northern India. Hydrobiologia, 54(3), 219-224.

Biswas BC & Panigrahi AK (2015). Ecology and zooplankton diversity of a wetland at Jhenidah district Bangladesh. International Journal for Innovative Research in Science and Technology, 1(9), 246-249.

Bruton MN (1996). Alternative life-history strategies of catfishes. Aquatic Living Resources, 9(S1), 35-41.

Carlander KD (1969). Handbook of Freshwater Fishery Biology, Volume One; Life History Data on Freshwater Fishes of the United States and Canada, Exclusive of the Perciformes.

Carmona-Isunza MC, Ancona S, Székely T, Ramallo-González AP, Cruz-López M, Serrano-Meneses MA & Küpper C (2017). Adult sex ratio and operational sex ratio exhibit different temporal dynamics in the wild. Behavioral Ecology, 28(2), 523-532.

Das P, Rahman W, Talukdar K & Deka P (2015). Length-weight relationship and relative condition factor of *Heteropneustes fossilis* (Bloch) of Deepar Beel, a Ramsar site of Assam, India. International Journal of Applied Research, 12, 1024-1027.

Emlen ST & Oring LW (1977). Ecology, sexual selection, and the evolution of mating systems. Science, 197(4300), 215-223.

Ferdaushy MH & Alam MM (2015). Length–length and length-weight relationships and condition factor of nine freshwater fish species of Nageshwari, Bangladesh. International Journal of Aquatic Biology, 3(3), 149-154.

Froese R (2006). Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. Journal of Applied Ichthyology, 22(4), 241-253.

Halwart M & Gupta MV (2004). Culture of fish in rice fields. FAO; WorldFish Center.

Handeland SO, Imsland AK & Stefansson SO (2008). The effect of temperature and fish size on growth, feed intake, food conversion efficiency and stomach evacuation rate of Atlantic salmon post-smolts. Aquaculture, 283(1-4), 36-42.

Hasan MR, Mawa Z, Hassan HU, Rahman MA, Tanjin S, ... & Hossain MY (2020). Impact of eco-hydrological factors on growth of the Asian stinging catfish *Heteropneustus fosslis* (Bloch, 1794) in a Wetland Ecosystem. Egyptian Journal of Aquatic Biology and Fisheries, 24(5), 77-94.

Hossain MY & Ohtomi J (2010). Growth of the southern rough shrimp *Trachysalambria curvirostris* (Penaeidae) in Kagoshima Bay, southern Japan. Journal of Crustacean Biology, 30(1), 75-82.

Hossain MY, Rahman MM, Jewel MAS, Hossain MA, ... & Ohtomi J (2013). Life history traits of the critically endangered catfish *Eutropiichthys vacha* (Hamilton 1822) in the Jamuna (Brahmaputra River Distributary) River, Northern Bangladesh. Sains Malaysiana, 42(3), 265-277.

Hossain MY, Pramanik MNU, Hossen MA, Nawer F, Khatun D, Rahman O, Ahmed ZF & Ahamed F (2018). Life-history traits of Pool barb *Puntius sophore* (Cyprinidae) in different Ecosystems of Bangladesh. Indian Journal of Geo-Marine Sciences, 47(07), 1446-1454.

Hossain MY, Rahman MM, Bahkali AH, Yahya K, Arefin M, ... & Masood Z (2016). Temporal variations of sex ratio, length-weight relationships and condition factor of *Cabdio morar* (Cyprinidae) in the Jamuna (Brahmaputra River Distributary) River, Northern Bangladesh. *Pakistan Journal of Zoology*, 48(4), 1099-1107.

Hossain MY, Hossen MA, Ahmed ZF, Hossain MA, Pramanik MNU, ... & Islam MA (2017). Length–weight relationships of 12 indigenous fish species in the Gajner Beel floodplain (NW Bangladesh). Journal of Applied Ichthyology, 33(4), 842-845.

Hossain MY, Ohtomi J, Jaman A, Jasmine S & Vadas Jr RL (2012). Life history traits of the monsoon river prawn *Macrobrachium malcolmsonii* (Milne-Edwards, 1844) (Palaemonidae) in the Ganges (Padma) river, northwestern Bangladesh. Journal of Freshwater Ecology, 27(1), 131-142.

Houlihan DF, Mathers EM & Foster A (1993). Biochemical correlates of growth rate in fish. Fish ecophysiology, pp.45-71.

Islam MA, Hossain MY, Rahman MA, Rahman O, Sarmin MS, .,............ and Parvin MF (2021). Some biological aspects of Asian stinging catfish, *Heteropneustes fossilis* (Bloch, 1794) (Teleostei: Siluriformes) in a wetland ecosystem. Iranian Journal of Ichthyology, 8(1), 52-61.

IUCN Bangladesh (2015). Red List of Bangladesh Volume 5: Freshwater Fishes. *IUCN, International Union for Conservation of Nature, Bangladesh Country Office, Dhaka, Bangladesh*, *16*, p.360.

IUCN (2021). The IUCN red list of threatened species. *Version, 2021-1*, Accessed on 10 June 2021. https://www.iucnredlist.org

Jayalal L & Ramachandran A (2012). Export trend of Indian ornamental fish industry. Agriculture and Biology Journal of North America, 3(11), 439-451.

Khan MA, Khan S & Miyan K (2012). Length–weight relationship of giant snakehead, Channa marulius and stinging catfish, *Heteropneustes fossilis* from the River Ganga, India. Journal of applied Ichthyology, 28(1), 154-155.

Khatun D, Hossain MY, Parvin MF & Ohtomi J (2018). Temporal variation of sex ratio, growth pattern and physiological status of *Eutropiichthys vacha* (Schilbeidae) in the Ganges River, NW Bangladesh. Zoology and Ecology, 28(4), 343-354.

King M (2007). *Fisheries biology, assessment and management*. 2nd ed. Oxford, UK: Blackwell Scientific Publications.

Kokko H & Jennions MD (2008). Parental investment, sexual selection and sex ratios. Journal of evolutionary biology, 21(4), 919-948.

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

Liker A, Freckleton RP & Székely T (2014). Divorce and infidelity are associated with skewed adult sex ratios in birds. Current Biology, 24(8), 880-884.

Mawa Z, Hossain MY, Hasan MR, Rahman MA, Tanjin S & Ohtomi J (2022). Life history traits of *Mystus vittatus* in the Ganges River, Bangladesh: recommendation for its sustainable management considering climate change. International Journal of Biometeorology, 66, 927-943.

McNamara JM, Szekely T, Webb JN & Houston AI (2000). A dynamic game-theoretic model of parental care. Journal of Theoretical Biology, 205(4), 605-623.

Msiska OV & Costa-Pierce BA (1997). Factors influencing the spawning success of *Oreochromis karongae* (Trewavas) in ponds. Aquaculture Research, 28(2), 87-99.

Muhammad H, Iqbal Z, Bashir Q & Hanif MA (2017). Length-weight relationship and condition factor of cat fish species from Indus River, Pakistan. Punjab University Journal of Zoology, 32(1), 35-38.

Neumann RM & Allen MS (2001). Analysis and interpretation of freshwater fisheries data. *Department of Natural Resources Management and Engineering, University of Connecticut*.

Rahman MA, Hasan MR, Hossain MY, Islam MA, ... & Khatun H (2019). Morphometric and meristic characteristics of the Asian Stinging Catfish *Heteropneustes fossilis* (Bloch, 1794): A key for identification. Jordan Journal of Biological Science, 12, 467-470.

Rahman MM, Hossain MY, Hossain MA, Ahamed F & Ohtomi J (2012). Sex ratio, length-frequency distributions and morphometric relationships of length-length and lengthweight for Spiny eel, *Macrognathus aculeatus* in the Ganges River, NW Bangladesh. World Journal of Zoology, 7(4), 338-346.

Ranjan JB, Herwig W, Subodh S & Michael S (2005). Study of the length frequency distribution of Sucker Head, *Garra gotyla gotyla* (Gray, 1830) in different rivers and seasons in Nepal and its applications. Kathmandu University Journal of science, engineering and Technology, 1(1), 1-14.

Sabbir W, Hossain MY, Khan MN, Rima FA, Sarmin MS & Rahman MA (2022). Biometric indices of flathead Sillago, *Sillaginopsis panijus* (Hamilton, 1822) from the Bay of Bengal (Southern Bangladesh). Thalassas: An International Journal of Marine Sciences, 1-10. https://doi.org/10.1007/s41208-022-00421-9

Saha KC & Guha BC (1939). Nutritional investigations on Bengal fish. Indian Journal of Medical Sciences, 26, 921-927.

Sarkar UK, Naskar M, Roy K, Sudeeshan D, ... & Nandy SK (2017). Benchmarking pre-spawning fitness, climate preferendum of some catfishes from river Ganga and its proposed utility in climate research. Environmental monitoring and assessment, 189(10), 1-13.

Silva IC, Mesquita N & Paula J (2010). Lack of population structure in the fiddler crab Uca annulipes along an East African latitudinal gradient: genetic and morphometric evidence. Marine Biology, 157(5), 1113-1126.

Sokal RR & Rohlf FJ (1987). Data in biostatistics. *Introduction to Biostatistics*, pp.7-8.

Sutharshiny S, Sivashanthini K & Thulasitha WS (2013). Lipid changes in relation to maturation and spawning of tropical double spotted queenfish, *Scomberoides lysan* (Forsskål, 1775). Asian Journal of Animal and Veterinary Advances, 8(4), 555-570.

Székely T, Weissing FJ & Komdeur J (2014). Adult sex ratio variation: implications for breeding system evolution. Journal of evolutionary biology, 27(8), 1500-1512.

Talwar PK & Jhingran AG (1991). *Inland fishes of India and adjacent countries* (Vol. 2). CRC Press.

Tesch FW (1971). Age and growth. *Methods for assessment of fish production in fresh waters*.

Timmons MB, Ebeling JM, Wheaton FW, Summerfelt S & Vinci BJ (2002). *Recirculating aquaculture systems*. Northeastern Regional Aquaculture Center, Ithaca (New York).

Vazzoler AEAM (1996). Reproduction biology of teleostean fishes: theory and practice. Maringá, EDUEM, Brazilian Society of Ichthyology, p.169.

Veran S & Beissinger SR (2009). Demographic origins of skewed operational and adult sex ratios: perturbation analyses of two-sex models. Ecology Letters, 12(2), 129-143.

How to cite this article: Parvin MF, Rahman MA, Rahman MM, Molla S, & Hossain MY (2024). Temporal variations of sex ratio, size structure, growth pattern and physiological conditions of Stinging Catfish *Heteropneustes fossilis* in the Ganges River in relation to eco-hydrological parameters. Aquatic Resource Sciences, 01, 24-35.