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MATURITY, BREEDING CYCLE, AND FECUNDITY OF *MASTACEMBELUS ARMATUS* (ACTINOPTERYGII: SYNBRANCHIFORMES: MASTACEMBELIDAE) IN THE SUB-TROPICAL WATERS OF THE RIVER GANGA

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Background. The investigation on different aspects of the reproductive biology is valuable information in the development of breeding technologies towards initiating conservation and other management measures of the indigenous fish stocks. The zig-zag eel, *Mastacembelus armatus* (Lacepède, 1800), is a commercially important fish species in the river Ganga of India. But, the data on the reproductive biology of this species is limited. Hence, this study was done to gather information on some aspects of the reproductive biology of *M. armatus* to address the gap in the current knowledge.

Materials and methods. Some biological traits relating to the reproduction of *M. armatus* from the river Ganga were studied based on the monthly sampling for one year from April 2015 to March 2016. A total of 286 fish specimens were collected, comprising 167 males and 119 females. Weight–length relations for both sexes were estimated with the aid of regression analysis. The fecundity was calculated following the gravimetric method. The length at 50% maturity (L_{50}) for the male and female were assessed employing maturity status data. The spawning season was predicted by employing gonadosomatic index and maturity status data.

Results. Monthly sex ratio (F ÷ M) ranging between 0.22 ÷ 1 and 2.75 ÷ 1 with a mean of 0.71 ÷ 1 observed in the population was significantly different from 1 ÷ 1. Analysis of mean monthly gonadosomatic index (GSI) and the existence of matured (IV and V) and spent (VI) individuals, indicated year-round spawning with two breeding seasons. The first breeding season, in the river Ganga, occurred between February and May, and the other between July and November. The L_{50} of *Mastacembelus armatus* female and male were determined as 362.2 and 385.6 mm total length (TL), respectively. The reproductive potential in terms of absolute fecundity ranged between 2546 and 6058 with a mean of 3962 ova.

Conclusion. The current investigation helps to report the size at maturity in the female and the male for the first time from Indian waters. *Mastacembelus armatus* represents a low fecundity, indicating that this species has a comparatively lower reproductive potential, making it more vulnerable to excessive fishing pressure. For the sustainable management of this species, it is necessary to utilize the resources wisely and avoid overfishing in the river Ganga.

Keywords: condition factor, fecundity, sex ratio, size at 50% maturity, zig-zag eel

INTRODUCTION

The zig-zag eel, *Mastacembelus armatus* (Lacepède, 1800), a ray-finned fish, is a member of the family Mastacembelidae and the order Synbranchiformes. The maximum total length reported for it is 90 cm (Froese and Pauly 2019). It is known to be benthic and usually inhabits rivers, reservoirs, and floodplain wetlands. It is a native fish species of India, Afghanistan, Bangladesh, Pakistan, Sri Lanka, and other Asian countries like Vietnam, Indonesia, Thailand, China, and Myanmar (Talwar and Jhingran 1991,

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Vidthayanon 2002). *Mastacembelus armatus* is locally known as *Bam* or *Gend* along the stretches of the river Ganga. It is a carnivorous fish (Serajuddin et al. 1998, Alam et al. 2013, Pannikar et al. 2013) and its flesh is tasty with high calorific value and protein content (Nasar 1997, Rashid et al. 2015). *Mastacembelus armatus*, as a food fish with an excellent market price and as valuable ornamental species, is one of the main fish species of the rivers in India with good commercial importance (Montaña et al. 2011, Tripathi et al. 2017)

The present scenario of fisheries in river Ganga shows that there is a drastic decline in the diversity and catches of the most commercially important fish species with an increasing trend in the relative abundance of small-sized fishes of low economic value and some exotic fishes (Vaas et al. 2009, Singh et al. 2013, Jha et al. 2017, Tripathi et al. 2017). The impact on fisheries of the river Ganga is further compounded through habitat modification, climate change, invasion of exotics, overfishing, and pollution (Natarajan 1989, Vass et al. 2009, Alam et al. 2016, Jha et al. 2017, Tripathi et al. 2017). To conserve the indigenous fish population in the river, due consideration should be given to stock management (restocking, ranching, etc.) or to increase the fish production by promoting aquaculture practices of its commercially important fish species in the future. The investigation into different aspects of the reproduction of fish species is a must in unfolding the breeding technologies and for initiating other conservation measures (Muchlisin 2014, Tripathi et al. 2017).

Though *Mastacembelus armatus* is an important species found in the river Ganga, there is a lack of literature on the reproductive biology of this species from this river. A few studies on different vistas of the reproductive biology of *M. armatus* have been reported from different parts of the world (Gupta 1974, Narejo et al. 2002, Rahman et al. 2012, Serajuddin and Pathak 2012, Ali et al. 2013). The presently reported investigation aimed to report different aspects of reproductive biology, including weight–length relation, sex ratio, hepatosomatic index, relative condition factor, gonadosomatic index, spawning season, L_{50}, and fecundity of *M. armatus* inhabiting the river Ganga.

MATERIALS AND METHODS

Study area. The river Ganga is a snow-fed perennial river. It is formed by the confluence of Bhagirathi and the Alaknanda rivers, originating from the Gangotri and Saptal glaciers of the Western Himalaya. The study was undertaken in the Allahabad stretch of the Ganga. The district of Allahabad is located in the northern part of India. The total area drained by the river Ganga and its tributaries in India is around 861 404 km^2. The average annual precipitation in the Ganga basin varies from 400 to 2000 mm. In Allahabad, it ranges from 600 to 800 mm (Pandit and Isaac 2016) that mostly occur in the monsoon months (July through October). The hottest month is June with an average temperature of 31.4°C while the coldest month is January with an average temperature of 6.4°C.

Sample collection and analysis. The sampling was conducted monthly from April 2015 through March 2016 at the Daraganj fish landing center (25°26′37″N, 081°52′54″E) located on the right bank of the river Ganga at Allahabad (Fig. 1). The fish were captured early in the morning for over 12 months from April 2015 through March 2016 and a total of 286 samples of *Mastacembelus armatus* were collected. In this number there were 167 males and 119 females. The collected specimens were suitably iced and immediately brought to the laboratory for further analysis. The size of each individual viz. body weight (W) and total body length (TL) were taken to the nearest 0.1 g and 1 mm, respectively. They were then dissected for the determination of their sex. The gonad weight (to nearest 0.01 g) was recorded separately for males and females for the calculation of the gonadosomatic index (GSI). For estimation of the fecundity, the ovaries were kept in modified Gilson's fluid of 4% concentration. The weight–length relation was established following allometric equation

$$W = a \cdot (\mathrm{TL})^b$$

where b and a are the regression parameters calculated using the regression equation from the log-transformed weight and length data (LeCren 1951). Analysis of variance (ANOVA) was performed (Snedecor and Cochran 1967) to identify whether there were any statistically significant differences in b values between sexes at 5% level of significance and Student's t-test was employed to test if the weight–length relations followed isometric growth at 5% level of significance or not.

The relative condition factor (K_n)was estimated using the formula by LeCren (1951) as

$$K_n = W_T \cdot \hat{W}^{-1}$$

where $\hat{W}$ represents the expected total weight [g], estimated from the weight–length relation, and W_T the actual total weight [g]. Monthwise homogeneity of the sex ratio (1 ÷ 1) in the population was tested using the Chi-square test in Microsoft Excel from the estimated numbers of males and females in the sample at a 5% level of significance. Maturity stages were noted as per Mous et al. (1995) as virgin (I), developing (II), early maturing (III), developed/pre-spawning (IV), spawning (V), and spent (VI) stages. Fish at I through III maturity stages were treated as immature and IV through VI as mature. The reproductive seasonality was predicted by considering the month-wise changes in the gonadosomatic index (GSI) and the maturity stages. The GSI and the HSI (hepatosomatic index) were estimated using the equations:

$$\mathrm{GSI} = 100 W_G \cdot W_T^{-1}$$

$$\mathrm{HSI} = 100 W_L \cdot W_T^{-1}$$

where W_G, W_L, and W_T are the gonad weight, liver weight, and the total body weight [g].

A normality test was employed to examine the length-frequency distribution of the populations of both the sexes (Shapiro–Wilk test). ANOVA followed by multiple comparison tests using Tukey's method was performed to test the monthly significant difference of GSI, HSI, and K_n parameters. The L_{50} was estimated by fitting the logistic model

$$P(x) = a \cdot e^{-(b + cx)}$$

where a, b, and c are constants to be estimated and $P(x)$ is the percentage of mature individuals at size (TL) x. The gravimetric method was used for the estimation of absolute fecundity from 18 ovaries following Bagenal and Braum (1971). Relative fecundity was expressed as the number of eggs per unit ovary weight [g] and body weight [g]. Relations of fecundity to total body length, ovary, and body weights were modeled using Regression technique (Snedecor and Cochran 1967). The data were analyzed using R, and SAS ver.9.3 software.

RESULTS

Length-frequency distribution and sex ratio. Out of 286 specimens collected for the investigation, females constituted 42% (n = 119) with 230 to 630 mm TL and males 58% (n = 167) with 230 to 600 mm TL. Males outnumbered the females and the overall female: male (F ÷ M) sex ratio of 0.71 ÷ 1 observed in the population was significantly different from 1 ÷ 1 ($\chi^2 = 31.63$, $P < 0.05$). The mean TL of female (386 ± 5 mm) were observed to be significantly different from that of male (410 ± 5 mm). The catch was dominated by a comparatively larger length class of 410–440 mm TL in males than females of 380–410 mm TL (Fig. 2). Shapiro–Wilk test for the normal distribution of the length-frequency distribution of the collected samples in male depicted normal distribution ($P > 0.3319$) while in the female it was not normal ($P < 0.05$) with a mean and modal size (TL) of 386 ± 5 mm and 430 mm, and 410 ± 5 mm and 360 mm, respectively (Fig. 2).

Weight–length relation. The weight–length- relations between female and male of *Mastacembelus armatus* were detected to be significant ($P < 0.05$) from the river Ganga at Allahabad, which was estimated as follows:

Male: $\log W_T = -4.6696 + 2.6175 \log TL$

or $W_T = 0.0000214 TL^{2.6175}$

($R^2 = 0.9481$)

Female: $\log W_T = -4.6346 + 2.6159 \log TL$

or $W_T = 0.0000232 TL^{2.6159}$

($R^2 = 0.927$)

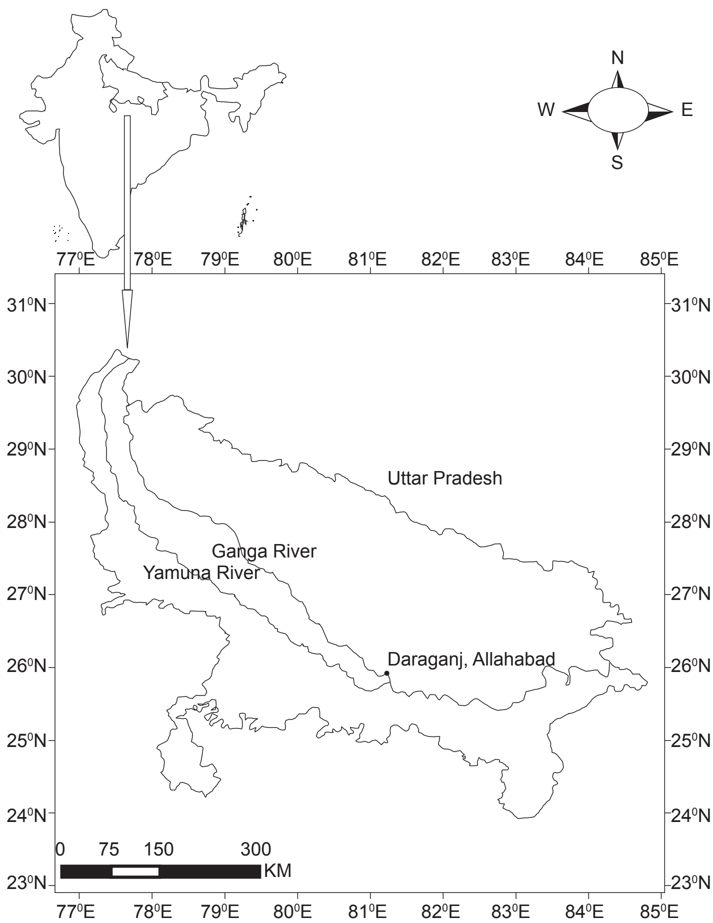

Fig. 1. Map showing the fish landing center along the river Ganga at Allahabad

Sex pooled: Log W_T = –4.5670 + 2.5829 log TL

or $W_T = 0.0000271\text{TL}^{2.5829}$

(R^2 = 0.941)

Power relations of *M. armatus* for both the sexes are illustrated in Fig. 3. The analysis of variance (ANOVA) test between two regression slopes of males and females showed no significant differences at a 5% level of significance (P = 0.985). The exponential value of the length–weight relation b tested against the exponent in isometric growth was found to be highly significant at a 5% level. Hence, it may be considered that it did not follow the cube law in both the male (t = 8.28, P < 0.05) and female (t = 8.49, P < 0.05), which indicated negative allometric growth pattern.

Relative condition factor. The K_n values varied from 0.96 to 1.01 with a mean of 1.005 ± 0.01 in males and 0.92 to 1.005 with a mean of 1.004 ± 0.01 in females. The observation that the mean K_n showed no significant difference between the sexes at a 5% level of significance (F = 0.534, P = 0.46) was similar to that reported by Narejo et al. (2003). The monthly mean relative condition factor (K_n) was found to be insignificant between the months in male (F = 1.71, P = 0.0759) while significant in female (F = 4.37, P = 0.0001) at 5% level of significance (Fig. 4).

Hepatosomatic index. Hepatosomatic index (HSI) was found to be significant in different months in female (F = 4.28, P = 0.0001) and not significant in male (F = 1.39, P = 0.18) at 5% level of significance. The overall mean values of HSI were higher in females (1.75 ± 0.45) than males (1.41 ± 0.03) and found to be significant between the sexes at a 5% level of significance (F = 42.86, P = 0.0001) (Figs. 5 and 6).

Gonadosomatic index and maturity. GSI for females ranged from 0.22% to 16.31% (Fig. 5) while in males, they varied from 0.04% to 1.74 % (Fig. 6), respectively. Mean monthly GSI ranged from 1.06% to 9.3%, and 0.09% to 0.32 % with a mean of 3.53%, and 0.22% in females and males, respectively (Figs. 5 and 6) and they were observed to be very significant (F = 112.48, P = 0.0001) during different months. Unlike male (F = 1.55, P = 0.119), the female depicted significant variations in mean monthly GSI between the months (F = 7.02, P = 0.0001) at 5% level of significance (Figs. 5 and 6). The mean GSI was found to be comparatively less in May, June, November, December, and January. Systematic fluctuations in mean monthly GSI was not observed in both the sexes. Several peaks of the mean monthly GSI were observed in April, August, October, and February, which coincided with a high percentage of matured individuals while months with low GSI agreed with the high occurrence of spent individuals. Individuals with maximum GSI in females occurred in almost all months (> 6.5%) except for June (2.67%), May (2.9%), and December (3.21 %) (Fig. 7). In addition to this, individuals with maximum GSI observed in the male in May and June were 2.92% (W_G = 2.22 g, TL = 400 mm, W_T = 128 g) and 2.66 % (W_G = 2.21 g, TL = 420 mm, W_T = 163 g), suggested the occurrence of active male spawner in these months. The HSI and GSI showed a significant positive correlation for males (r = 0.593, P < 0.05) and female (r = 0.821, P < 0.05) *Mastacembelus armatus* (Figs. 5 and 6).

Matured (IV and V) female samples were noted in all months except in May, June, and December while spent (VI) individuals were recorded in all the months. But mature male individuals in the spawning phase were recorded in May and June. The majority of the matured females were observed in the months between February to April, and July to October (>40%) with the maximum

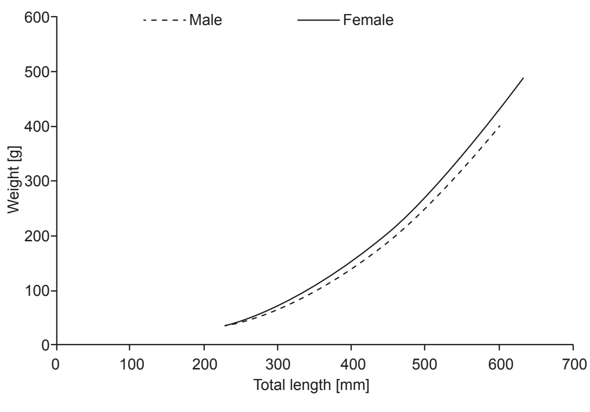

Fig. 3. Length–weight relation of both the sexes of *Mastacembelus armatus* from the river Ganga

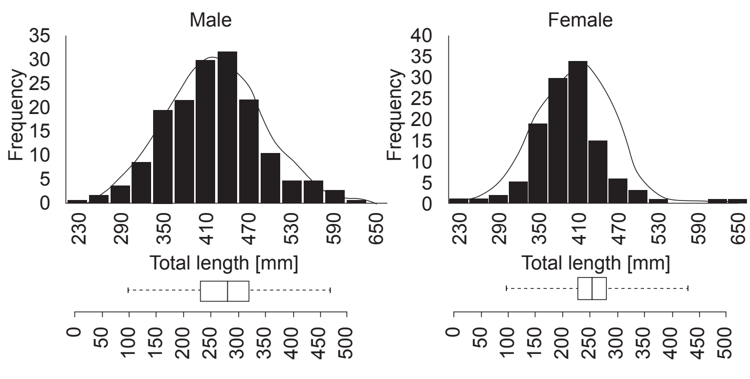

Fig. 2. Length-frequency along with normal distribution curve and box plot of samples of *Mastacembelus armatus*

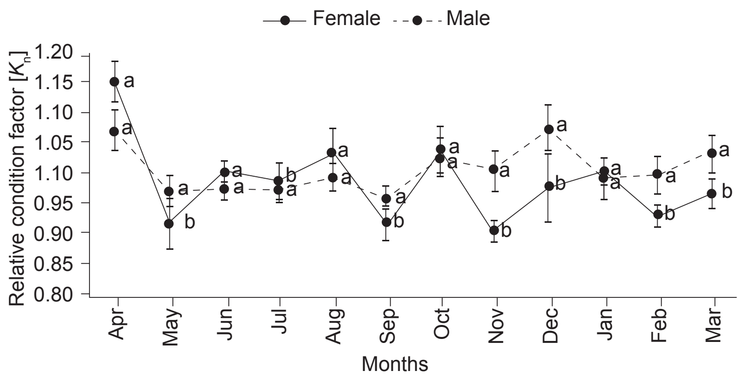

Fig. 4. Monthly variation in the Relative Condition Factor (K_n) in both the sexes of *Mastacembelus armatus* in the river Ganga

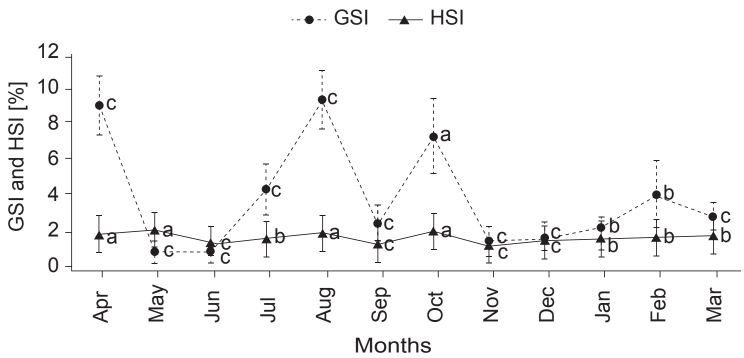

Fig. 5. Month-wise variations in the hepatosomatic index (HSI) and gonadosomatic index (GSI) in the female of *Mastacembelus armatus* in the river Ganga

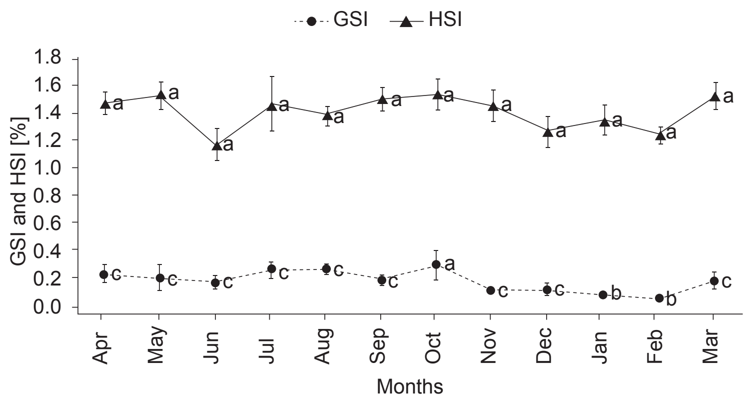

Fig. 6. Month-wise variations in the hepatosomatic index (HSI) and gonadosomatic index (GSI) in the male of *Mastacembelus armatus* in the river Ganga

being in April and August (89%) followed by October (80%). Also, the maximum percentage of spent females was recorded during May and December (75%) followed by November (71%), June (47%), and January (40%), respectively (Fig. 7).

The smallest matured female was 305 mm TL (W_T = 80 g) and for males, it was 320 mm TL (W_T = 92 g). The females were observed to mature at length shorter than males. The mean L_{50} of *Mastacembelus armatus* female and male from the river Ganga at Allahabad was estimated as 362.2 and 385.6 mm TL, respectively (Fig. 8).

Fecundity. The fecundity ranged from 2546 to 6058 with a mean value of 3962 ± 250 eggs per fish for the fish of size ranging from 330 to 490 mm TL and weighing 80 to 276 g. The fecundity relative to body size [g] and ovary weight [g] ranged from 20 to 31 and 191 to 462 with a mean of 26 and 310, respectively. The relations of fecundity to total body length, ovary weight (W_G) and body weight were observed to be significant, which are described by three respective equations:

$$\text{Log } F = 0.2941 \text{ Log TL} + 1.5048792$$

$$(R^2 = 0.699)$$

$$\text{Log } F = 1.1616 \text{ Log } W_G$$

$$(R^2 = 0.6078)$$

$$\text{Log } F = 0.8324 \text{ Log } W_T - 0.8054$$

$$(R^2 = 0.7404)$$

DISCUSSION

Interpretation of the length–weight data of fishes revolving around the body shapes has resulted in many useful concepts. A model by LeCren (1951) that described weight as a function of length has proved beneficial. The value of regression slope (b) for male and female were found to be within the anticipated range of 2.5 to 3.5 for the fish species (Froese 2006). Because of the insignificant variation between the regression slope b of length and weight of males and females at a 5% level, only one power model could be used for both the sexes. The negative allometric growth pattern observed for *Mastacembelus armatus* in the presently reported study was in agreement with reports by Najero et al. (2003) and Sani et al. (2010) but different from Que et al. (2015), who observed isometric growth pattern in the river Hongsui in China (b = 3). The b values can be smaller, larger, or equal to 3 (Froese 2006). In the presently reported study $b < 3$ suggested that the weight of *M. armatus* fish surged at a rate lower than the cube of its length. The different values of exponents (b) could mean the existence of more than one stock. But the values of b for this species are not available from the studied stretch of the river Ganga for the assessment of the stock. The weight–length relation resulting from this investigation contributes to the basic information for undertaking future research work on *M. armatus*.

The catch of *Mastacembelus armatus* was dominated by males agreed with studies of Serajuddin and Pathak (2012) as sex ratio (M ÷ F) of 1 ÷ 0.8 in the river Kalinadi but differ from Pannikar et al. (2013), that reported the dominance of females in *M. armatus* population in the Karapuzha Reservoir, Wayanad district of Kerala, India. The dominance of males in the population might be due to differential migration of the sexes (Rinne and Wanjala

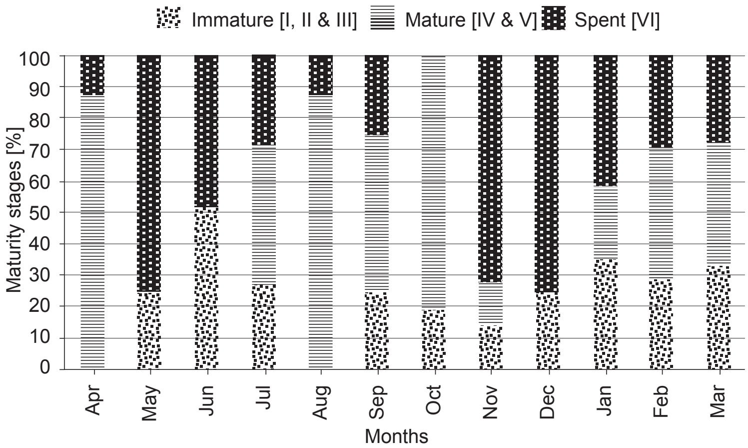

Fig. 7. Month-wise distribution of the various reproductive stages in female of *Mastacembelus armatus* in the river Ganga

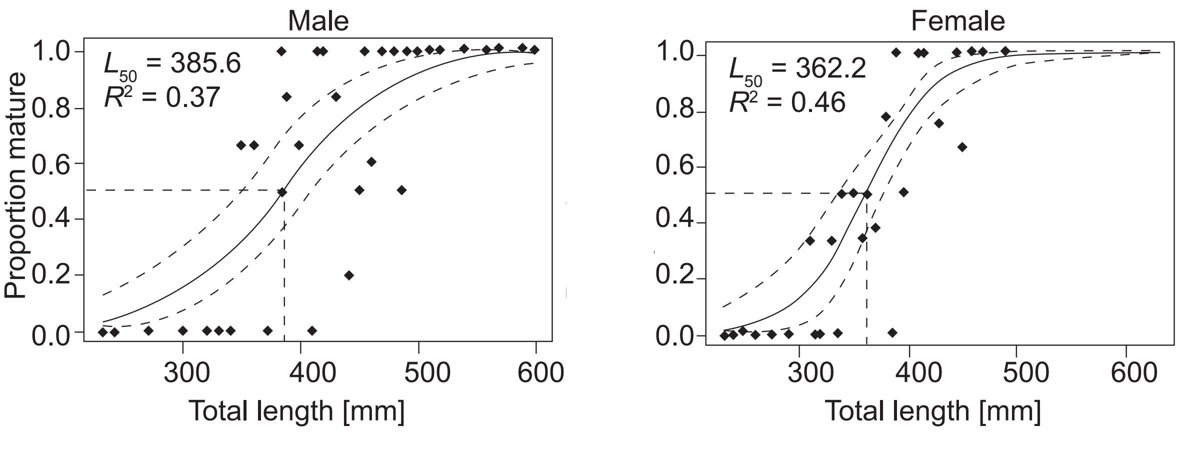

Fig. 8. The length at 50% maturity (L_{50}) (logistic regression model) of the female and the male of *Mastacmbelus armatus* in the river Ganga

1982), habitat variation favoring one sex over other (Balirwa 1998), and greater vulnerability of males to the fishing gears in use (Rahman et al. 2012). The higher K_n values were observed in the spawning months between July, and October could be due to the weight gain on gonads. The lower K_n values were recorded in May, June, and January, when maximum individuals were in the spent phase (Narejo et al. 2002, Alam et al. 2015). Also, higher values in K_n were observed in September, and November, when the values of the gastrosomatic index (GaSI) were high (Alam et al. 2020). This depicted the effect of gonad weight and intensity of feeding on the relative condition of the fish. The variations in K_n could also be attributed to other causes such as environmental and biological factors (Narejo et al. 2002, Alam et al. 2015).

The data related to mean GSI depicts the gonadal activity. However, mean GSI used in fishes for identification of the spawning season which does not have a discrete breeding season (like *Mastacembelus armatus* under the present investigation) always does not depict the spawning activity of the bulk of the population (Hails and Abdullah 1982). In the presently reported study, analysis of mean monthly GSI along with the occurrence of matured individuals in most months revealed that the *M. armatus* spawns round the year with two peak breeding seasons, one between February and May and the other between July and November in the river Ganga. Gupta (1974) too reported prolonged spawning season with peaks in May and November. However, this study revealed four peak months, one in May, second in September, third in November, and the fourth in March, when there is a sharp decline in GSI values (Fig. 5). Narejo et al. (2002) from Bangladesh and Serajuddin and Pathak (2012) from India reported one breeding season in a year. Gupta (1974) from India and Ali et al. (2003) from Bangladesh observed two spawning seasons in a year, was similar to our observations. Lengthy spawning period is an adaption illustrated by the population of *M. armatus* in the river Ganga which is under tremendous stress (McEvoy and McEvoy 1992). Breeding in fishes is mostly regulated by rainfall and seasonal changes in temperature (Qasim and Qayyum 1961). The higher mean monthly values of HSI coincided with higher mean monthly values of GSI indicated that more energy is diverted towards reproduction, irrespective of the sex. The higher HSI values observed in females than males suggested that the female invested more energy in the reproduction process. This showed the impact of gonad weight on HSI.

The L_{50} for the female and male were identified at 362.2 and 385.6 mm TL, respectively. The L_{50} is one of the important traits necessarily required by the fish managers to regulate the size in the catch (Hossain et al. 2012). Around 60 % of the individuals in the catch were above the L_{50} which relatively contributed a greater proportion to the next generation. This suggested that the population is under the recruitment overfishing pressure. In the future, this may lead to a serious decline in the population of *Mastacembelus armatus* in the river Ganga.

Effective fish management depends on the accurate assessment of fecundity required for the recovery of the declining fish population (Lagler 1956). In the presently reported study, fecundity appeared to increase with ovary weight than with body size (total length and body weight) as the regression coefficient value showed a better relation between ovary weight and fecundity than with length–fecundity and body weight–fecundity relations, respectively. During the study, fecundity was found to be low with a mean of 3962 ± 279 eggs per fish. Narejo et al. (2002), Rahman et al. (2006), Serajuddin and Pathak (2012), and Ali et al. (2013) too reported low absolute fecundity. Rahman et al. (2012) suggested that low reproductive potential in terms of fecundity was due to the larger size of the ova in *Mastacembelus armatus armatus*.

CONCLUSIONS

One of the many ways to identify stocks and the life cycles of the fishes is through the investigation of their reproductive biology. The presently reported investigation on the reproductive biology of *Mastacembelus armatus* from the river Ganga helps to formulate the first-time report on its L_{50}. The study confirms the spawning pattern of the tropical fish with peak breeding occurring in the rainy season (July–October), even though females with matured gonads were observed in most months. A negative allometric growth pattern was proved for the species in this study suggesting that the shape changes as the fish increase in size. As compared to other freshwater fish species of the tropics, *M. armatus* possess a relatively lower reproductive potential, making it more susceptible to the fishing operations. The output of the currently reported investigation forms an addition to the scarce database on different facets of the reproductive biology of this tropical riverine species. The information generated would be useful in understanding its resilience capacity that could be instrumental in formulating management policies for conservation and sustainable exploitation of this fishery resource in its associated ecosystems and also to develop breeding technology for the aquaculture production of this species.

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