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Modeling the Growth of Silver Hatchet Chela *Chela cachius* (Cyprinidae) from the Old Brahmaputra River in Bangladesh Using Multiple Functions

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Zoarder Faruque Ahmed, Md. Yeamin Hossain, and Jun Ohtomi (2012) Modeling the growth of silver hatchet chela *Chela cachius* (Cyprinidae) from the Old Brahmaputra River in Bangladesh using multiple functions. *Zoological Studies* **51**(3): 336-344. The silver hatchet chela *Chela cachius*, is a freshwater Cyprinidae commercially important for both subsistence and artisanal fisheries in Bangladesh. This small, indigenous fish is widely distributed in Bangladesh, India, Pakistan, and Myanmar. Ages and growth patterns of male and female *C. cachius* were separately estimated using monthly length-frequency distributions through multiple functions. In total, 2396 specimens were captured from the Old Brahmaputra River in Bangladesh from July 2007 to June 2008. A birth date was assigned to the month when the peak mean gonadosomatic index (GSI) occurred. The age of each cohort was estimated in weeks from the assigned birth date to each sampling month. Growth patterns for both males and females were modeled by fitting 3 different equations between mean standard lengths and the corresponding ages. The growth of *C. cachius* was best described by the von Bertalanffy model as $L_t \equiv 67.26\ (1 - \exp(-0.024\ (t + 20.22)))$ for males and $L_t \equiv 69.92\ (1 - \exp(-0.027\ (t + 22.90)))$ for females based on the coefficient of determination (r^2), Chi-squared (χ^2) values, and Akaike's information criterion (AIC), where L_t is the standard length (mm) at age t (wk). Females grew faster than males, and their absolute growth was larger than that of males at any age. The von Bertalanffy growth model, in terms of body weight, provided equations as $W_t \equiv 3.30\ (1 - \exp(-0.032\ (t + 14.32)))^3$ for males and $W_t \equiv 3.38\ (1 - \exp\ (-0.034\ (t + 20.42)))^3$ for females, where W_t is the body weight (g) at age t (wk). The present study provides a new record of the maximum length of *C. cachius* from the Old Brahmaputra River and South Asia, which should be useful to fishery managers. http://zoolstud.sinica.edu.tw/Journals/51.3/336.pdf

Key words: *Chela cachius*, Gonadosomatic index, von Bertalanffy, Old Brahmaputra River, Bangladesh.

The silver hatchet chela *Chela cachius* (Hamilton 1822), (Cypriniformes: Cyprinidae) is locally known as the chhep chela, a fish species widely distributed on the Indian subcontinent including Bangladesh, India, Pakistan, and Myanmar. The silver hatched chela is benthopelagic and inhabits ponds, ditches, and rivers on plains and in submontane regions (Menon 1999). This small indigenous fish is found in almost all inland habitats and commonly appears in the catch of both subsistence and artisanal fisheries in this region (Craig et al. 2004, Kibria and Ahmed 2005). Studies of fish consumption and nutritional values revealed that *C. cachius* and other small fishes are an important part of the diet of rural people. These small fishes are a rich source of animal protein, vitamins, and essential micronutrients, and as such, they contribute towards reducing malnutrition, particularly of vulnerable groups such as poor women and children in Bangladesh (Thilsted et al. 1997, Roos et al. 2002). Unfortunately, inland capture

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fisheries are sharply declining in Bangladesh, and concomitantly the essential tool for stock management (Santos et al. 1995) cannot be implemented because fisheries biology data are lacking. Since *C. cachius* is an important component of small-scale inland capture fisheries, and there is an urgent need to manage the numerous discrete stocks, we investigated the population dynamics of this species in Bangladesh.

A few studies investigated the biology of *C. cachius* including its feeding ecology, diet, seasonal variations in weight, and diet-size relationships (Butt and Khan 1987, Ahmed et al. 2003 2004 2005). In addition, Kohinoor et al. (2005) studied the reproductive biology, i.e., the reproductive cycle and spawning season. Our study describes age and growth patterns of both male and female silver hatchet chela by analyzing length data of samples collected over a period of 12 mo from the Old Brahmaputra River in Bangladesh.

MATERIALS AND METHODS

Study area and fish sampling

Fish were captured from the Old Brahmaputra River near Bangladesh Agricultural Univ., Mymensingh. The main channel of the Brahmaputra flowing through Bangladesh is known as the Jamuna, and the old channel is known as the Old Brahmaputra which runs through Mymensingh, a northeastern district of Bangladesh (23°N, 90°E). We used traditional fishing boats for sampling once a month during the daytime (10:30-14:30) from July 2007 to June 2008. Fine-meshed cast and seine nets (2-mm mesh) were used in order to ensure that all size groups of the population were captured. All specimens at each sampling were preserved in 10% buffered formalin in small plastic jars. Details of the collections are given in table 1.

Recording of length and weight

All fish were sacrificed using anesthesia (tricaine methanesulfonate: MS-222) before preservation with 10% neutralized formalin. The standard length (SL) was measured to the nearest 0.01 mm using digital slide calipers (Mitutoyo, CD-15PS, Tokyo, Japan). The body weight (BW) of each individual was measured on an electronic balance (Shimadzu, EB-430DW, Tokyo, Japan) to the nearest 0.01 g.

Collection of gonads and sex determination

Fish were dissected, and both gonads were carefully removed, cleaned, and weighed together (total gonad weight, GW) to the nearest 0.001 g. Fish were sexed as either males or females by visual observation of the gonads with the naked eye.

Age-group analysis

We examined both scales and otoliths from

Table 1. Collection data of *C. cachius* from the Old Brahmaputra River, Bangladesh

Sampling date	Total fish	No. of males	Size range		No. of females	Size range	
			SL (mm)	BW (g)		SL (mm)	BW (g)
4 July 2007	206	114	29-50	0.30-2.35	92	31-60	0.32-2.07
3 Aug.	206	112	32-56	0.30-1.59	94	32-61	0.43-2.62
5 Sept.	230	110	34-58	0.39-2.51	120	36-63	0.56-3.47
4 Oct.	194	104	36-60	0.55-2.51	90	37-60	0.91-2.39
1 Nov.	192	100	34-54	0.45-1.55	92	39-60	0.95-2.48
7 Dec.	200	100	36-57	0.44-2.48	100	40-57	1.00-2.51
1 Jan. 2008	196	86	30-59	0.29-2.55	110	33-58	0.56-2.43
8 Feb.	202	82	35-58	0.57-2.56	120	37-61	0.58-2.71
7 Mar.	192	92	31-57	0.35-2.42	100	43-60	1.12-2.63
6 Apr.	218	100	37-58	0.62-2.21	118	37-61	0.81-2.57
4 May	176	82	35-61	0.47-2.76	94	35-60	0.75-2.66
4 June	184	98	33-59	0.39-2.52	86	37-60	0.84-2.56

SL, standard length; BW, body weight.

a large number of individuals in a preliminary study investigating the age and growth dynamics of *C. cachius*. These structures revealed no growth markers and therefore were not suitable as indicators/predictors of age. The present study estimated age and growth using data from length-frequency distributions of multiple samples collected at different times (Ahmed et al. 2007). SL frequency distributions by sex at 1-mm intervals were plotted for each sample. The SL frequency distribution of each sample by sex was dissected into component normal distributions using Bhattacharya's method (Bhattacharya 1967) and the normal distribution separator routine of the FiSAT Program (Gayanilo et al. 1994, Halls 1998, Ahmed et al. 2007). Each component's normal distribution was assumed to represent separate age groups. This analysis provided the mean SL, standard deviation, and proportion of each age group in the length-frequency data.

Determination of the birth date

The gonadosomatic index (GSI) was used to estimate the birth date, and was calculated for each specimen as $GSI = (GW / BW) \times 100$. The birth date was assigned to an arbitrary day in the month when the monthly mean GSI was highest.

Age assignment and growth-curve fitting

Age was calculated as the time in weeks elapsed from the assigned birth date to each sampling month. Growth patterns of SL for male and female *C. cachius* were modeled by fitting the following 3 equations to the mean SL at age which was estimated for each component normal distribution at each sampling date: the von Bertalanffy equation (von Bertalanffy 1938) $L_t = L_\infty (1 - \exp(-k(t - t_0)))$; the Gompertz equation (Beverton and Holt 1957) $L_t = L_\infty \exp(-\exp(-k(t - t_0)))$; and the Robertson equation (Iwakawa and Ozawa 1999, Granada et al. 2004) $L_t = L_\infty / (1 + \exp(-k(t - t_0)))$; where L_t is the SL (mm) at age t (wk), L_∞ is the asymptotic length, k is a growth coefficient, t is age, and t_0 is the theoretical age at zero length. Growth patterns of BW for male and female *C. cachius* were also modeled by fitting the von Bertalanffy equation to the mean BW at age: $W_t \equiv W_\infty (1 - \exp(-k(t - t_0)))^3$; where W_t is the BW (g) at age t (wk), W_∞ is the asymptotic body weight, k is a growth coefficient, t is age, and t_0 is the theoretical age at zero weight. BWs of both males and females in each age group were calculated from their corresponding mean SLs using Huxley's (1932) allometric equation of the respective length-weight relationship.

Growth curves in the present study were fitted by a routine that performs Gaussian elimination using the curve-fitting function of the personal computer software, Delta Graph 4.5 (Delta Point, Monterey, CA, USA). Levels of goodness of fit of these growth equations were compared on the basis of the coefficient of determination (r^2) and Chi-squared (χ^2) values. In addition, the best-fitting model among these 3 equations was then selected on the basis of Akaike's information criterion (AIC) (Akaike 1973), although the number of parameters was the same among these 3 equations (Ohtomi and Irieda 1997, Hossain and Ohtomi 2010). The AIC was calculated as: $AIC \equiv n \ln Y_{\min} + 2r$, where n is the number of data, r is the number of estimated parameters, and $Y_{\min}$ is the minimum value of the objective function (residual sum of squares/n). According to this method, the model with the lowest AIC value was selected as the best-fitting model. Furthermore, according to Chen et al. (1992), the F-test was used to check whether there was a difference in the best-fitting model between males and females. The F-statistic was calculated as $F \equiv [(S_b - S_m - S_f) / r] / [(S_f + S_m) / (n_m + n_f - 2r)]$, where S_m is the residual sum of squares (RSS) for males; S_f is the RSS for females; S_b is the RSS for both sexes (pooled data); n_m is the number of plots for males; n_f is the number of plots for females; and r is the number of parameters.

Growth-performance index and longevity

Estimated values of L_∞ and k from the best-fitting model were then used for comparison of growth-performance indices ($Ø'$) between sexes in the equation of Pauly and Munro (1984): $Ø' = \log_e k + 2\log_e L_\infty$. Additionally, Taylor (1958) defined longevity (A) as the time required to attain 95% of the L_∞ with the following equation:

$$A_{95\%} = t_0 + \frac{\log_e (1 - 0.95)}{k}.$$

This equation can be used to determine longevity based on 99% of L_∞ by substituting 0.99 for 0.95 in the equation (Taylor 1958).

Statistics analysis

Statistical analyses were performed using Microsoft® Excel-add-in-DDXL (Redmond, WA, USA), GraphPad Prism 5 (GraphPad Software, Inc., San Diego, CA, USA), and VassarStats software (http://faculty.vassar.edu/lowry/VassarStats.html). A Chi-square test was applied to identify the sex ratio from the expected value of 1:1 (male: female). All statistical analyses were considered significant at 5% ($p < 0.05$).

RESULTS

SL and BW

In total, 2396 specimens from 12 samples were captured over the study period, of which 1180 were male and 1216 were female. The sex ratio did not statistically differ from the expected 1:1 ratio (*d.f.* = 1, $\chi^2 = 0.54$, $p > 0.05$). The SL of male fish ranged 29-61 mm, and the BW ranged 0.29-2.76 g. The SL of female fish ranged 31-63 mm, and the BW ranged 0.32-3.47 g (Table 1). This study found a new record of maximum length (SL = 6.30 cm) of *C. cachius* for the Old Brahmaputra River and also for South Asia.

Age group and cohort

Sequentially arranged SL frequency distributions from samples collected over the study period revealed 3 cohorts for both males and females (Figs. 1, 2). Age-group analyses indicated that a maximum of 3 age groups was present in the frequency distributions. Figure 1 shows that each of the fish samples collected on 1 Nov. and 7 Dec. 2007, and 7 Mar., 6 Apr., and 4 June 2008 was comprised of 3 age groups, while other samples showed 2 age groups in males. In females, each of the samples collected on 3 Aug. and 5 Sept. 2007, and 6 Apr., 4 May, and 4 June 2008 exhibited 3 age groups, while 2 age groups were evident on other sampling dates. Both male and female *C. cachius* were first recruited to the fishing ground in July with a mean SL of about 34 mm.

Birth date

The minimum, mean, and maximum GSI values of each monthly sample for females are shown in figure 3. The mean female GSI of silver hatchet chela was low in Jan., then gradually increased beginning in Feb. and remained high until Sept. The GSI then decreased from Oct. and remained low through Dec. and Jan. Similar patterns were found in monthly changes in the mean GSI for males. Since the mean GSI of females peaked in June, the birth date was arbitrarily assigned to 1 June 2007 (the 1st day in the peak spawning month) as the 1st day in the life cycle of *C. cachius*.

Age and growth patterns

SL frequency data collected at monthly intervals showed 3 traceable cohorts for both males and females (Figs. 1, 2). Since the youngest cohort was found in July 2007 for both sexes, only the initial cohort was analyzed for

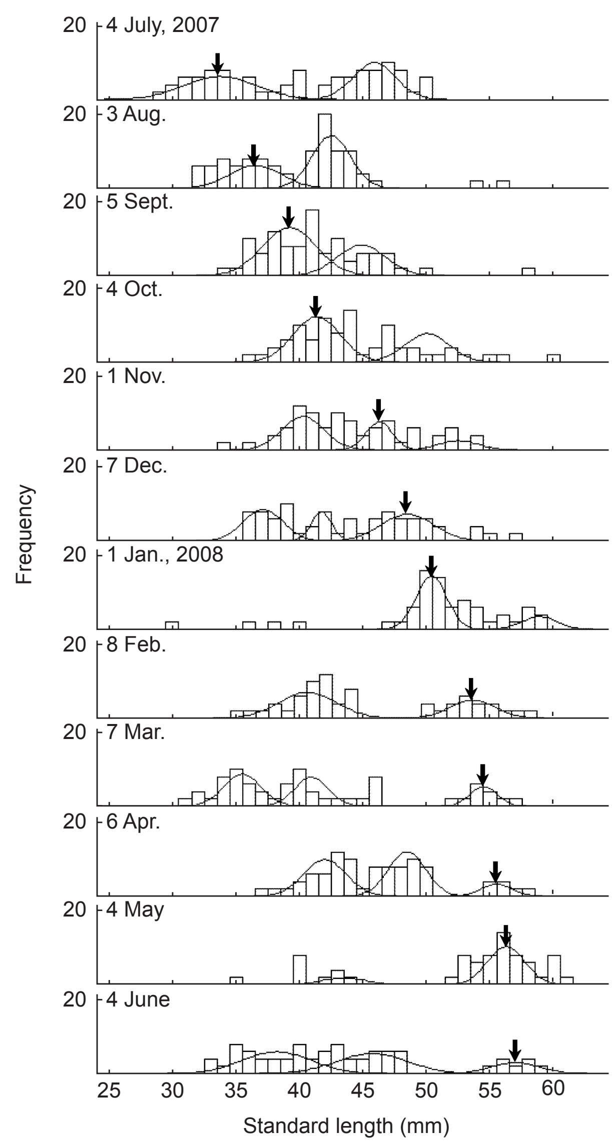

Fig. 1. Length-frequency distributions of male *C. cachius* in the Old Brahmaputra River, Bangladesh from July 2007 to June 2008. Curves show the normal distributions, and arrows trace the progress of the cohort.

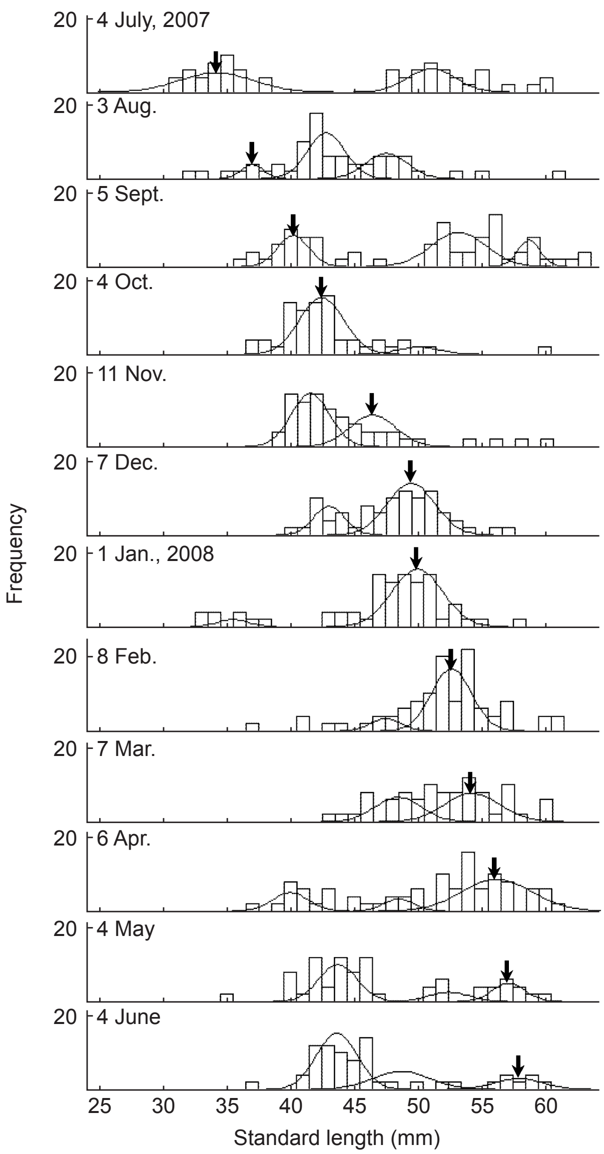

Fig. 2. Length-frequency distributions of female *C. cachius* in the Old Brahmaputra River, Bangladesh from July 2007 to June 2008. Curves show the normal distributions, and arrows trace the progress of the cohort.

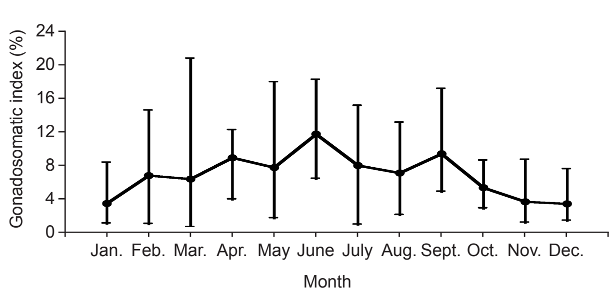

Fig. 3. Monthly changes in the gonadosomatic index (GSI) for female *C. cachius* in the Old Brahmaputra River, Bangladesh from July 2007 to June 2008. Solid circles indicate the mean GSI, and vertical bars show its range.

growth modeling in this study. The growth curves fitted to the length-at-age data were as follows:

von Bertalanffy

Male $L_t \equiv 67.26\ (1 - \exp(-0.024\ (t + 20.22)))$ ($n = 12$, $r^2 = 0.993$, $d.f. = 11$, $\chi^2 = 4.918$, AIC = -19.27) and

Female $L_t \equiv 69.92\ (1 - \exp(-0.027\ (t + 22.90)))$ ($n = 12$, $r^2 = 0.997$, $d.f. = 11$, $\chi^2 = 1.828$, AIC = -31.25);

Gompertz

Male $L_t \equiv 63.62 \exp(-\exp(-0.039\ (t + 5.798)))$ ($n = 12$, $r^2 = 0.992$, $d.f. = 11$, $\chi^2 = 6.053$, AIC = -16.78) and

Female $L_t \equiv 65.63 \exp(-\exp(-0.036\ (t + 6.715)))$ ($n = 12$, $r^2 = 0.994$, $d.f. = 11$, $\chi^2 = 2.049$, AIC = -29.88); and

Robertson

Male $L_t \equiv 61.51 / (1 + \exp(-0.052\ (t - 1.97)))$ ($n = 12$, $r^2 = 0.990$, $d.f. = 11$, $\chi^2 = 7.423$, AIC = -14.33) and

Female $L_t \equiv 63.20 / (1 + \exp(-0.047\ (t - 1.72)))$ ($n = 12$, $r^2 = 0.996$, $d.f. = 11$, $\chi^2 = 2.457$, AIC = -27.70).

Comparing among the models fitted to the age-length data, the von Bertalanffy equation had the highest r^2 and lowest χ^2 values for both males and females. In addition, the von Bertalanffy equation provided the best model for describing the growth of both sexes on the basis of the AIC. We therefore adopted the von Bertalanffy equation for both males and females as the appropriate growth model for *C. cachius* (Figs. 4, 5) in this study. According to Chen et al. (1992), the *F*-test revealed that there was a significant difference in the von Bertalanffy equation between the sexes ($p < 0.05$) (Figs. 4, 5).

Relationships between the pooled data of SL (mm) and BW (g) fit by the double-logarithmic regression line were allometric and yielded high correlation coefficients for both sexes (Table 2). The von Bertalanffy growth curves fit with weight-at-age data are illustrated in figures 6 and 7. The equations were as follows:

Male $W_t \equiv 3.30\,(1 - \exp(-0.032\,(t + 14.32)))^3$, ($r^2 = 0.991$) and

Female $W_t \equiv 3.38\,(1 - \exp(-0.034\,(t + 20.42)))^3$, ($r^2 = 0.997$).

Growth-performance index and longevity

Following Pauly and Munro (1984), the calculated growth-performance indices were $Ø' = \log_{10}(0.024 + 2\log_{10}(67.26)$ for males and $Ø' = \log_{10}(0.027 + 2\log_{10}(69.92)$ for females. The overall growth-performance index ($Ø'$) was higher for females (2.12) than males (2.04). These results also indicate that females had higher growth rates than males of the same age (Figs. 4, 5). In addition, using Taylor's (1958) method, we calculated the ages at which 95% and 99% of L_∞ were reached, and respective values were 104.60 and 171.66 wk for males, and 88.05 and 147.66 wk for females.

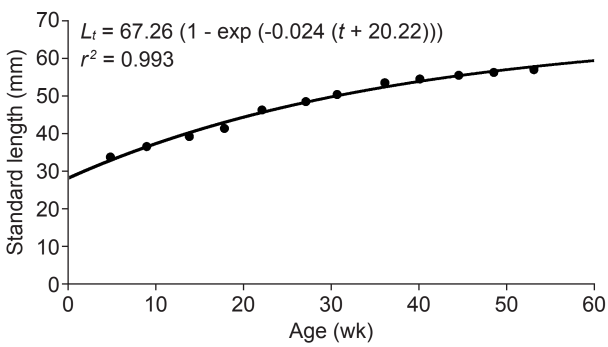

Fig. 4. Growth curve of male *C. cachius* in the Old Brahmaputra River, Bangladesh. Solid circles show the mean standard lengths of the various age groups.

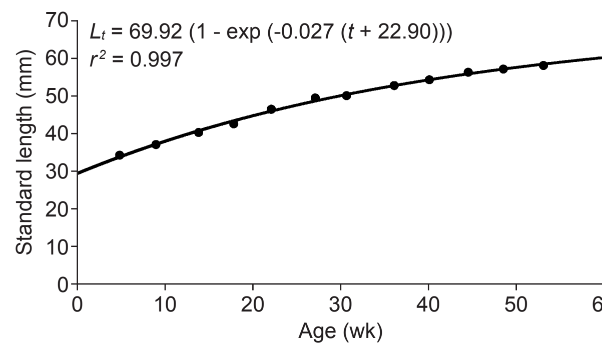

Fig. 5. Growth curve of female *C. cachius* in the Old Brahmaputra River, Bangladesh. Solid circles show the mean standard lengths of the various age groups.

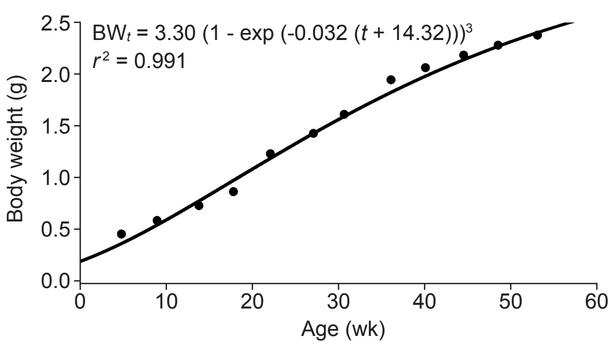

Fig. 6. Growth curve fitted to the weight-at-age data of male *C. cachius* in the Old Brahmaputra River, Bangladesh. Solid circles show the mean body weights of the various age groups.

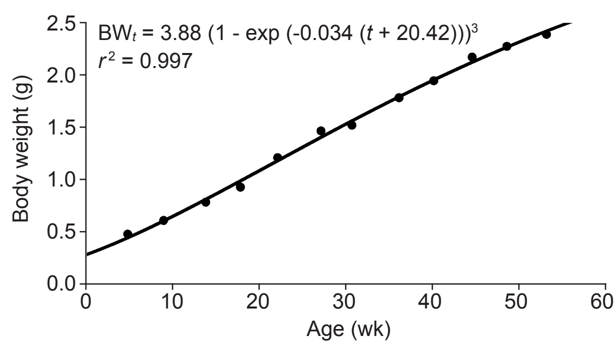

Fig. 7. Growth curve fitted to the weight-at-age data of female *C. cachius* in the Old Brahmaputra River, Bangladesh. Solid circles show the mean body weights of the various age groups.

Table 2. Allometric relationships between body weight (BW, g) and standard length (SL, mm) of *C. cachius* from the Old Brahmaputra River, Bangladesh

Sex	SL range	Sample size	q (intercept)	b (slope)	Correlation coefficient (r)
Male	29-61	1180	0.000007	3.15	0.921
Female	31-63	1216	0.000010	3.05	0.914

DISCUSSION

The reproductive biology of *C. cachius* from the Old Brahmaputra River is insufficiently known, and the quality of previous data from that region was poor (Kohinoor et al. 2005). To the best of our knowledge, no references to the age and growth of *C. cachius* are available from the Old Brahmaputra River, Bangladesh. However, the Old Brahmaputra River is considered an important spawning and feeding ground for riverine fishes of Bangladesh, and large numbers of these including some commercially important species are fished by both small- and large-scale fisheries throughout the year (Hossain and Ahmed 2008). Studies of the age and growth of *C. cachius* are not easy due to the difficulty of obtaining representative samples (Ohtomi and Irieda 1997). In the present study; however, collection of a large number of specimens from this river was possible using traditional fishing gear including cast and seine nets (Kibria and Ahmed 2005). But it was not possible to catch fishes smaller than 29.00 mm SL during the sampling period, despite their presence, which is indicative of the selectivity of the fishing gear. Hossain (2010a b) noted a similar hypothesis, when he was studying biometric relationships of some small indigenous species from the Ganges River, northwestern Bangladesh. However, this deficiency could be overcome if specimens smaller than the smallest specimens (< 29 mm) could be collected by a larval survey net and later adjusting the length-frequency data for gear selectivity. It is important to mention that the river under study, like all other inland water bodies in Bangladesh, is inhabited by several (about 25) small indigenous species. It is difficult to separate larvae of *C. cachius* from larvae of other whitefin fish species captured together, because the larvae are undescribed, and a manual for the region is lacking. Moreover, great efforts are required to sex larvae into males and females. We recorded the maximum size of *C. cachius* in the Old Brahmaputra River as 63.00 mm SL, which is larger than the maximum observed value of 60.00 mm TL from the Krishna River, Karnataka and Tamil Nadu, India (Chandrashekhariah et al. 2000, Rema and Indra 2000) and elsewhere in Bangladesh. The present study reports a new record of maximum length for *C. cachius* from the Old Brahmaputra River and South Asia. The maximum length is necessary to estimate population parameters important for fishery resource planning and management (Hossain 2010c). Size differences might be attributed to variations in environmental factors, particularly water temperature and food availability (Hossain and Ohtomi 2010).

According to Soriano et al. (1992), the von Bertalanffy model is most commonly used in fishery biology to describe length-at-age relationships of juvenile and adult fishes. This model is easy to fit and generally a good descriptor of growth patterns of fish; however, it has several limitations that prompted us to seek alternative solutions. There are several procedures available for estimating parameters of growth functions including a length-frequency analysis, mark-recapture experiments, and growth checks formed in hard parts, such as scales, otoliths, and vertebrae (King 2007). Although a length-frequency analysis has limited applicability (DeVries and Frie 1996) and a multi-model inference (Liu et al. 2011) is preferable, even with multiple models, no single model can adequately explain growth (Ma et al. 2010, Jia and Chen 2011), and even the best candidate model can be misleading. The results should be questioned until validated by aging of hard parts. Because our preliminary investigation showed that scales and otoliths of *C. cachius* revealed no determinant marker of age, we estimated parameters of the growth curves using data of multiple samples identifying successive progressions of growth along length axes from sequentially arranged length-frequency distributions. The limited number of age and growth studies on freshwater fish species in Bangladesh is due to the difficulty of collecting large samples in some months (ODA 1995). However, in the present study, we were able to collect year-long monthly samples, which in turn, allowed us to trace growth modes that can be used to estimate the mean length and age. Growth patterns of male and female *C. cachius* were modeled by fitting 3 different growth functions. The von Bertalanffy equation exhibited the best fit among the models examined. Our findings showed that growth parameters were L_∞ = 67.26 mm SL and k = 0.024/wk for males, and L_∞ = 69.92 mm SL and k = 0.027/wk for females. Females grew slightly faster, and the back-calculated SL at each age for females was larger than that of males.

There is no information on the dynamics of age and growth of *C. cachius*, or for other closely related species, and therefore, we could not compare the present findings to previous studies. Although Forese and Pauly (2011) recorded 6.0 cm as the maximum total length of male/unsexed *C. cachius*, Menon (1999) was cited as the main reference. This value cannot be used because it is not reported whether the maximum length means the asymptotic length. Moreover, the growth model with which the estimate was calculated was not reported either. However, Ahmed et al. (2007) observed an almost similar growth rate k = 0.026/wk for males and k = 0.025/wk for females of a population of *Gudusia chapra* (Hamilton-Buchanan 1822) in a large perennial pond in the same region of Bangladesh; nevertheless, males had higher k values than females. In this study, females showed faster growth and were larger than males at all ages. In fish, fecundity generally increases with fish size. A larger female size may be considered a life-history strategy supporting increased egg production (Roff 1983, Beckman et al. 1989, Wootoon 1998). For males, relatively less foraging, which may result in decreased risks of predation, may slow growth (Roff 1983). These speculations may also explain growth differences between males and females in fish (Hyendes et al. 1992). However, the best-fitting model (von Bertalanffy) had relatively higher t_0 values than the other models in this study. King (2007) interpreted t_0 (age at zero length) as merely a scaling factor in the growth curve. It is sometimes not reasonable to extrapolate the age when the length of the fish is 0 in this curve. However, negative t_0 values are explained biologically as a species growing faster in the juvenile stage than in the adult stage. This study reports the 1st reference on longevity for any small indigenous fish species in Bangladesh using mathematical models or modeling (Taylor 1958). Additional studies of other parameters for *C. cachius* are required to properly assess and manage this important species.

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