

Growth Study of the Pool Barb *Puntius sophore* (Cyprinidae: Barbinae) through Multi-Model Inferences

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Ferdous Ahamed, Zoarder Faruque Ahmed, Md. Yeamin Hossain, and Jun Ohtomi (2012) Growth study of the pool barb *Puntius sophore* (Cyprinidae: Barbinae) through multi-model inferences. *Zoological Studies* 51(7): 1077-1085. The pool barb *Puntius sophore* (Hamilton 1822), is a freshwater to brackish-water cyprinid widely distributed in Asia, including Bangladesh, Pakistan, India, Nepal, Myanmar, Bhutan, Afghanistan, and China. The growth pattern and longevity of *P. sophore* were studied in the Old Brahmaputra River, Bangladesh, using time series of the length-frequency distributions through multi-model inferences in Jan.-Dec. 2009. Both males and females were recruited in May, with respective modal sizes of 32 and 36 mm standard length. Growth was best described by the von Bertalanffy equation as $L_t \equiv 63.90[1 - \exp\{-0.156(t + 3.418)\}]$ for males and $L_t \equiv 74.17[1 - \exp\{-0.141(t + 3.839)\}]$ for females. Females grew faster and reached a larger size at the same age than males. The longevity of this species was estimated to be ~15 months for both sexes. The relationship between the standard length and body weight indicated isometric growth in both sexes. <http://zoolstud.sinica.edu.tw/Journals/51.7/1077.pdf>

Key words: Cyprinidae, Growth, Length-frequency, Multi-model, *Puntius sophore*.

The pool barb *Puntius sophore* (Hamilton 1822) is a freshwater to brackish-water cyprinid widely distributed in inland waters of Asia, including Bangladesh, Pakistan, India, Nepal, Myanmar, Bhutan, Afghanistan, and China. This fish is benthopelagic (demersal) and inhabits rivers, streams, and ponds of plains and submontane regions (Menon 1999). Recent studies on fish consumption and nutritional values of small fishes in Bangladesh indicated that *P. sophore* was both an important food resource and a crucial source of micronutrients essential in preventing malnutrition and vitamin and mineral deficiencies in rural communities, particularly of vulnerable groups such as poor women and children in Bangladesh (Thilsted et al. 1997, Roos et al. 2002, Thilsted 2003). In addition, it is an important, small

indigenous fish species of Bangladesh and a very popular food fish item (Rahman 2005) and is also used as an aquarium fish (Froese and Pauly 2011).

Numerous studies from various water bodies were conducted on the biology of *P. sophore*, including the length-weight relationship and relative condition factor in Indian waters (Talwar and Jhingran 1991, Reddy and Rao 1992, Menon 1999), growth in the Jamuna River, Bangladesh (De Graff 2003), length-weight and length-length relationships in the Mathabhanga River, northwestern Bangladesh (Hossain et al. 2006a), biodiversity in the Pravara Sangam district of Ahmednagar, India (Shinde et al. 2009), and the breeding-ground suitability profile in the Damodar River System, India (Sarkar and Banerjee 2010).

The Old Brahmaputra River is considered

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an important spawning and feeding ground for riverine fishes of Bangladesh, and large numbers of species like *P. sophore* are fished by both small- and large-scale fisheries throughout the year (Hossain and Ahmed 2008). However, there is no published report on the biology of *P. sophore* from this Bangladeshi river, which is thus an obstacle for defining proper management strategies for this important fishery. Our main purpose here was to provide information on growth patterns and longevity of *P. sophore* based on monthly length-frequency distributions using multi-model inferences for the sake of robustness. In addition, the length-weight relationship was examined for both sexes to estimate the weight-based growth parameter of *P. sophore* in the Old Brahmaputra River.

MATERIALS AND METHODS

Study site

The present study was conducted in the Old Brahmaputra River of Bangladesh, which is comprised of 2 channels: a main channel, the Jamuna, which flows through Bangladesh; and an old channel, commonly known as the Old Brahmaputra River that runs through Mymensingh, a northeastern district of Bangladesh (straddling 23°58'-25°25'N, and 89°38'-91°15'E).

Fish sampling and measurement

Monthly samples were collected from the river section passing through the Bangladesh Agricultural Univ. campus at 24°42'N and 90°28'E in Jan.-Dec. 2009. Sampling was conducted from a traditional fishing boat, using a combination of fine-meshed cast nets and seine nets of < 2-mm mesh, to catch all size groups within the population. All specimens were preserved on ice, transferred to the laboratory, and fixed in 10% buffered formalin prior to analysis. The standard length (SL) of all individuals was measured to the nearest 0.01 mm using digital slide calipers (CD-15PS, Mitutoyo, Tokyo, Japan), while the body weight (BW) was recorded using a digital balance (EB-430DW, Shimadzu, Tokyo, Japan) to 0.01-g accuracy. All collected specimens were sexed by making an incision in the abdomen and visually inspecting the gonads. All fat, connective tissue, and blood vessels were carefully removed from the gonads, and the gonadal weight (GW) was

measured to the nearest 0.001 g.

Length-frequency analysis

Monthly length-frequency distributions were constructed using 5-mm SL intervals for both sexes. Series of component normal distributions were fitted to the length-frequency data of each sample by sex, using a computer analysis (Microsoft Excel-add-in-Solver) based on Hasselblad's (1966) maximum-likelihood method. The normal distribution of each component was assumed to represent an age group in the population. The outputs from this analysis included the mean SL, standard deviation, and proportion of each age group explained by the normal distribution of each component. A birth date was assigned to an arbitrary day in the month when the GSI was highest. Then, ages (in months) were calculated for the mean SLs belonging to each of the cohorts.

Determination of the birth date and longevity

The gonadosomatic index (GSI) was used to determine 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. Longevity was estimated from the time series of length-frequency distributions.

Age assignment and growth patterns

Age was calculated as the time in months that had elapsed from the assigned birth date to each sampling date. Length growth patterns for both male and female *P. sophore* were described by fitting the following 4 equations to the mean SLs at the ages estimated for the normal distribution of each component at the various sampling dates in Jan.-Dec. 2009:

the von Bertalanffy (1938) equation:

$$L_t = L_{\infty}[1 - \exp\{-k(t - t_0)\}];$$

the Gompertz equation (Beverton and Holt 1957):

$$L_t = L_{\infty}\exp[-\exp\{-k(t - t_0)\}];$$

the Robertson equation (Iwakawa and Ozawa 1999, Granada et al. 2004):

$$L_t = L_{\infty}/[1 + \exp\{-k(t - t_0)\}]; \text{ and the}$$

Pauly-Gaschütz equation (Pauly and Gaschütz 1979):

$$L_t = L_\infty [1 - \exp\{-k(t/12 - t_0) - (CK/2\pi)\sin(2\pi(t/12 - t_s))\}];$$

where L_t is the SL (mm) at age t (month), L_∞ is the asymptotic SL (mm), k is a growth coefficient (1/yr), t_0 is the theoretical age at zero length, C is the intensity of seasonal growth oscillations, and t_s is the age at the beginning of growth oscillation. The goodness of fit of these equations was compared on the basis of the Akaike information criterion (AIC) (Akaike 1973), because the number of parameters was not the same among these 4 equations. 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. An F -test was conducted to compare the best-fitting growth curves between sexes using the following formula (Chen et al. 1992):

$$F \equiv [(S_b - S_m - S_f)/r] / [(S_f + S_m)/(n_m + n_f - 2r)];$$

where S_m is the residual sum of squares (RSS) for males, S_f is the RSS of females, S_b is the RSS for the 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 patterns of BW for both male and female *P. sophore* from the Old Brahmaputra River of Bangladesh were also modeled using the best-fitting equation. 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 performance

To compare growth between the sexes, a growth performance index (\emptyset') (Pauly and Munro 1984) was calculated by the equation:

$$\emptyset' = \log_e k + 2 \log_e L_\infty.$$

The growth performance index is more robust than either L_∞ or K individually, as these 2 parameters are inversely correlated, and fulfils the requirement for a simple, single parameter for comparing growth (Pauly and Munro 1984).

Length-weight relationship

Relationships between SL and BW in both sexes were obtained using the equation of Huxley (1932): $\ln(BW) = \ln(a) + b \ln(SL)$, with the slope b defining the type of growth. Significant deviation of the b value from the theoretical isometric value ($b = 3$) indicates either positive ($b > 3$) or negative ($b < 3$) allometric growth (Tesch 1971), which was verified using Student's t -tests (Sokal and Rohlf 1981). An analysis of covariance (ANCOVA) (Zar 1984) was used to test for significant differences in slopes and intercepts between sexes.

RESULTS

In total, 1755 specimens of *Puntius sophore* were collected during this study, including 813 (46.3%) males and 942 (53.7%) females. The sex ratio showed a significant difference from the expected value of 1:1 and was found to be slightly in favor of females (male: female = 1:1.16, $\chi^2 = 9.48$, $p < 0.01$). The SL of males ranged 19.0-76.0 mm and BW 0.19-14.21 g. The SL of females ranged 23.0-91.0 mm and BW 0.43-28.20 g.

Modal analysis of the length-frequency distribution

Length-frequency distributions for both male and female *P. sophore* are shown in figure 1. Both males and females were first recruited in May with respective modal sizes of 32 and 36 mm SL. The length-frequency distributions showed that 1 or 2 age groups were found to be present in each month, and similar patterns were displayed by both sexes. Only 1 age group was identified in the majority of months, whereas 2 age groups were identified from May to July. The length-frequency distribution exhibited a distinct new cohort, which appeared in May, that was clearly distinguishable from the older individuals. This newly recruited cohort rapidly grew and existed until June-July of the 2nd year.

Birth date and longevity

Monthly variations in the mean GSI with minimum and maximum values of female *P. sophore* are shown in figure 2. The mean GSI was low in Jan., then gradually increased until Apr., and remained high until Sept., indicative of winter spawning. Thereafter, the GSI began to decrease

in Oct. and remained low in subsequent months. Since the mean GSI peaked in Apr., the birth date was arbitrarily assigned to 30 Apr. 2009 (the last day in the peak spawning month) as the 1st day

in the life cycle of *P. sophore*. Longevity was calculated from the time series of length-frequency distributions using the assigned birth date and was estimated to be ~15 mo for both sexes.

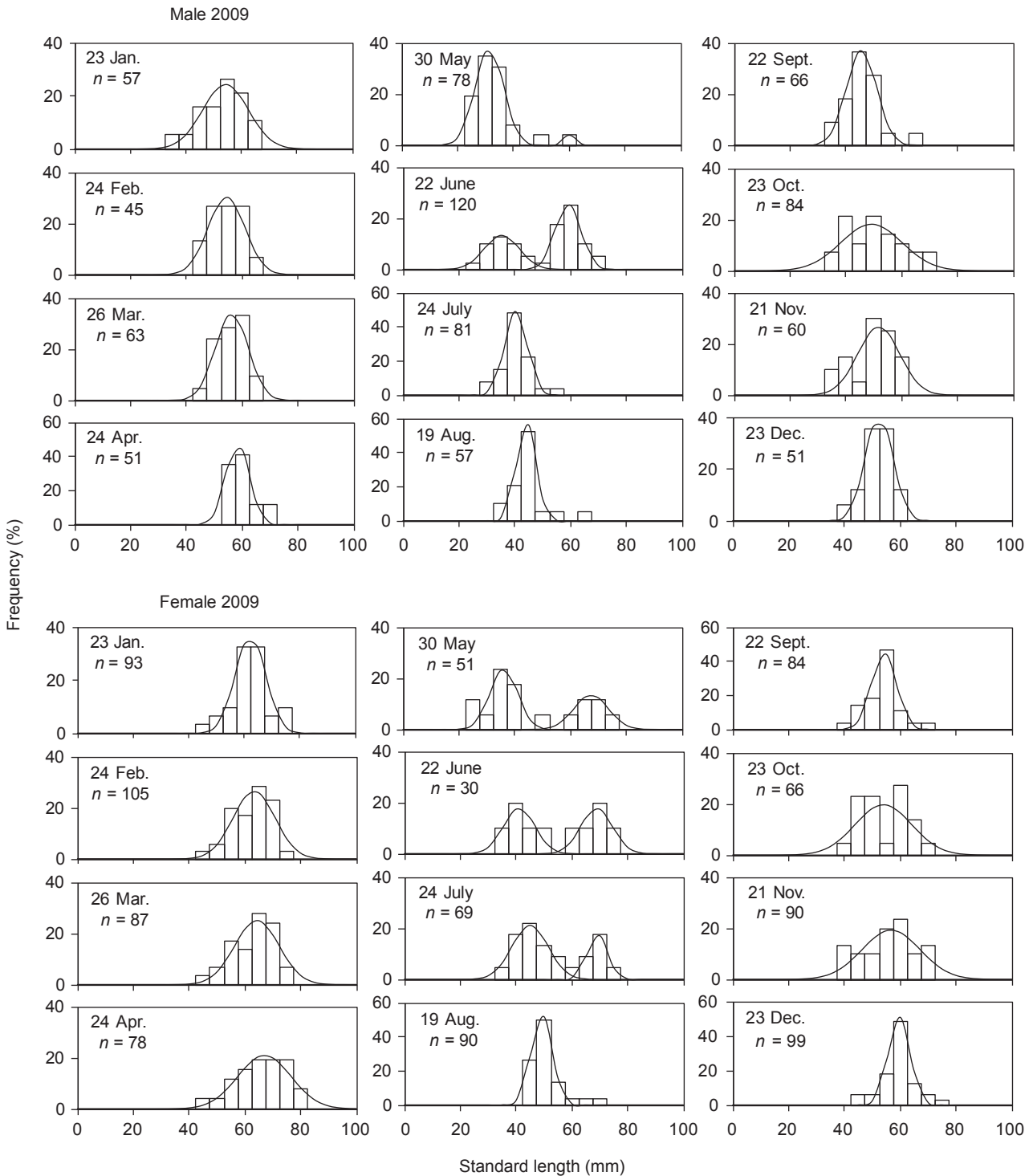


Fig. 1. Length-frequency distributions of males and females of *P. sophore* in the Old Brahmaputra River, northeastern Bangladesh in Jan.-Dec. 2009.

Growth pattern

The calculated growth parameters obtained from fitting 4 different growth models to the mean SLs at ages of both male and female *P. sophore* are shown in table 1. Among these 4 models, the von Bertalanffy model provided the lowest AIC values for both males and females, so it was adopted as the appropriate growth model for our study population of *P. sophore*. Growth curves for both sexes are shown in figure 3. There was a significant difference in growth curves between the sexes (*F*-test, *F* = 59.75; *p* < 0.001). Females had higher *L*_∞ and lower *k* values than males, as the former are larger-bodied. The growth performance index (*Ø'*) was slightly higher in females (2.89) than males (2.80) of the same age group. The von

Bertalanffy growth equations fit with weight-at-age data were as follows:

males: $W_t \equiv 9.98[1 - \exp\{-0.131(t + 4.192)\}]^3$
 (*r*² = 0.980), and

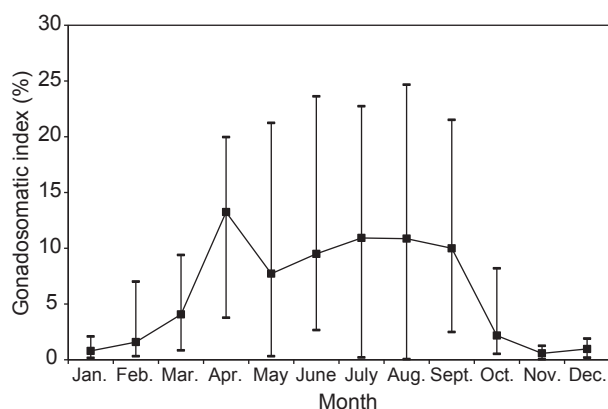


Fig. 2. Monthly changes in the gonadosomatic index (GSI) for female *P. sophore* in the Old Brahmaputra River in Jan.-Dec. 2009. Solid squares indicate the mean GSI and vertical bars show its range.

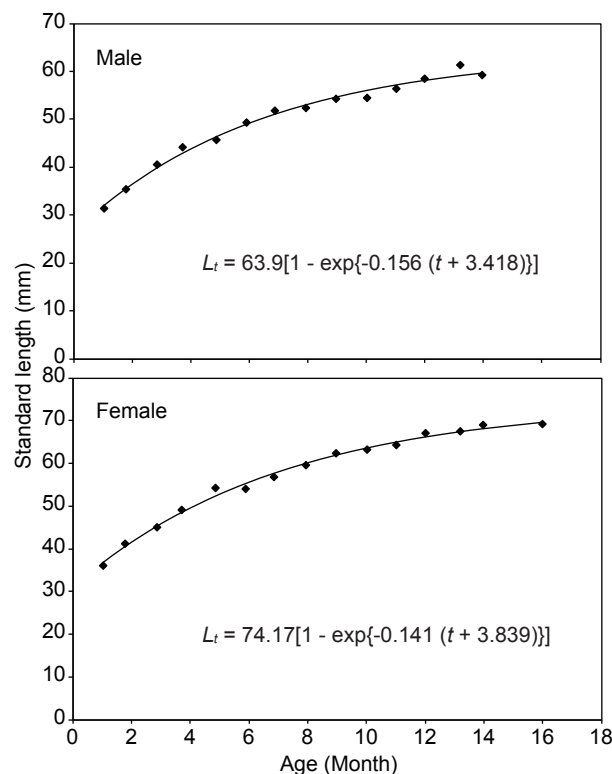


Fig. 3. Growth curves fitted to the observed mean standard length at age data for male and female *P. sophore* in the Old Brahmaputra River, northeastern Bangladesh in Jan.-Dec. 2009.

Table 1. Growth parameters obtained from fitting 4 growth models to mean standard lengths at age of *P. sophore*. *L*_∞, asymptotic standard length (mm); *k*, growth coefficient (1/yr), *t*₀, theoretical age at 0 length; *C*, intensity of seasonal growth oscillation; *t*_s, age at the beginning of growth oscillation; AIC, Akaike information criterion

Sex	Model	Parameters					
		<i>L</i> _∞	<i>k</i>	<i>t</i> ₀	<i>C</i>	<i>t</i> _s	AIC
Male	von Bertalanffy	63.90	0.156	-3.418	-	-	4.21
	Gompertz	62.23	0.206	0.811	-	-	6.43
	Robertson	61.18	0.131	0.256	-	-	8.69
	Pauly-Gaschütz	74.96	1.017	-0.505	0.347	0.226	5.74
Female	von Bertalanffy	74.17	0.141	-3.839	-	-	-0.42
	Gompertz	72.25	0.186	0.805	-	-	1.97
	Robertson	71.03	0.123	0.231	-	-	4.76
	Pauly-Gaschütz	74.92	1.636	-0.318	0.121	0.066	1.36

females: $W_t \equiv 15.03[1 - \exp\{-0.134(t + 4.006)\}]^3$
($r^2 = 0.993$).

Length-weight relationships

Statistical relationships between SL and BW for both males and females are summarized in table 2. The *t*-test revealed no significant difference between the allometric coefficient *b* values and the expected isometric value of 3; therefore, neither males ($p = 0.231$) nor females ($p = 0.141$) showed notable allometric growth. However, significant differences in both the slope (*b*) and intercept (*a*) were observed between sexes (ANCOVA, $p < 0.05$).

DISCUSSION

Several approaches have been used to estimate the growth of fish, including length-frequency analyses, mark-recapture experiments, and growth checks of hard parts like scales, otoliths, and vertebrae (King 2007). However, the most commonly used method of growth determination is the identification and tracing in time of length-frequency distributions of modes (cohorts) (Bergström 1992). But for such analyses, no single model can adequately explain growth (Ma et al. 2010, Jia and Chen 2011); so a multi-model inference is preferable (Liu et al. 2011). Even with multiple models, the best candidate model can be misleading until the results are validated by the aging of hard parts. However, our preliminary investigation showed that scales and otoliths of *Puntius sophore* revealed no determinant marker of age. Therefore, 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. We found that the maximum size of *P. sophore* was 76.0 mm SL for males and 91.0 mm SL for females (≈ 114.0 mm TL for the combined data), which is much lower

than the maximum record value of 180.0 mm TL in India (Froese and Pauly 2011). However, Hossain et al. (2006a) reported the maximum TL for *P. sophore* from the Mathabhangha River, northwestern Bangladesh as 102.0 mm, whereas Shrestha (1994) recorded the maximum length of this fish from Nepal as 100.0 mm TL, which is in accordance with the present study. But Shan et al. (2000) recorded the maximum size of this fish as 60.0 mm SL (~ 75.0 mm TL), which is lower than any population of Bangladesh, India, or Nepal. In addition, the maximum weight of *P. sophore* observed in this study (28.20 g) was lower than the maximum recorded value of 70.0 g in Maharashtra, India (Archarya and Iftekhhar 2000). Most likely, these growth differences can be attributed to differences in environmental factors, particularly water temperature and food availability.

In accordance with other studies (Masuda et al. 2000, Maiorano et al. 2002, Iqbal et al. 2006, Ahmed et al. 2007, Hossain and Ohtomi 2010, Ahmed et al. 2012, Ahamed and Ohtomi 2012), a size predominance of females over males was found throughout the study period. Moreover, both sexes showed perceptible shifts in the modal SL with time during the study period. Recruitment occurred in May, and fish continued to grow until the following year when they reached sexual maturity and reproduced for the rest of their lives. Because the larger size group disappeared in the time series of length-frequency distributions in the following year during June-July, the longevity of *P. sophore* was estimated to be ~ 15 mo for both sexes. Results differed from the only other study on the growth of *P. sophore* by De Graaf (2003), who reported the longevity of this species as 3 yr in the Jamuna River, Bangladesh. Several studies reported that differences in longevity are primarily attributed to environmental factors, particularly water temperature (Cha et al. 2004, Choi et al. 2005). However, our own findings are in accordance with studies by Halls et al. (1998 1999), who reported that small, indigenous fishes of Bangladesh rarely survive for more than 1 yr,

Table 2. Allometric relationships between the standard length (SL) and body weight of *P. sophore*. *n*, number of individuals; *a*, intercept; *b*, slope; r^2 , coefficient of determination

Sex	<i>n</i>	SL range (mm)	<i>a</i>	<i>b</i>	r^2
Male	813	19.0-76.0	0.00003	3.034	0.982
Female	942	23.0-91.0	0.00003	3.042	0.988

perhaps due to environmental conditions (see above).

The growth of *P. sophore* was best expressed by the von Bertalanffy model among the models examined. This model is most commonly used in fishery biology, and is a good descriptor of fish growth patterns (Soriano et al. 1992). Our estimated growth equations showed a larger L_{∞} in females (74.17 mm SL) than in males (63.90 mm SL). Several studies indicated that size predominance in females is a common feature for offshore shrimp (Dailey and Ralston 1986, Ohtomi 1997, Colloca 2002). Because fecundity generally increases with fish size, a larger female size may be considered a life-history strategy for enhancing egg production (Roff 1983, Beckman et al. 1989). For male fish, reduced foraging to decrease predation risk may slow growth (Roff 1983). The k value was lower in females (0.141/yr) than in males (0.156/yr). But because the growth pattern of fish is nonlinear, a direct comparison of growth parameters is not biologically feasible (Cartaxana 2003). The growth performance index (Φ') is an indicator of the well-being of aquatic animals relative to their environment (Gabche and Hockey 1995), and it is easy to compare the growth (a) between sexes of a species and (b) between species rather than comparing L_{∞} and k , as these 2 parameters are intrinsically negatively correlated (Pauly and Munro 1984). We found differences in the growth performance indices, and the growth rate of females was higher than that of males, as also found in several studies of fin- and shellfishes (De Silva and De Silva 1989, Bergström 1992, Baelde 1994). These differences in the growth performance index between the sexes can be attributed to the life-history strategy stated above to explain the size differences between males and females.

We found isometric growth in the SL-BW relationships for both sexes of pool barb, indicating that BW increases relative to SL during growth. In a recent study, Hossain et al. (2006a) recorded length-weight regression parameters of $a = 0.0134$ and $b = 3.05$ for *P. sophore* from the Mathabhanga River, southwestern Bangladesh, which is in accordance with our study (Table 2). Similar results ($b = 3.03$) were also observed by Reddy and Rao (1992) for pool barb from Lake Hussain Sagar, Hyderabad, India. But De (1985) reported a much lower b value (2.44) than 3.00 for Bankura District in West Bengal, India, perhaps due to differences in ecological conditions and/or the physiology of the animals (Le Cren 1951). In

addition, the length-weight relationship in fishes can significantly vary due to sex, season (Hossain et al. 2006b), feeding rate, gonadal development, growth phase (Tarkan et al. 2006), behavior (active or passive swimmer), and water flow (Muchlisin et al. 2010). Values of b were within the limits of 2.5-3.5 reported by Froese (2006) across fin- and shellfish species. Fishes usually show allometric coefficients (b) close to the 3, indicating isometric rather than allometric growth (Tesch 1971).

In conclusion, this is the 1st comprehensive study on the growth of *P. sophore* from the Old Brahmaputra River, Bangladesh. Our findings can provide growth comparisons of this species with studies from other habitats, to facilitate sustainable management of *P. sophore* along with additional studies of other life-history and environmental parameters that deserve to be explored in future research.

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