Growth and reproduction of the Indian river shad, *Gudusia chapra* (Clupeidae)

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A b s t r a c t . The Indian river shad, *Gudusia chapra*, is a commercially important clupeid that contributes to subsistence and artisanal fisheries in inland waters in Bangladesh. Population parameters for this species were collected from a study of a population in a large perennial pond in Mymensingh, Bangladesh from May 2003 to April 2004. The gonado-somatic indices indicated a spawning season in spring, with a mean birth date estimated as 30 April. The growth equations, provided by three models, for males and females respectively, were: L_t = 140.42 (1- exp (-0.026 (t + 6.717))) and L_t = 145.39 (1- exp (-0.025 (t + 7.113))) for the von Bertalanffy model; L_t = 121.53 exp (-exp (-0.050 (t - 8.274))) and L_t = 124.95 exp (-exp (-0.048 (t - 8.421))) for the Gompertz model; and L_t = 114.27 / (1 + exp (-0.074 (t – 14.260))) and L_t = 117.19 / (1 +2 exp (-0.071 (t - 14.524))) for the Robertson model, where L_t is standard length (mm) at age t (weeks). Growth was best described by the von Bertalanffy growth equation for both male and female based on Chi-squared (χ^2) values and Akaike's information criterion. The absolute growth rates of males were slower than that of females. The von Bertalanffy growth model expressed in terms of body weight (BW) yielded functions for males and females of: BW_t = 53.63 (1- exp {-0.028 (t + 6.320)))^3 and BW_t = 53.89 (1- exp (-0.023 (t + 9.215))^3, respectively.

Key words: Clupeidae, ecology, gonadosomatic index, growth model, population parameters

Introduction

The Indian river shad, *Gudusia chapra* (Hamilton-Buchanan, 1822), is a freshwater clupeid widely distributed in the river systems of India and Bangladesh affluent to the Bay of Bengal; principally the Ganges and Brahmaputra systems and the River Mahanadi in Orissa (W h i t e h e a d 1985). It has additionally been reported in Nepal and Pakistan (S h r e s t h a 1994, M e n o n 1999). The species is pelagic and potamodromous (R i e d e 2004), and occurs in lakes, ponds, ditches and inundated fields (R a h m a n 1989). The fish is caught in large quantities and is an important component of the catch of subsistence and artisanal fisheries (T a l w a r & J h i n g r a n 1991, J a y a r a m 1999, D a n i e l s 2002). Recent socio-economic studies have identified *G. chapra* as both an important food resource and a crucial source of micronutrients essential in preventing malnutrition and vitamin and mineral deficiencies in rural communities, particularly among women and children in Bangladesh (T h i l s t e d et al. 1997, T h i l s t e d 2003). There is an urgent need to manage and regulate

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the small-scale inland fishery for *G. chapra*, and to do this there is a clear requirement for data on the population dynamics of this species.

Several studies have already been conducted on *G. chapra*. Rahman (1989) reported details of its ecology, and its distribution in the Indian sub-continent is well described (Menon 1999, Talwar & Jhingran 1991, Rao 1995). Its diet and feeding habitats have also been studied (Jhingran 1972, Bhuiyan & Hossain 1988, Gosh et al. 1988, Rahmatullah et al. 1995). In addition, a handful of studies on its reproductive biology have been completed, providing basic data on size at sexual maturity, spawning season and fecundity (Jhingran & Verma 1967, 1973, Chondar 1977, Afroz 2000). Age and growth estimates for *G. chapra* have also been made using scale characteristics (Jhingran 1977, Saleem & Ansari 1983, Afroz 2000, Narejo et al. 2000).

Here the results of a study to estimate the growth, recruitment and spawning period of *G. chapra* based on a length-frequency analysis of multiple samples over a 12-month period from Bangladesh are reported. Bangladesh has a monsoon climate with wide seasonal variation in the extent of freshwater habitats. Standing waterbodies in the form of lakes, ponds, ‘beels’ (blind-ended river channels), and flooded low-lying areas known as ‘hoars’, which flood extensively during the monsoon months, constitute 25% of the inland waters in Bangladesh. These standing waterbodies support a wide range of indigenous fish species in the dry season and make a crucial contribution to fishery production (Hoggarth et al. 1999, Craig et al. 2004,), with *G. chapra* an important element of the catch.

Study Area

This study was conducted at the Fisheries Field Laboratory of the Faculty of Fisheries at the Bangladesh Agricultural University, Mymensingh. Mymensingh (23 58 N, 89 38 E) is in the northeast district of Bangladesh, in the catchment of the River Brahmaputra. The study population occupied a small perennial lake of approximately 3.42 ha with an average depth of 1.2 m and a silt substrate and abundant aquatic vegetation at the margins. The annual range in water temperature was 17–33 ºC.

Materials and Methods

Fish sampling

Fish were collected at pre-determined randomly selected points from a boat once each month between May 2003 and April 2004. Sampling always took place at midday (between 12:30 and 13:30). Fish were caught using a combination of fine mesh cast and seine nets in order to ensure all size groups within the population were represented in the catch. On each sampling occasion at least 200 specimens were collected, which pilot studies had demonstrated provided a representative sample. All specimens were fixed in buffered formalin and stored before analysis. Collection details of *G. chapra* are shown in Table 1.

Sample and data analysis

The standard length (SL) of all specimens was measured to the nearest 1 mm and body weight (BW) to the nearest 0.01 g. The abdomen of each fish was opened and the specimen sexed.

All fat, connective tissue and blood vessels were carefully removed from the gonads, which were weighed to the nearest 0.001 g (GW).

In a preliminary study, scales and otoliths were collected and examined for growth checks. However, none were obvious on these structures, at least in our study population. Consequently, the age and growth of *G. chapra* were estimated using data from length-frequency analysis. Standard length frequency distributions by sex with 1 mm size classes were constructed for each sample. The growth of *G. chapra* was modelled using the von Bertalanffy growth equation (W o o t t o n 1998), with parameters derived from length-frequency analysis using FiSAT (G a y a n i l o & P a u l y 1997).

The recruitment pattern of was determined by spawning events. The timing of spawning in *G. chapra* was identified from estimates of the gonado-somatic index (GSI), which illustrated the reproductive cycle over the year at monthly intervals. The GSI was calculated for each specimen from monthly samples as GSI = (GW/BW) × 100. Birth-date was assigned to an arbitrary day in the month when the peak of mean GSI occurred. Age in each month was calculated as the time in weeks from the assigned birth-date to each sampling month.

The growth patterns of male and female *G. chapra* were modelled by fitting the following three equations to the mean SL at age, estimated for each component normal distribution at each sampling date: von Bertalanffy equation (v o n B e r t a l a n f f y 1938), $SL_t = L_\infty (1\text{-}exp(\text{-}K(t\text{-}t_0)))$; Gompertz equation (B e v e r t o n & H o l t 1957), $SL_t = L_\infty exp(\text{-}exp(\text{-}K(t\text{-}t_0)))$; and Robertson equation (I w a k a w a 1999, G r a n a d a et al. 2004), $SL_t = L_\infty / [1+exp(\text{-}K(t\text{-}t_0)))$ where SL is SL (mm) at age t (weeks), L_∞ is the asymptotic length, K is the growth coefficient, and t_0 the theoretical age at zero length. Growth patterns of BW for male and female *G. chapra* were also modelled by fitting the von Bertalanffy equation to mean BW at ages: $BW_t = BW_\infty (1\text{- } exp(\text{-}K (t\text{-}t_0)))^3$ where BW_t is BW (g) at age t (weeks), and BW_∞ the asymptotic body weight. Male and female BW was estimated from their corresponding SL by means of respective length-weight relationships.

Growth parameters were estimated by non-linear methods of fitting growth curves based on a direct search for parameters that best fitted SL and BW at age. Growth curves were fitted by Gaussian elimination using the curve-fitting function of Delta Graph 4.5 (Delta Point Inc., Monterey, CA, USA). A Chi-squared analysis and Akaike's Information Criterion (AIC) (A k a i k e 1973) were used to evaluate the goodness of fit of growth equations.

Results and Discussion

Standard length and body weight

A total of 2,630 specimens of *G. chapra* from 12 monthly samples were collected over the study period. The SL and BW ranged from 30 to 137 mm and 0.80 to 44.54 g respectively. The sample comprised 1,414 males and 1,216 females; a sex ratio of 1.16:1 male: female, which does not deviate significantly from unity (Chi-squared test, $d.f. = 1$, $P = 0.344$). The SL of males ranged from 30 to 126 mm and BW from 0.80 to 33.01 g. The SL of females ranged from 31 to 137 mm and the BW from 0.91 to 44.54 g (Table 1).

Age group and cohort

Length-frequency analysis of the 12 consecutive monthly samples collected for growth studies indicated a maximum of three age cohorts of males and females combined. In samples

Table 1. Collection record of *G. chapra* from the large perennial pond.

Sampling date	Total fish	No. of males	Size range		No. of females	Size range	
			L_s(mm)[1]	BW(g)[2]		L_s (mm)	BW(g)
30 May 2003	200	108	30–56	1.32–3.94	92	31–115	1.67–33.44
21 June	202	80	36–126	0.85–25.01	122	38–123	1.00–37.90
24 July	212	112	47–95	3.05–16.06	100	49–137	3.14–44.50
18 August	208	104	57–69	3.70–6.13	104	57–120	3.48–31.75
22 September	234	140	44–80	1.59–7.97	94	40–124	1.34–29.00
23 October	242	122	52–86	3.21–6.70	120	50–136	3.08–35.02
22 November	226	122	56–93	3.32–7.74	104	54–118	3.27–30.68
23 December	224	122	60–120	1.77–32.93	102	44–100	1.73–16.67
27 January 2004	214	116	35–104	0.80–11.45	98	40–106	1.43–20.00
26 February	204	100	37–108	0.89–20.94	104	31–110	0.91–20.18
28 March	222	112	45–112	1.26–18.70	110	37–132	1.06–38.97
14 April	200	96	51–125	1.84–33.01	104	60–137	1.74–41.12

collected on 30 May, 24 July and 18 August 2003 a single age class is evident, while on 21 June, 23 October, 22 November, and 23 December 2003, and 26 February, 28 March and 14 April 2004 two age groups are present (Figs 1 & 2). Notably, on 22 September 2003 and 27 January 2004 three age groups were present. These data indicate that in the study population at least three cohorts were present and that both male and female *G. chapra* recruited to the population during summer with modal size of around 36 mm SL (Figs 1 & 2).

Birth-date

The minimum, mean, and maximum GSI of each monthly sample of female were plotted in Fig. 3. Female mean GSI was relatively low in January, but gradually increasing until April, thereafter decreasing in May and remaining low in the subsequent months. A similar pattern was detected for monthly changes of the mean GSI for males. Since the mean GSI of females peaked in April, the birth-date for *G. chapra* can be arbitrarily assigned as 30 April 2003 (the last day during the main spawning month), representing day 1 in the life cycle for this species.

Age and growth pattern

Length-frequency data collected at monthly intervals showed at least three cohorts for both male and female *G. chapra* (C-1, C-2 and C-3) in Figs 1 and 2. The youngest cohort (C-1) was used for age and growth analysis. The mean age of each modal group for cohort C-1 was calculated using the estimated birth date of 30 April 2003 (above). The growth parameters fitted to the length-at-age data were as follows:

von Bertalanffy:

$$\text{Male: } SL_t = 140.42\ (1 - \exp(-0.026\ (t + 6.717)))$$
$$(\chi^2 = 4.44,\ AIC = 31.25)$$
$$\text{Female: } SL_t = 145.39\ (1 - \exp(-0.025\ (t + 7.113)))$$
$$(\chi^2 = 5.88,\ AIC = 34.59)$$

Gompertz:

$$\text{Male: } SL_t = 121.53 \exp(-\exp(-0.050\ (t - 8.274)))$$
$$(\chi^2 = 6.71,\ AIC = 32.99)$$

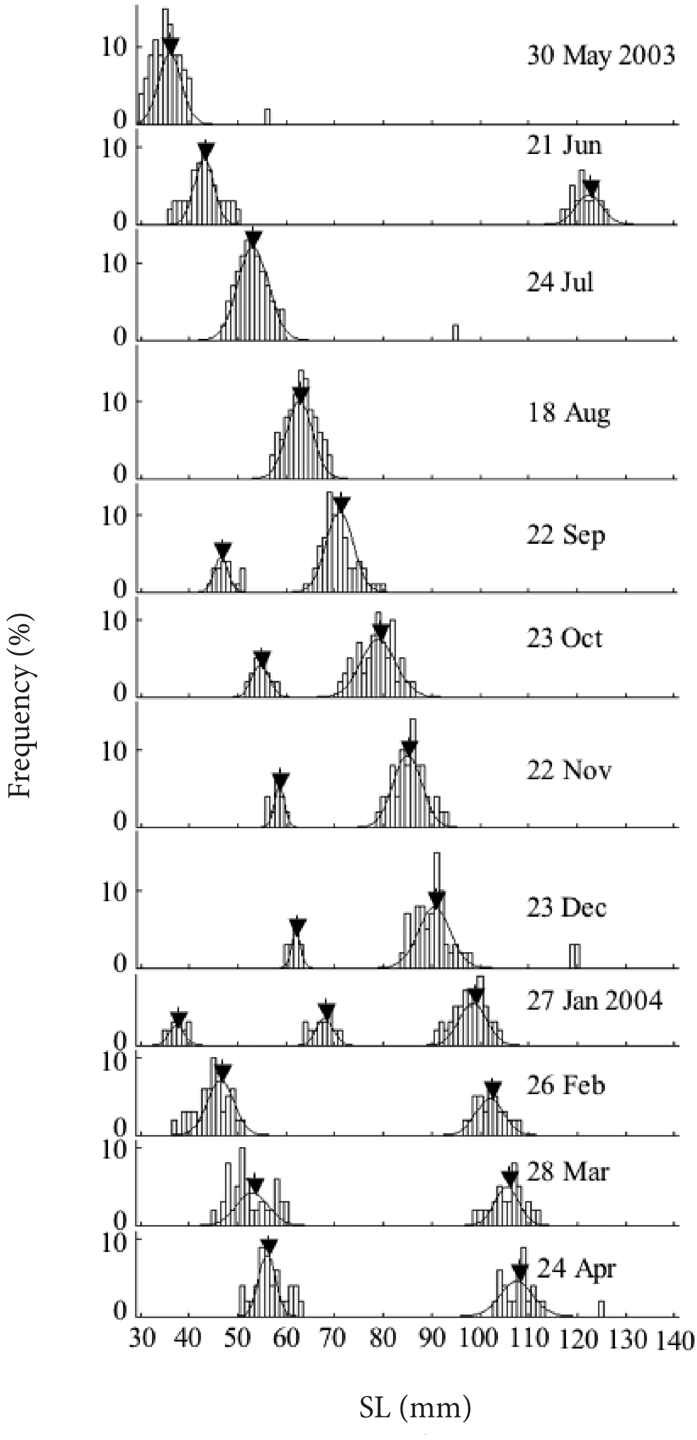

Fig. 1. Length-frequency distributions of male *G. chapra* over 12 months. Curves and arrows show the normal distributions of age groups and their means, respectively.

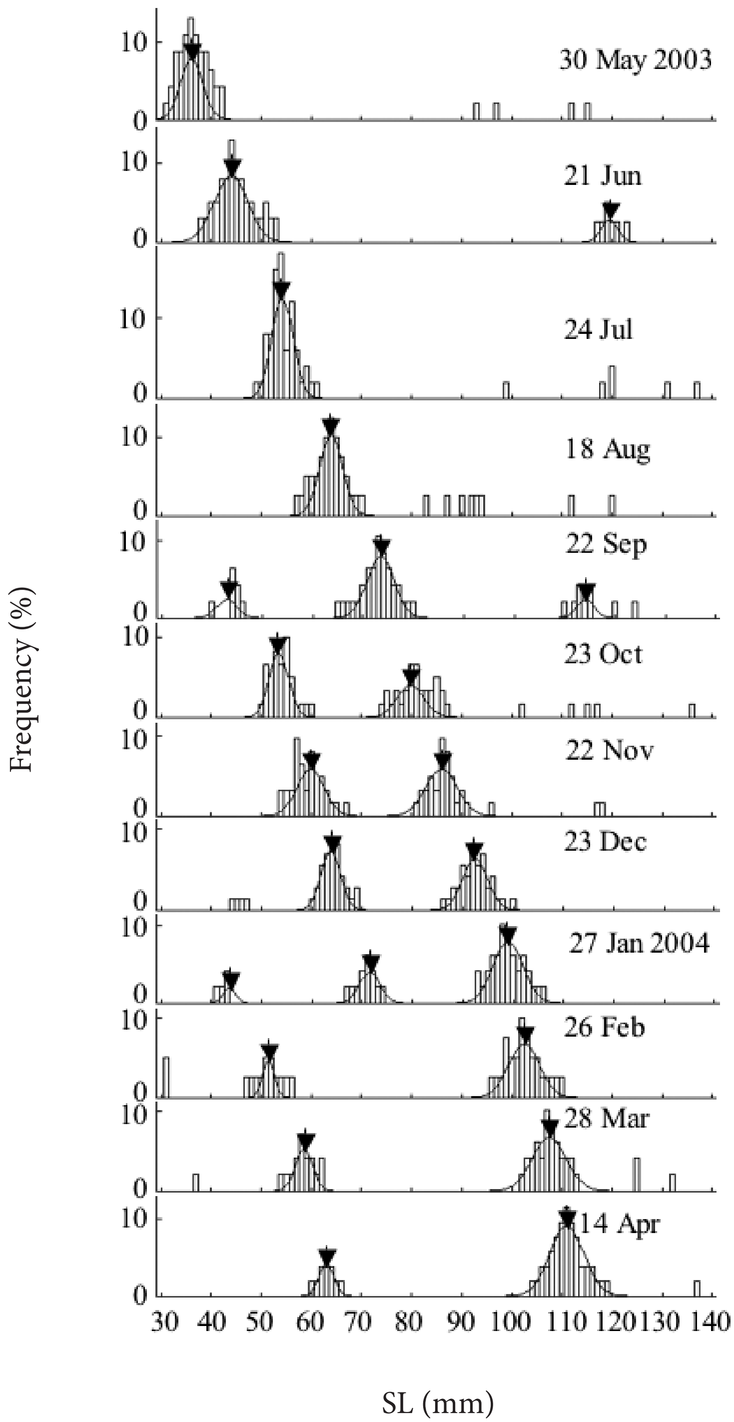

Fig. 2. Standard length frequency distributions of female *G. chapra* over 12 months. Curves and arrows show the estimated normal distributions of age groups and their means respectively.

$$\text{Female: } SL_t = 124.95 \exp(-\exp(-0.048\,(t - 8.421)))$$
$$(\chi^2 = 13.06,\ AIC = 36.89)$$

Robertson:

$$\text{Male: } SL_t = 114.27 / (1 + \exp(-0.074\,(t - 14.260)))$$
$$(\chi^2 = 10.20,\ AIC = 39.33)$$
$$\text{Female: } SL_t = 117.19 / (1 + \exp(-0.071\,(t - 14.524)))$$
$$(\chi^2 = 27.28,\ AIC = 45.76)$$

Among the three models fitted to the age-length data, the von Bertalanffy equation yielded the lowest χ^2 and AIC values for both males and females (Figs 4 and 5). Therefore, we adopted this model as the most suitable for both sexes of *G. chapra* for the study population.

The allometric relationships between the pooled standard length data and body weight for both sexes were approximated by a double logarithmic regression line with high correlation coefficients (Table 2). Body weight at each mean length of modal groups for cohort C-1 for both males and females were calculated from the above equations accordingly. The von Bertalanffy growth curves fitted weight-at-age data are shown in Figs 6 and 7. The equations were as follows:

$$\text{Male: } BW_t = 53.63\,(1 - \exp(-0.028\,(t + 6.320)))^3$$
$$(r^2 = 0.999)$$
$$\text{Female: } BW_t = 53.89\,(1 - \exp(-0.023\,(t + 9.215)))^3$$
$$(r^2 = 0.999)$$

Despite the importance of freshwater fishes as a food resource in Bangladesh there are surprisingly few studies on their age and growth, largely due to the difficulty of collecting large samples in some months (FAP 17). In the present study a year long monthly set of samples was collected and analysed for *G. chapra*, a highly important commercial species in the Indian subcontinent. A pilot study demonstrated that scales and otoliths of *G. chapra* did not reveal annuli as potential age markers. Consequently, growth parameters were derived from length-frequency analysis, yielding the first comprehensive study on the age and growth of *G. chapra*.

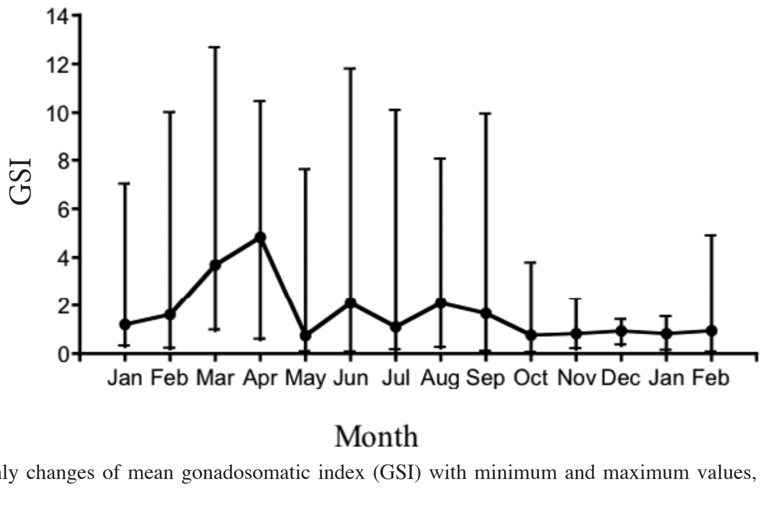

Fig. 3. Monthly changes of mean gonadosomatic index (GSI) with minimum and maximum values, for female *G. chapra*.

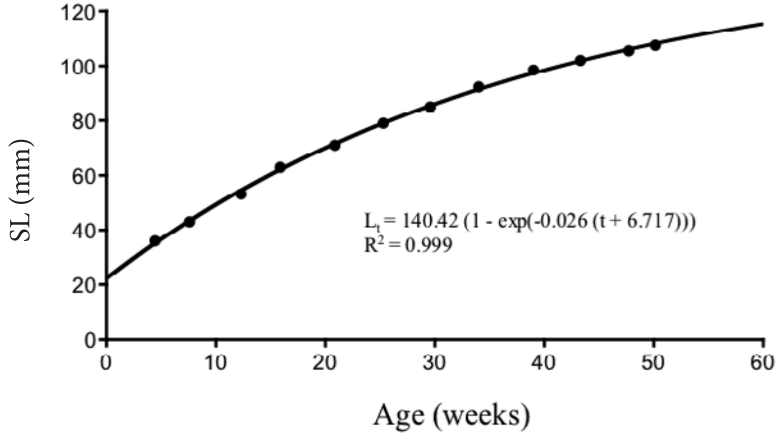

Fig. 4. Von Bertalanffy growth curve fitted to length-at-age data for male *G. chapra*.

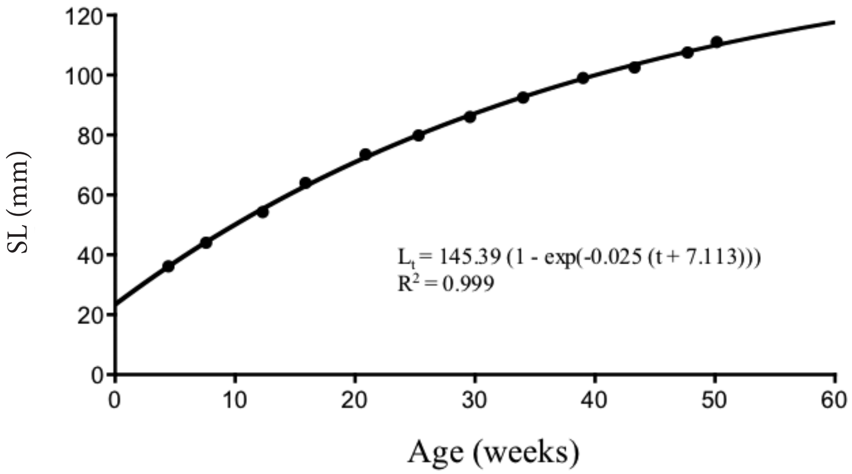

Fig. 5. Von Bertalanffy growth curve fitted to length-at-age data for female *G. chapra*.

The growth pattern of male and female *G. chapra* was modelled by fitting three different growth equations. The von Bertalanffy equation provided the best fit of the data among the models. The findings indicate that the growth parameters were L_α = 140.42 mm and K = 0.026 week^{-1} for males, L_α = 145.39 mm and K = 0.025 week^{-1} for females. Females grew slightly faster than males and the back-calculated SL at age for females were always higher than that for males. In fish, fecundity correlates closely with size (Wootton 1998). A

Table 2. Allometric relatonship between body weight (BW in g) and standard length (L_s in mm) of *G. chapra* in a perennial pond. The form of the relationship is: BW = aSL^b.

Sex	SL range	Sample size	a	b	Correlation coefficient
Male	30-126	1334	0.00003	2.97	0.977
Female	31-137	1254	0.00004	2.82	0.988

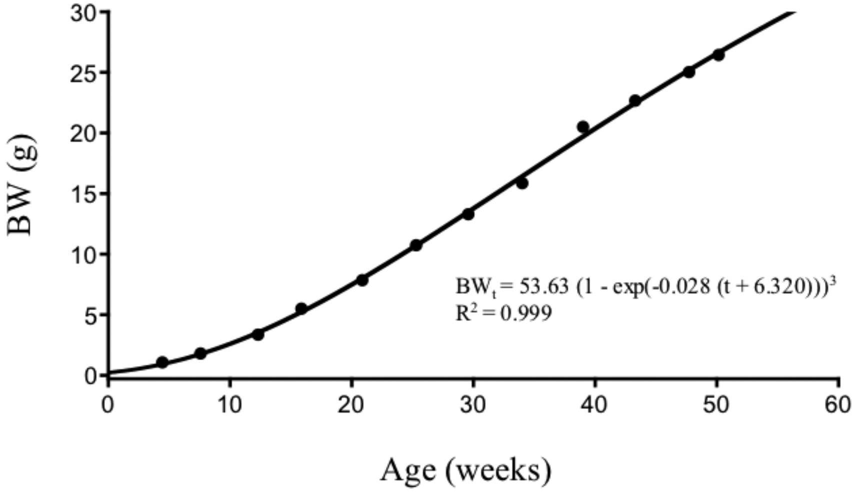

Fig. 6. Von Bertalanffy growth curve fitted to weight-at-age data for male *G. chapra*.

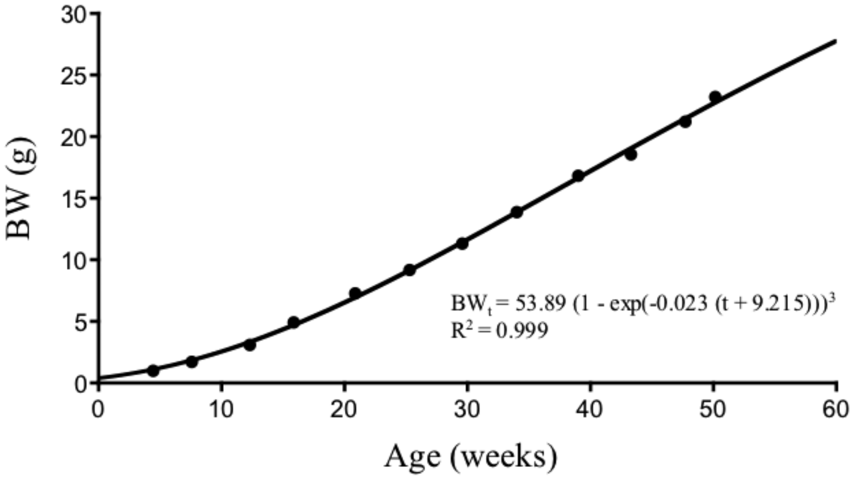

Fig. 7. Von Bertalanffy growth curve fitted to weight-at-age data for female *G. chapra*.

larger body size in females is characteristic of many fish species, and probably represents a life history strategy that maximises egg production (R o f f 1983, B e c k m a n et al. 1989). For males, large body size may not confer adaptive benefits and selection may not act as strongly for rapid growth to a larger size, though details of the mating system of *G. chapra* are currently lacking.

A previous reference to the maximum and asymptotic lengths of this species was 200 mm and 210 mm respectively (T a l w a r & J h i n g r a n 1992). Allusion to the growth model by which these estimates were made is absent. Based on the present study these length parameters appear to be greatly overestimated. An explanation for this disparity is that they may have been derived from specimens that were misidentified as *G. chapra*. Alternatively, these data may be reliable and the species does indeed achieve such large sizes under some circumstances.

A recent study on the age and growth of *G. chapra* in Bangladesh was reported by Afroz (2000), who estimated age using annuli formed on scales, and modelled age-length data using the von Bertalanffy growth equation; asymptotic length was estimated as 217.05 mm, K = 0.25 yr^{-1} and t_0 = -2.10 years, more closely matching the estimates given by Talwar & Jhingran (1992) than the present study. However, the results of Afroz (2000) are questionable; the estimation of age and growth was of unsexed *G. chapra*, and calculated using a Ford-Walford plot in which there are errors of interpretation; the plot clearly illustrates an estimate of L_α of 150 mm though a figure of 217.05 mm is reported in the text. The study by Afroz (2000) does not mention how the parameters K and t_0 were estimated, or the method by which the von Bertalanffy growth model was fitted. Consequently, these growth parameters are questionable and should be treated with caution.

In a second recent study on *G. chapra* conducted in Pakistan, Narejo et al. (2000) estimated age and growth of unsexed *G. chapra* from length-frequency data and scale annuli. The authors reported mean lengths at age and estimated longevity to be 3–4 years. However, data were not fitted to a growth model and estimates of growth parameters are consequently lacking. Further studies on the ecology of *G. chapra* are urgently required, as well as studies to understand the effects of harvesting on the population dynamics of this highly important species.

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