

SEASONAL VARIATIONS IN THE POPULATION BIOLOGY OF *SALMOSTOMA BACAILA* (CYPRINIDAE) FROM A TRIBUTARY OF THE PAYRA RIVER, BANGLADESH

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Abstract. Some biological parameters of *Salmostoma bacaila* – including sex ratio, length-frequency distributions (LFDs), size at sexual maturity, spawning season, length-weight relationships (LWRs) and condition factor – were studied. Samples were collected seasonally during June 2017 to May 2018 from a tributary of the Payra River. The overall sex ratio was significantly different from the expected value of 1:1 ($p < 0.001$), in favour of male specimens. Females were significantly larger than males. Size at sexual maturity was estimated at 7.6–7.7 cm total length. Seasonal variations in the gonadosomatic index (GSI) indicate that the main spawning season is from spring to summer. The LWRs showed negative allometric growth in both sexes, but with clear seasonal variation. Fulton's condition factor varied in both sexes and was attributed to variations in GSI with maturity. The findings of this study will be helpful for management and conservation of *S. bacaila* populations.

INTRODUCTION

Salmostoma bacaila (Hamilton 1822) is a member of the family Cyprinidae, commonly known as the large razorbelly minnow (Talwar and Jhingran 1991). This is a benthopelagic and potamodromous species, usually found in slow running streams but also occurring in rivers, ponds, and inundated fields throughout the Indian sub-continent, including Bangladesh, Pakistan, India, and Nepal (Talwar and Jhingran 1991). The species has also been reported from Afghanistan (Petr 1991).

S. bacaila is one of the important, small-indigenous fish species of Bangladesh. In Bangladesh, consumers' interest is vigorously growing towards small indigenous fish species, given their good taste and as a crucial source of micronutrients essential for preventing malnutrition and vitamin and mineral deficiencies in rural communities, particularly for vulnerable groups like poor women and children (Thilsted et al. 1997; Thilsted 2003).

Despite the enormous economic and nutritional importance of this species, no adequate information on its biology is available from Bangladeshi waters or elsewhere. The available studies on this species have only examined length-weight relationships (Masud and Singh 2015; Islam and Mia 2016; Kumar and Kiran 2016; Muhammad et al. 2016; Nath et al. 2017; Ahamed et al. 2018). However, this biological information is very important to develop effective strategies for the management and conservation of the species.

Therefore, the present study was designed to address some biological parameters – including sex ratio, length-frequency distributions (LFDs), size at sexual maturity, spawning season, length-weight relationships (LWRs) and condition factor – of *S. bacaila* collected from a tributary of the Payra River, Bangladesh.

MATERIALS AND METHODS

Study site and sampling

The samples for the present study were collected from a tributary (straddling 22°50' N and 90°35' E) of the Payra River running through Patuakhali district of Bangladesh (Figure 1). The Payra River exits into the Bay of Bengal as the Burishwar River. Samples were collected seasonally during June 2017–May 2018. Seasons were defined as summer (June–August), autumn (September–November), winter (December–February), and spring (March–May). The samples were collected using a cast net (mesh size: 1.5–2.0 cm) and a lift net (mesh size: 2.0 cm) with the help of local fishers. The freshly collected samples were preserved with ice on site and fixed with 10% formalin upon arrival at the laboratory prior to further analysis.

Fish measurement

Total length (TL) for each individual was measured to the nearest 0.1 cm using a measuring scale, and body



Figure 1. Map showing location of the study area (dotted circle) for *Salmostoma bacaila* collected from a tributary of the Payra River, Bangladesh.

weight (BW) was measured using a digital balance (AND, FSH, Korea) with 0.01 g accuracy. Sex was determined by abdominal incision of each individual and visual inspection of the gonad. In the case of females, gonad weight was measured to the nearest 0.001 g.

Sex ratio and length-frequency distributions (LFDs)

Sex ratio (male/female) was calculated and the results were analyzed by a χ^2 test (1:1; $p < 0.05$). Length-frequency distributions for both male and female *S. bacaila* specimens were constructed using 1 cm intervals of TL. The normality of TL frequency distributions was fitted based on Hasselblad's maximum likelihood method (Hasselblad 1966).

Size at sexual maturity and spawning season

The gonadosomatic index (GSI) was calculated as $GSI (\%) = (GW/BW) \times 100$. Size at sexual maturity was estimated using two approaches. First, it was estimated by the relationship between TL and GSI. Mature female individuals were defined from the above relationship, and the percentage of mature females for each 1-cm TL class was calculated. The second approach was used to estimate the size at sexual maturity (TL_m) (total length at which 50% of females are mature) from the relationship between the percentage of mature females in each TL class. The percentage of mature females (P) by TL class was fitted to a logistic equation described by King (2007): $p = 100/[1 + \exp \{-r(TL_M - TL_m)\}]$, where r is

the slope of the curve and TL_M is the median of each size class. In this case, the percentage of mature females in the largest TL class was still under 100%. Therefore, to avoid an unreasonable overestimate of TL_m , the percentage of mature females of all TL classes was adjusted by multiplying a correction factor (100/percentage of mature females in the largest TL class) via King's (2007) method. The spawning season was estimated based on the seasonal variations of the GSI.

Length-weight relationships (LWRs) and condition factor

LWRs were calculated from the equation: $BW = a \times TL^b$, where BW is the body weight (g) and TL is the total length (cm). The parameters a and b were estimated by linear regression analysis based on natural logarithms: $\ln(BW) = \ln(a) + b \ln(TL)$. Extreme outliers were excluded from the analyses (Froese 2006). A 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 with Student's t-tests (Sokal and Rohlf 1981). Analysis of covariance (ANCOVA) (Zar 1984) was used to test for significant differences in slopes and intercepts between sexes. Fulton's condition factor (K) was estimated using the following equation: $K = (BW/TL^3) \times 100$.

RESULTS

Sex ratio and length-frequency distributions (LFDs)

A total of 728 specimens of *S. bacaila* were collected during this study, among which 66.2% were males and 33.8% females (Table 1). The TL ranged from 5.1 to 11.4 cm in males and from 6.7 to 12.4 cm in females, whereas BW ranged from 1.5 to 9.2 g vs. 1.1 to 11.3 g, respectively. The seasonal and overall sex ratio significantly deviated from the expected value of 1:1 ($p < 0.001$) in favour of male specimens. The overall TL-frequency distributions showed a similar pattern, with a mean of ~9.0 cm for both sexes (Figure 2). The highest frequencies of males occurred between the 8.0 and 10.0-cm TL classes, which constituted 85.1% of the total male population. In females, the highest frequencies occurred between the 8.0 and 11.0-cm TL classes constituting 91.9% of the total female population. Seasonal changes in TL-frequency distributions by sex revealed the size predominance of females over males, with the mean female size consistently exceeding that of males throughout the year (Figure 3).

Size at sexual maturity

The relationship between TL and GSI of female *S. bacaila* is shown in Figure 4. The lowest and highest

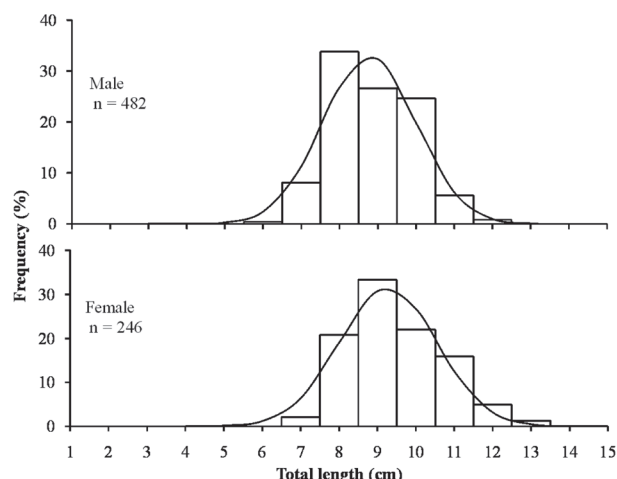


Figure 2. Length-frequency distribution of pooled male and female *Salmostoma bacaila* collected from a tributary of the Payra River, Bangladesh.

GSI_s recorded during this study were 0.09 vs. 14.72, respectively. The GSI (> 2.4%) rose sharply at ~7.6 cm TL for females, so the size at sexual maturity was considered to be 7.6 cm TL, and individuals with a GSI ≥ 2.4% could be roughly defined as mature females at the study site.

Furthermore, the relationship between TL and the percentage of mature females was expressed by a logistic function (Figure 5): $p = 100 / [1 + \exp \{-2.081 (TL_M - 7.7)\}]$ with $r^2 = 0.852$. The estimated size at sexual maturity for females was 7.7 cm TL, which was similar to the first method.

Spawning season

The seasonal mean GSI with minimum and maximum values of female *S. bacaila* is plotted in Figure 6. The

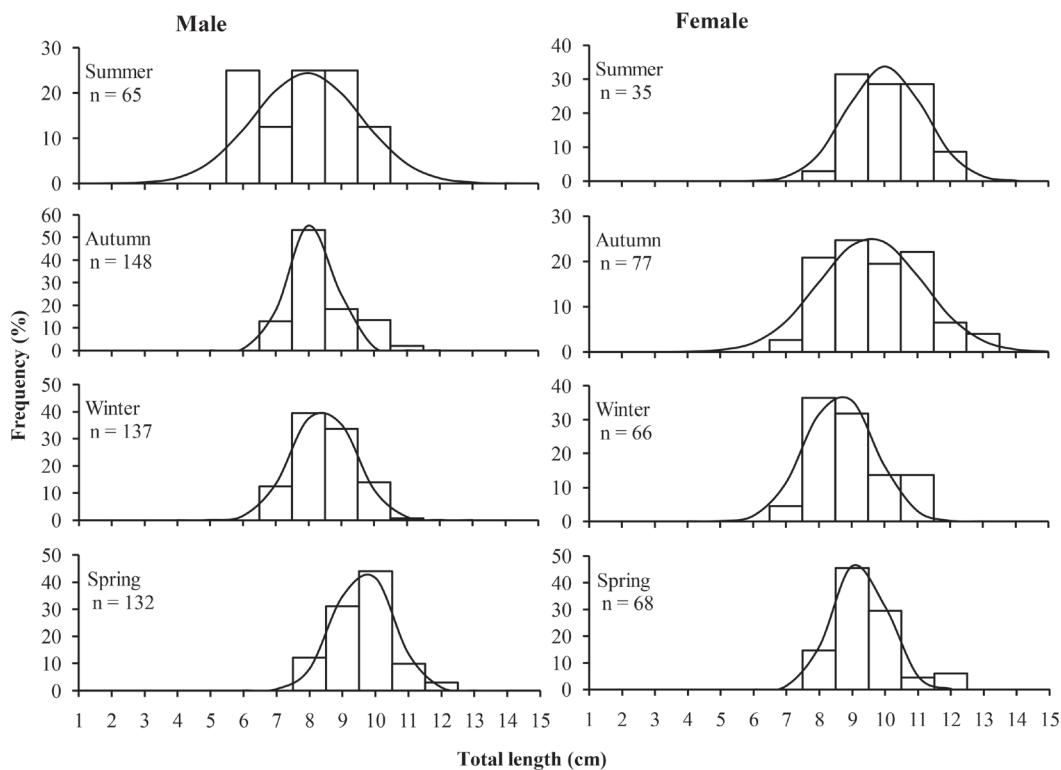


Figure 3. Seasonal length-frequency distribution of male and female *Salmostoma bacaila* collected from a tributary of the Payra River, Bangladesh.

Table 1. Collection records and sex ratio (male:female = 1:1) of *Salmostoma bacaila* (Hamilton, 1822) collected from a tributary of the Payra River, Bangladesh.

Sampling season	Total fish	No. of males	Size range		No. of females	Size range		Sex ratio (Male/female)	χ^2 (df = 1)	Significance level
			TL (cm)	BW (g)		TL (cm)	BW (g)			
Summer	100	65	5.1–10.9	1.5–9.0	35	7.9–11.6	2.3–11.0	1:0.54	9.00	**
Autumn	225	148	6.1–10.4	1.5–6.6	77	6.7–12.4	1.1–11.3	1:0.52	22.40	**
Winter	203	137	6.3–10.7	1.6–7.0	66	7.0–10.8	1.8–6.4	1:0.48	24.83	**
Spring	200	132	7.3–11.4	2.2–9.2	68	7.6–11.5	2.6–11.3	1:0.52	2048	**
Overall	728	482	5.1–11.4	1.5–9.2	246	6.7–12.4	1.1–11.3	1:0.51	76.51	**

Note: TL, total length; BW, body weight; ** significant at 1% level.

mean GSI varied from 0.44 in autumn to 8.34 in spring. The GSI value began to rise from winter and remained high during spring and summer, with a peak in spring. Thereafter, the GSI decreased sharply in autumn. Therefore, the spawning season of *S. bacaila* was estimated to be from spring to summer.

Length-weight relationships (LWRs)

The detailed statistics of LWRs for *S. bacaila* are given in Table 2. The overall LWRs indicated negative allometric growth in both sexes as the allometric coefficient *b* values were significantly different from the expected isometric value of 3 (*t*-test; *p* < 0.05). Seasonal variations in LWRs

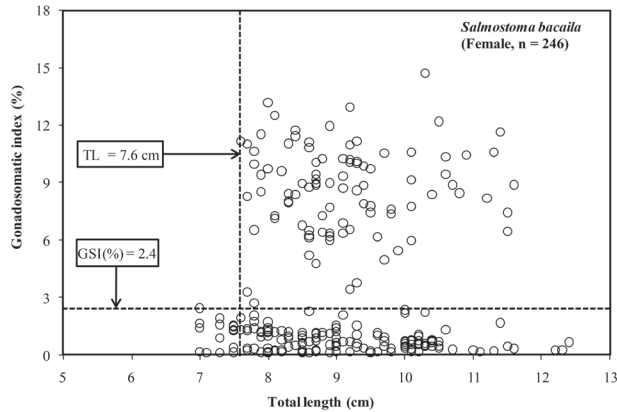


Figure 4. Relationship between the gonadosomatic index and total length (cm) for female *Salmostoma bacaila* collected from a tributary of the Payra River, Bangladesh.

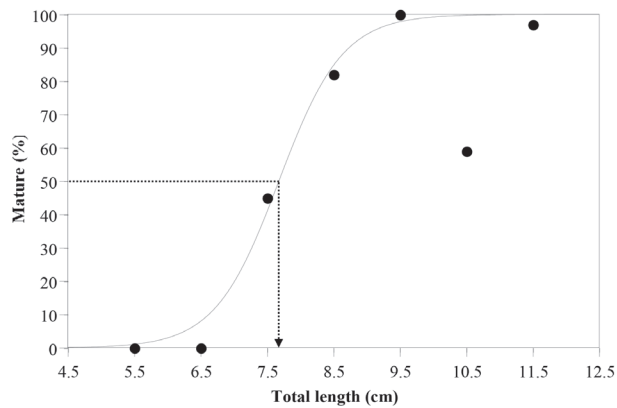


Figure 5. The percentage of mature females of *Salmostoma bacaila* in each total length class.

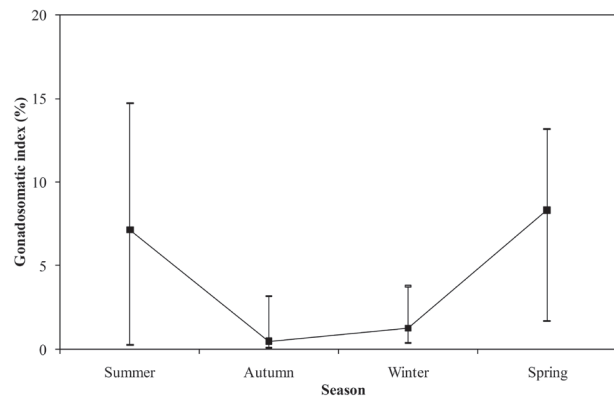


Figure 6. Seasonal changes of the mean gonadosomatic index (GSI) with minimum and maximum values, for female *Salmostoma bacaila* collected from a tributary of the Payra River, Bangladesh.

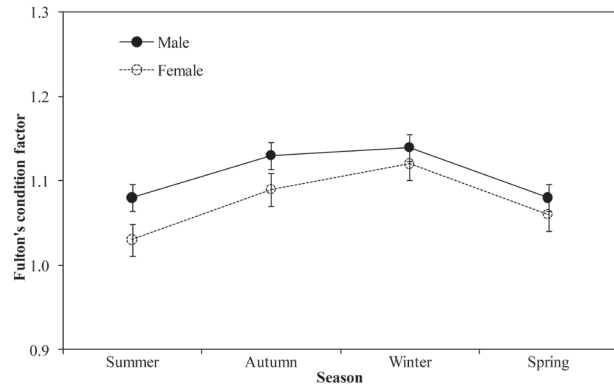


Figure 7. Seasonal changes of Fulton's condition factor for male and female *Salmostoma bacaila* collected from a tributary of the Payra River, Bangladesh.

Table 2. Descriptive statistics of length-weight relationships (LWRs) and allometric of *Salmostoma bacaila* collected from a tributary of the Payra River, Bangladesh.

Season	Sex	n	Parameters of the LWR		r ²	GT
			a (95% CL)	b (95% CL)		
Summer	M	65	0.0269 (0.0157–0.0462)	2.53 (2.25–2.80)	0.844	-A
	F	35	0.0081 (0.0033–0.0204)	3.11 (2.67–3.55)	0.860	I
Autumn	M	148	0.0255 (0.0199–0.0328)	2.56 (2.42–2.69)	0.906	-A
	F	77	0.0179 (0.0106–0.0300)	2.75 (2.49–3.01)	0.858	-A
Winter	M	137	0.0248 (0.0185–0.0332)	2.58 (2.43–2.74)	0.887	-A
	F	66	0.0183 (0.0136–0.0246)	2.74 (2.59–2.90)	0.951	-A
Spring	M	132	0.0086 (0.0062–0.0118)	3.11 (2.96–3.27)	0.920	I
	F	68	0.0071 (0.0045–0.0113)	3.20 (2.97–3.43)	0.920	+A
Overall	M	482	0.0212 (0.0184–0.0244)	2.66 (2.59–2.74)	0.912	-A
	F	246	0.0157 (0.0123–0.0199)	2.81 (2.69–2.94)	0.893	-A

Note: n, sample size; M, male; F, female; CL, confidence limit of mean; GT, growth type; I, isometric; +A, positive allometric; -A, negative allometric.

were observed, however, with the calculated b values ranging from 2.53 in summer to 3.11 in spring for males and from 2.74 in winter to 3.20 in spring for females. For males, negative allometric growth was observed throughout the seasons, except for spring when isometric growth was recorded. For females, negative allometric growth was observed during autumn and winter, but positive allometric and isometric growth was observed in spring vs. summer, respectively. Significant differences in both slope (b) and intercept (a) were always observed between sexes (ANCOVA; $p < 0.001$).

Condition factor

The seasonal variations of Fulton's condition factor (K) for both sexes are shown in Figure 7. The K values ranged from 1.08 to 1.14 in males and from 1.03 to 1.12 in females. The lowest K was found in summer, whereas the highest was in winter for both sexes. K in males was higher than in females in all the seasons.

DISCUSSION

We investigated some basic biological parameters of the life history of *S. bacaila* to help develop proper management and conservation strategies. The overall and seasonal sex ratio was found to be greatly in favour of males. This variation in sex ratio might be due to reproduction, growth, and longevity of an aquatic species (Oh et al. 2002; Chilari et al. 2005; Ahamed et al. 2014, 2018). However, the specific reason was unknown in the present study.

Analysis of LFDs is important to understand ecological and life history traits of fishes (Ranjan et al. 2005). The LFDs revealed that females were larger in size than males. Similar results were also reported by several studies of other fin- and shellfish species (Dailey and Ralston 1986; Ohtomi 1997; Colloca 2002; Ahamed and Ohtomi 2012; Ahamed et al. 2012, 2017), indicating that size predominance in females is a common feature. Increased female body size in fishes is a typical phenomenon to support increased fecundity (Parker 1992).

Size at sexual maturity is widely used as an indicator of the minimum permissible capture size, which is crucial for fisheries management (Lucifora et al. 1999; Ahamed and Ohtomi 2011; Hossain et al. 2013; Ahamed and Ohtomi 2014; Ahamed et al. 2014, 2015). In our study, the size at sexual maturity of *S. bacaila* was estimated at 7.6~7.7 cm TL on the basis of the TL-GSI relationship and using the 50% method. As there are no previous studies on size at sexual maturity of this species, our results constitute a baseline for future work.

Seasonal variations of the GSI indicated that *S. bacaila* has a prolonged spawning period from spring to summer

with a spring peak. To our knowledge, no references deal with the spawning season of this species. Several studies (Ahamed et al. 2014; Allen 1966; Bauer 1992; Kikuchi 1962) reported that temperature and rainfall play an important role to control fish spawning. Increasing temperatures promote reproduction in spring-spawning species, and falling temperatures stimulate reproduction in autumn-spawners (Pankhurst and Munday 2011). Rainfall brings down the temperature and increases the dissolved oxygen of water which is the optimal condition for some fish spawning (Jain et al. 1985). Our findings might be attributed to seasonal variations of temperature, as a recent study (Ahamed et al. 2018) reported that the temperature of the study area is high during spring to summer, after which it sharply decreases in autumn and remains low until winter.

In our study, the overall LWRs indicated negative allometric growth for both sexes, though some seasonal variation in growth types was observed. However, all allometric coefficients (b) estimated in the present study were within the expected range of 2.5 to 3.5 (Froese 2006). The highest b values in both sexes were observed in spring, which could be attributed to the presence of matured individuals with developed gonads, whereas negative allometric growth by summer (males) or autumn (females) could reflect the occurrence of mostly spent and undeveloped gonads. Seasonality in b values could also be related to season, diet, stomach fullness and gender (Tesch 1971; Bagenal and Tesch 1978).

The condition factor (K) is an index reflecting interactions between biotic and abiotic factors on the physiological condition of the fishes, and thus can be used to assess the status of the aquatic ecosystem where they live (Anene 2005). K is generally correlated with temporal changes in fish GSI (Ahamed et al. 2014; Hossain et al. 2012, 2013). In our study, K started to increase in autumn and remained high in winter. Thereafter, K was low during spring and summer for both sexes. On the other hand, the GSI began to rise from winter and remained high during spring and summer with a spring peak, thereafter decreasing sharply in autumn. Therefore, it appears that K of *S. bacaila* started to decrease with the start of reproduction and recovered at the end of the reproductive period.

In conclusion, this is the first comprehensive study to provide some basic information on the population biology of *S. bacaila*, which will be helpful to formulate conservation and management strategies for this species.

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DISCLOSURE STATEMENT

On behalf of all authors, the corresponding author states that there is no potential conflict of interest.

REFERENCES

- Ahamed, F., and J. Ohtomi. 2011. Reproductive biology of the pandalid shrimp *Plesionika izumiae* (Decapoda: Caridea). *Journal of Crustacean Biology* 31: 441–449.
- Ahamed, F., and J. Ohtomi. 2012. Growth patterns and longevity of the pandalid shrimp *Plesionika izumiae* (Decapoda: Caridea). *Journal of Crustacean Biology* 32 (5): 733–740.
- Ahamed, F., and J. Ohtomi. 2014. Relative growth and sexual maturity of the pandalid shrimp *Plesionika izumiae* (Decapoda, Caridea) in Kagoshima Bay, southern Japan. *Crustaceana* 87: 1567–1577.
- Ahamed, F., Z. F. Ahmed, M. Y. Hossain, and J. Ohtomi. 2012. Growth study of the pool barb *Puntius sohpore* (Cyprinidae: Barbinae) through multi-model inferences. *Zoological Studies* 51 (7): 1077–1085.
- Ahamed, F., Z. F. Ahmed, M. Y. Hossain, and J. Ohtomi. 2014. Population biology of the Indian river shad, *Gudusia chapra* (Clupeidae) in the old Brahmaputra River, North-Eastern Bangladesh. *Sains Malaysiana* 43: 1645–1655.
- Ahamed, F., Z. F. Ahmed, M. Y. Hossain, and J. Ohtomi. 2015. Size at sexual maturity of the female pool barb, *Puntius sophore* (Cyprinidae) in the Old Brahmaputra River, north eastern Bangladesh. *Ecologia* 5 (2): 54–61.
- Ahamed, F., Z. F. Ahmed, M. Y. Hossain, and J. Ohtomi. 2017. Growth and longevity of the mola carplet *Amblypharyngodon mola* (Cyprinidae) in the Payra River, southern Bangladesh. *Egyptian Journal of Aquatic Research* 43 (4): 291–295.
- Ahamed, F., N. Saha, M. A. Nishat, M. K. Biswas, M. Sultana, M. S. Khatun, Z. F. Ahmed, M. Y. Hossain, and J. Ohtomi. 2018. Length-weight and length-length relationships of three small indigenous fishes from the Payra River, southern Bangladesh. *Journal of Applied Ichthyology* 34 (3): 777–779.
- Allen, J. A. 1966. The dynamics and interrelationships of mixed populations of Caridea found off north-east coast of England. In *Some Contemporary Studies of Marine Science*, edited by H. B. Barnes, 45–66. London: Allen and Unwin.
- Anene, A. 2005. Condition factor of four cichlid species of a man-made lake in Imo State, Southeastern Nigeria. *Turkish Journal of Fisheries and Aquatic Sciences* 5 (1): 43–47.
- Bagenal, T. B., and F. W. Tesch. 1978. Age and growth. In *Methods for Assessment of Fish Production in Fresh Waters*, 3rd ed., IBP Handbook No. 3, edited by T. Bagenal, 101–136. Oxford (UK): Blackwell.
- Bauer, R. T. 1992. Testing generalization about latitudinal variation in reproduction and recruitment patterns with sicyoniid and caridean shrimp species. *Invertebrate Reproduction and Development* 22 (1–3): 193–202.
- Chilari, A., M. T. Legaki, and G. Petrakis. 2005. Population structure and reproduction of the deep-water shrimp *Plesionika martia* (Decapoda: Pandalidae) from the western Ionian Sea. *Journal of Crustacean Biology* 25 (2): 233–241.
- Colloca, F. 2002. Life cycle of the deep-water pandalid shrimp *Plesionika edwardsii* (Decapoda, Caridea) in the central Mediterranean Sea. *Journal of Crustacean Biology* 22 (4): 775–783.
- Dailey, M. D., and S. Ralston. 1986. Aspects of the reproductive biology, spatial distribution, growth, and mortality of the deepwater caridean shrimp, *Heterocarpus laevigatus*, in Hawaii. *Fishery Bulletin* 84: 915–925.
- Froese, R. 2006. Cube law, condition factor and weight-length relationships: History, meta-analysis and recommendations. *Journal of Applied Ichthyology* 22 (4): 241–253.
- Hamilton, F. 1822. *An account of the fishes found in the River Ganges and its branches*. Edinburg: Archibald Constable and Company, 405 p.
- Hasselblad, V. 1966. Estimation of parameters for a mixture of normal distributions. *Technometrics* 8 (3): 431–444.
- Hossain, M. Y., M. M. Rahman, M. A. S. Jewel, Z. F. Ahmed, F. Ahamed, B. Fulanda, and J. Ohtomi. 2012. Conditions- and form- factor of the five threatened fishes from the Jamuna (Brahmaputra River distributary) River, northern Bangladesh. *Sains Malaysiana* 41: 671–678.
- Hossain, M. Y., M. S. Arefin, M. S. Mohmud, M. I. Hossain, M. A. S. Jewel, M. M. Rahman, F. Ahamed, Z. F. Ahmed, and J. Ohtomi. 2013. Length-weight relationships, condition factor, gonadosomatic index-based size at first sexual maturity, breeding season and fecundity of *Aspidoparia morar* (Cyprinidae) in the Jamuna River (Brahmaputra River distributary), northern Bangladesh. *Journal of Applied Ichthyology* 29: 1166–1169.
- Islam, M. R., and M. J. Mia. 2016. Length-weight and length-length relationships of five fish species in the Atrai River, Dinajpur, Bangladesh. *Journal of Applied Ichthyology* 32 (6): 1371–1373.
- Jain, A. K., R. Singh, D. Alkesh, and S. D. Mitra. 1985. Role of rainfall in the breeding of *Labeo rohita* (Ham.), *Cir-*

- rhinus mrigala* (Ham.), *Catla catla* (Ham.), at Damata (Haryana), a semi-aride zone. *Journal of the Indian Fisheries Association* 14 & 15: 67–73.
- Kikuchi, T. 1962. An ecological study on animal community in *Zostera* belt, in Tomioka Bay, Amakusa, Kyushu (II) community composition (2) decapod crustaceans. *Records of Oceanographic Works in Japan* 6: 135–146.
- King, M. 2007. *Fisheries Biology Assessment and Management*. 2nd ed. Oxford: Blackwell, 381 p.
- Kumar, K. H., and B. R. Kiran. 2016. Length-weight relationship of fresh water cyprinid fishes of the genus *Salmostoma* and *Chela* in India. *International Journal of Research* 3 (13): 977–982.
- Lucifora, L. O., J. L. Valero, and V. B. Garcia. 1999. Length at maturity of the greeneye spurdog shark, *Squalus mitsukurii* (Elasmobranchii: Squalidae), from the SW Atlantic, with comparisons with other regions. *Marine and Freshwater Research* 50 (7): 629–632.
- Masud, S., and K. P. Singh. 2015. Studies on length-weight relationship and condition factor of *Salmophasia bacaila* (Hamilton) from the lower stretch of River Yamuna at Allahabad, India. *International Journal of Fisheries and Aquatic Studies* 2 (5): 147–150.
- Muhammad, H., Z. Iqbal, and T. Akhlaq. 2016. Length-weight, length-length relationships and condition factor of fishes of family Cyprinidae from the Indus River, Pakistan. *Punjab University Journal of Zoology* 31 (2): 143–147.
- Nath, K. D., S. Borah, A. K. Yadav, B. K. Bhattacharjya, P. Das, P. M. Deka, O. Darnagawn, and D. J. D. Nath. 2017. Length-weight and length-length relationship of four native fish species from Barak River, Assam, India. *Journal of Experimental Zoology, India* 20 (2): 977–979.
- Oh, C. W., H. L. Suh, K. Y. Park, C. W. Ma, and H. S. Lim. 2002. Growth and reproductive biology of the freshwater shrimp *Exopalaemon modestus* (Decapoda: Palaemonidae) in lake of Korea. *Journal of Crustacean Biology* 22 (2): 357–366.
- Ohtomi, J. 1997. Reproductive biology and growth of the deep-water pandalid shrimp *Plesionika semilaevis* (Decapoda: Caridea). *Journal of Crustacean Biology* 17 (1): 81–89.
- Pankhurst, N. W., and P. L. Munday. 2011. Effect of climate change on fish reproduction and early life history stages. *Marine and Freshwater Research* 62 (9): 1015–1026.
- Parker, G. A. 1992. The evolution of sexual size dimorphism in fish. *Journal of Fish Biology* 41 (sB): 1–20.
- Petr, T. 1999. Coldwater fish and fisheries in Afghanistan. In *Fish and fisheries at higher altitudes: Asia*. *FAO Fish. Tech. Pap. No. 385*. FAO, Rome, edited by T. Petr, 304, 138–148.
- Ranjan, J. B., W. Herwig, S. Subodh, and S. Michael. 2005. Study of the length frequency distribution of sucker head, *Garragotyla gotyla* (Gray, 1830) in different rivers and seasons in Nepal and its applications. *Kathmandu University Journal of Science, Engineering and Technology* 1 (1): 1–14.
- Sokal, R. R., and F. J. Rohlf. 1981. *Biometry*. 2nd ed. New York: W. H. Freeman and Company.
- Talwar, P. K., and A. G. Jhingran. 1991. *Inland fishes of India and adjacent countries*. Vol. 1. New Delhi-Calcutta: Oxford and IBH, pp. 152–541.
- Tesch, F. W. 1971. Age and growth. In *Methods for Assessment of Fish Production in Fresh Waters*, edited by W. E. Ricker, 99–130. Oxford: Blackwell.
- Thilsted, S. H. 2003. The importance of small indigenous fish species for improved human nutrition in rural Bangladesh. In *Small Indigenous Species of Fish in Bangladesh, Technical Proceedings of BAU-ENRECA/DANIDA Workshop on Potentials of Small Indigenous Species of Fish (SIS) in Aquaculture and Rice-field Stocking for Improved Food and Nutrition Security in Bangladesh*, edited by M. A. Wahab, S. H. Thilsted, and M. E. Hoq. Mymensingh: Bangladesh Agricultural University.
- Thilsted, S. H., N. Roos, and N. Hasan. 1997. The role of small indigenous fish species in food and nutrition security in Bangladesh. *NAGA, ICLARM Quarterly* 20 (3/4): 82–84.
- Zar, J. H. 1984. *Biostatistical Analysis*. 2nd ed. New Jersey, USA: Prentice-Hall, Englewood Cliffs, 718 p.