Population Parameters of a Freshwater Clupeid, *Corica soborna* (Hamilton, 1822) from the Ganges River, Northwestern Bangladesh

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ABSTRACT

Our study illustrates the first complete description on population parameters of *Corica soborna* including sex ratio (SR), length-frequency distributions (LFDs), length-weight relationships (LWRs), length-length relationships (LLRs), condition factors (allometric, K_A, Fulton's, K_F, relative, K_R, and relative weight, W_R), form factor ($a_{3.0}$), size at fist sexual maturity (L_m) and natural mortality (M_W) using multi-model indices from the Ganges River of northwestern Bangladesh. For each individual, the total length (TL), fork length (FL), standard length (SL), and body weight (BW) were measured by digital slide calipers and an electric balance, respectively. A total of 303 individuals (male = 140, female = 163) were collected from the fishers catch during January to December, 2016. The overall SR differed statistically from the expected 1:1 ratio (df = 1, χ^2 = 4.06, $P > 0.05$). The TL of males and females ranged from 2.7–4.7 cm vs. 2.8–5.0 cm, respectively. The LFDs showed that the 3.99-4.49 cm TL size group was numerically dominant for both sexes. The *b* values of LWRs (TL vs. BW) indicates negative allometric growth, (*b* = 2.82 for males and *b* = 2.63 for females). K_F was the best condition for assessing the well-being of this species in the Ganges River. The W_R was not significantly different from 100 for males ($P = 0.6137$) and females ($P = 0.6185$), indicating that habitat was still in good condition. The $a_{3.0}$ were 0.0067 and 0.0050 whereas L_m was 3.14 and 3.32 cm for males and females, respectively. Also, M_W was 2.55 and 2.50 year^{-1}, respectively in the Ganges River. In addition, this study estimates the $a_{3.0}$, L_m and M_W from other water-bodies using the available literature. Finally, these findings will be crucial for further studies to suggest suitable policy for the sustainable management of *C. soborna* in the Ganges River and surrounding ecosystems.

INTRODUCTION

The Clupeidae is the main family of the order Clupeiformes, containing approximately 200 species in 54 genera (Froese and Pauly, 2014). It is considered as the most valuable food fish family in the world (Csirke, 2005), being represented mostly by herrings, sardines, anchovies and shads and their relatives (Royce, 1996). The Ganges River sprat, *Corica soborna* is a member of the family Clupeidae, one of the representative and abundant species in the Ganges River of Bangladesh,

which encompasses an important fisheries in the country's enormous river system. This clupeid is a freshwater, brackish, marine and pelagic-neritic species (Whitehead, 1985), generally known as kechki in Bangladesh, Godhae in India, and Gangesbrisling in Denmark (Froese and Pauly, 2019). *C. soborna* is termed as small indigenous fish species (SIS) (the species which attains a maximum length of 5-25 cm in their life cycle) along with other 150 SIS available in Bangladesh (Amin *et al*., 2009; Felts *et al*., 1996). It occurs throughout the major river systems and estuaries, being reported from the Kaptai Lake of Bangladesh, where it comprised about 20% of the total fish catch (Wahab *et al*., 2007). Beside Bangladesh, this fish has a wide geographical distribution covering the Indian sub-continent, i.e., Brunei, India, Indonesia, Malaysia, and

Thailand (Froese and Pauly, 2019; Talwar and Jhingran, 1991). This clupeid is a plankton feeder that mostly inhabits ponds and pools of creeks, rivers, and estuaries (Talwar and Jhingran, 1991; Rahman, 1989; Bhuiyan, 1964), sometimes also being found in Bay of Bengal (Kapoor *et al*., 2002). It is a highly popular food fish due to its taste and high content of protein and micronutrients (Hossain *et al*., 2009, 2017a), as well as having some medicinal value (Bhuiyan, 1964). However, this species has a small contribution in commercial fisheries probably because of its small size and is generally caught by small- and large-scale fishers as bycatch (Bhuiyan, 1964; Talwar and Jhingran, 1991). The conservation status of this species is categorized as least concern both in Bangladesh (IUCN Bangladesh, 2015) and elsewhere in South Asia (IUCN, 2018).

Information on life-history traits of fish species is very crucial for the execution of appropriate management approaches for sustaining the indigenous fishes like *C. soborna* (Hossain *et al*., 2013a). Sex ratio (SR) and size structure (length-frequency distribution, LFD) reveals major information to evaluate reproductive prospective of fish populations (Vazzoler, 1996). The study of LFDs revealed the status of stock, breeding period, and ecology of riverine fishes (Ranjan *et al*., 2005). Such study also expresses the relations of the dynamic rates of growth, recruitment, and mortality (Neuman and Allen, 2001). Length–weight relationships (LWRs) and length-length relationships (LLRs) are valuable parameters for determining the well-being of individuals, and to differentiate different stocks within species (King, 2007). LWRs of fish species have significant implications for fishery assessments and estimates of fishery biomass and yield (Ricker, 1975; Martn-Smith, 1996; Garcia *et al*., 1998), as well as to prove data for aquatic ecosystem modeling (Christensen and Walters, 2004). Moreover, LWRs are fundamental for evaluating the life histories of fishes among diverse geographic localities (Le Cren, 1951; Hossain *et al*., 2009, 2012a, 2016a; Azad *et al*., 2018) and are also helpful for conservation and stock assessment (Ahmed *et al*., 2012; Hossain *et al*., 2013b, 2016b, 2017b). Additionally, LLRs are also important in fisheries management for comparative growth studies where one length type is preferred (Hossain *et al*., 2006, 2015a; Wang *et al*., 2015). Condition factors are valuable parameters to examine for differences among numerous stocks within species (King, 2007). Furthermore, relative weight (W_R) is one of the most renowned indices to ascertain the status of fishes in various water bodies (Rypel and Richter, 2008; Hossen *et al*., 2018). In addition, the form factor ($a_{3.0}$) can be used to determine whether the body shape of a certain population or species is significantly distinct from others (Froese, 2006). On the other hand,

the status of fish stock and its management policies is often depends on the assessment of natural mortality (M_W) (Brodziak *et al*., 2011).

Although some studies have been done on *C. soborna* regarding LWRs (Hossain *et al*., 2017a); LWRs, LLRs, size at first sexual maturity, and fecundity (Hossain *et al*., 2008) and LWRs and condition factors (Kamal, 1982), to knowledge no studies have done on population used multi-models for this important fishery. Therefore, this study focused on the complete and comprehensive description on population parameters, including sex ratio (SR), length-frequency distributions (LFDs), length-weight (LWRs) and length-length relationships (LLRs), condition factors (allometric, K_A; Fultons, K_F; relative, K_R; relative weight, W_R), form factor ($a_{3.0}$), size at first sexual maturity (L_m), and natural mortality (M_W) of *C. soborna* using many specimens of different body sizes from the Ganges River in northwestern Bangladesh as sampled over a 1 year study period.

MATERIALS AND METHODS

Study site and sampling

The present study was carried out in the Ganges River (well-known as Padma River in Bangladesh; Latitude. 24°35′ N; Longitude. 88°64′ E) in NW Bangladesh, which is considered a vital breeding and feeding ground for riverine fishes (Hossain *et al*., 2016a; Rahman *et al*., 2018). In total, 303 specimens (male=140, female=163) were collected occasionally during January to December, 2016 from the fishers' catch in different areas (Godagari: 24°26′N, 88°19′E; Charghat: 24°15′N, 88°44′E and Bagha: 24°70′N, 88°49′E) in the Rajshahi region, using different traditional fishing gears, i.e., cast net (mesh size ranges: 1.0–2.0 cm), gill net (mesh size ranges: 1.5–2.5 cm), and square lift net (mesh size ~ 1.0 cm). Collected fishes were immediately chilled on ice and fixed in 5% formalin upon arrival in the laboratory.

Fish measurement

Sex identification of fish was done by (i) morphometric and meristic traits and (ii) microscopic observation of the gonads. Before weighing, each individual was rinsed with water and kept exposed to air-dry it, although blotting paper was also used to eliminate excess moisture. For each individual, total (TL), fork (FL), and standard lengths (SL) were measured by a digital slide calipers to the closest 0.01 cm. Whole body weight (BW) were taken by an electronic balance to the nearest 0.01 g, precision.

Sex ratio (SR) and length-frequency distribution (LFDs)

The variation of sex-ratio from the anticipated 1:1

(male: female) value was determined by chi-square test. The length-frequency distribution for male and female *C. soborna* was made individually with 1cm intervals of TL. The normal-frequency distribution was fitted to the TL frequency distribution of *C. soborna* using a computer program (Microsoft Excel add insolver), based on Hasselblad's maximum-likelihood method (Hasselblad, 1966).

Length-weight and length- length relationships (LWRs and LLRs)

The LWRs was calculated using the equation: $W = a \times L^b$, where, W is body weight (BW, g) and L is body length (cm). The parameters a and b were estimated by linear regression analyses based on natural logarithms: $\ln(W) = \ln(a) + b \ln(L)$. In addition, 95% confidence limits of a and b and the coefficient of determination (r^2) were estimated. Based on Froese (2006), all extreme outliers were excluded from the analyses. A t-test was used to confirm whether b values obtained in the linear regression were significantly different from the isometric value ($b= 3$), (Sokal and Rohlf, 1981). Furthermore, LLRs - including TL *vs*. SL, TL *vs*. FL, and SL *vs*. FL relationships- were estimated by linear regression (Hossain *et al*., 2006).

Condition factors

The allometric condition factor (K_A) was estimated using the equation of Tesch (1971): W/L^b, where W is the body weight (g) and L is the TL (cm), and b is the LWR parameter. The Fulton's condition factor (K_F) was calculated using the equation of Fulton (1904): $K_F =100\times (W/L^3)$, where W is the body weight (g) and L is the TL in cm. The scaling factor of 100 was used to bring the K_F close to unit. Moreover, the relative condition factor (K_R) was calculated following the equation of Le Cren (1951): $K_R = W/(a \times L^b)$, where W is the body weight (g), L is the TL (cm), and a and b are LWR parameters. For assessing the relative weight (W_R), the equation of Froese (2006): $W_R = (W / W_s) \times 100$ was used, where W is the weight of a particular individual and W_s is the predicted standard weight for the same individual as calculated by $W_s = a \times L^b$. For the latter, a and b values are gained from the relationships between TL *vs*. BW.

Form factor (a$_{3.0}$)

The $a_{3.0}$ of *C. soborna* was calculated using the equation of Froese (2006) as: $a_{3.0} = 10^{\log a - s (b-3)}$, where a and b are regression parameters of LWR, and s is the regression slope of *ln a vs*. b. We used a mean slope $S = -1.358$ for estimating $a_{3.0}$ because information on LWR is not available for this species to estimate the regression (S) of *ln a vs*. b.

Size at first sexual maturity (L$_m$) and natural mortality (M$_W$)

L_m was estimated by the equation of Binohlan and Froese (2009) as $\log (L_m) = -0.1189 + 0.9157 \times \log (L_{max})$, where L_{max} signifies maximum TL. M_W was calculated using the model of Peterson and Wroblewski (1984) as $M_W = 1.92$ year^{-1} *(W)$^{-0.25}$, where, M_W = natural mortality at mass W, and W= $a \times L^b$, and a and b are regression parameters of LWR.

Statistical analysis

Statistical analyses were performed using GraphPad Prism 6.5 software. Homogeneity and normality of the data were tested prior to analysis. A 1-sample t-test was used to compare the mean relative weight (W_R) with 100 (Anderson and Neumann, 1996). In addition, the Spearman rank correlated body measurements (e.g., TL and BW) with condition factors (K_A, K_F, K_R, and W_R). Furthermore, the LWRs between sexes were compared by the analysis of covariance (ANCOVA). All statistical analyses were considered significant at 5% ($P < 0.05$).

RESULTS

Sex ratio (SR) and length-frequency distributions (LFDs)

During the study, a total of 303 individuals of *C. soborna* were collected from the Ganges River, where 41.55% were males and 58.45% were females, hence the overall sex ratio differed statistically from the expected 1:1 ratio ($df = 1$, $\chi^2 = 4.06$, $P > 0.05$) (Table I).

Descriptive statistics for length and weight measurements and their 95% confidence limit (CL) for *C. soborna* are demonstrated in Table II. Specimens ranged from 2.70cm to 5.00cm for TL and 0.22 to 1.08 g for BW, regardless of sex. LFDs revealed that the 3.99–4.49 cm TL size group was numerically dominant for both males and females, constituting 72% vs. 69% of the total population, respectively (Fig. 1). There was a significant difference for LFD between sexes (Mann-Whitney U-Test, U= 9727, $P = 0.027$). But BW showed insignificant differences between males and females (Mann-Whitney U-test, U= 10726, $P= 0.367$).

Length-weight and length- length relationships (LWRs and LLRs)

Descriptive statistics and estimated parameters of length-weight relationships, sample sizes (n), regression parameters a and b of the LWRs, 95% confidence limits, and coefficients of determination (r^2) of *C. soborna* are given in Table III and Fig. 2. All LWRs were highly significant ($P < 0.001$), with all r^2 values ≥0.963. In addition, all LLRs were also highly significant ($P < 0.001$) with all r^2 values ≥ 0.971 (Table IV and Fig. 3).

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Table I. Number of males, females, and sex ratio (male: female) of *Corica soborna* from the Ganges River, northwestern Bangladesh.

Length class (TL, cm)	Number of specimens			Sex ratio (Male/Female)	χ^2 (df=1)	Significance
	Male	Female	Total			
5.00 – 5.99	12	14	26	1 : 1.17	0.15	ns
6.00 – 6.99	11	7	18	1 : 0.64	0.89	ns
7.00 – 7.99	20	16	36	1 : 0.80	0.44	ns
8.00 – 8.99	6	18	24	1 : 3.00	6.00	*
9.00 – 9.99	7	18	25	1 : 2.57	4.84	*
10.00 – 10.99	0	3	3	-	3.00	ns
11.00 – 11.99	3	2	5	1 : 0.67	0.20	ns
12.00 – 12.99	0	5	5	-	5.00	*
Overall	59	83	142	1 : 1.41	4.06	*

TL, total length; df, degree of freedom; ns, not significant; *, significant at 5% level ($\chi^2 > \chi^2$t 1, 0.05 = 3.84).

Table II. Descriptive statistics of length (cm) and weight (g) measurements of *Corica soborna* (Hamilton, 1822) specimens in the Ganges River, Bangladesh.

Characteristics	n	Min	Max	Mean ± SD	95%CL
Male	140				
Total length (cm)		2.7	4.7	3.898±0.444	3.82-3.97
Fork length (cm)		2.5	4.2	3.526±0.404	3.46-3.59
Standard length (cm)		2.3	3.8	3.194±0.363	3.13-3.25
Body weight (g)		0.22	0.9	0.558±0.170	0.53-0.59
Female	163				
Total length (cm)		2.8	5.0	3.790±0.465	3.72-3.86
Fork length (cm)		2.5	4.4	3.383±0.404	3.32-3.45
Standard length (cm)		2.3	4.1	3.093±0.385	3.03-3.15
Body weight (g)		0.26	1.08	0.543±0.175	0.52-0.57
Combined	303				
Total length (cm)		2.7	5	3.840±0.457	3.79-3.89
Fork length (cm)		2.5	4.5	3.449±0.414	3.40-3.50
Standard length (cm)		2.3	4.1	3.139±0.378	3.10-3.18
Body weight (g)		0.22	1.08	0.550±0.172	0.53-0.57

n, sample size; Min, minimum; Max, maximum; SD, standard deviation; CL, confidence limit for mean values.

Table III. Descriptive statistics and estimated parameters of the length-weight relationships (BW = $a \times L^b$) of *Corica soborna* from the Ganges River, northwestern Bangladesh.

Equation	Sex	n	Regression parameters		95% CL of *a*	95% CL of *b*	r^2	GT
			a	*b*				
BW=$a \times TL^b$	M	140	0.0117	2.82	0.0108–0.0126	2.760 – 2.876	0.986	-A
BW=$a \times FL^b$			0.0157	2.81	0.0143–0.0173	2.732 – 2.883	0.975	
BW=$a \times SL^b$			0.0205	2.82	0.0187–0.0224	2.741 – 2.895	0.974	
BW=$a \times TL^b$	F	163	0.0158	2.63	0.0145–0.0172	2.566 – 2.692	0.977	-A
BW=$a \times FL^b$			0.0195	2.70	0.0178–0.0212	2.632 – 2.775	0.972	
BW=$a \times SL^b$			0.0284	2.59	0.0265–0.0304	2.524 – 2.646	0.977	
BW=$a \times TL^b$	C	303	0.0143	2.69	0.0134–0.0153	2.639 – 2.737	0.975	-A
BW=$a \times FL^b$			0.0196	2.67	0.0182–0.0211	2.606 – 2.725	0.963	
BW=$a \times SL^b$			0.0256	2.65	0.0240–0.0273	2.595 – 2.708	0.966	

M, male; F, female; C, combined sex; n, sample size; *a, b* are LWR parameters; CL, confidence limit for mean values; r^2, coefficient of determination; GT, growth type; -A, negative allometric.

Table IV. The estimated parameters of the length-length relationships (y = a +b × x) of *Corica soborna* from the Ganges River, northwestern Bangladesh.

Equation	Sex	Regression parameters		95% CL of *a*	95% CL of *b*	r^2
		a	*b*			
TL = *a* + *b* × SL	M	0.0389	1.208	-0.0609 to 0.1387	1.177 – 1.124	0.977
TL = *a* + *b* × FL		0.0641	1.087	-0.0292 to 0.1575	1.061 – 1.113	0.980
SL = *a* + *b* × FL		0.0604	0.889	-0.0196 to 0.1404	0.866 – 0.911	0.978
TL = *a* + *b* × SL	F	0.1019	1.193	0.0095 to 0.1942	1.163 – 1.222	0.975
TL = *a* + *b* × FL		-0.0551	1.137	-0.1495 to 0.0393	1.109 – 1.164	0.976
SL = *a* + *b* × FL		-0.0837	0.939	-0.1691 to 0.0018	0.914 – 0.964	0.971
TL = *a* + *b* × SL	C	0.0820	1.197	0.0149 to 0.1492	1.176 – 1.218	0.976
TL = *a* + *b* × FL		0.0750	1.092	0.0072 to 0.1428	1.072 – 1.111	0.975
SL = *a* + *b* × FL		0.0383	0.899	-0.0221 to 0.0987	0.882 – 0.917	0.972

TL, total length; FL, fork length; SL, standard length; M, male; F, female; C, combined sex; *a*, intercept; *b*, slope ; CL, confidence limit for mean values; r^2, coefficient of determination.

Table V. Allometric (K_A), Fulton′s (K_F), and relative condition factors (K_R) and relative weight (W_R) of *Corica soborna* from the Ganges River, northwestern Bangladesh.

Condition factors	Sex	n	Min	Max	Mean ± SD	95% CL
K_A	M	140	0.0107	0.0134	0.0117±0.0005	0.0116 – 0.0118
K_F			0.8573	1.1177	0.9141±0.0430	0.9069 – 0.9213
K_R			0.9162	1.1446	0.9993±0.0406	0.9926 – 1.0061
W_R			91.623	114.460	99.933±4.055	99.256 –100.611
K_A	F	163	0.0141	0.0174	0.0158±0.0008	0.0157 – 0.0160
K_F			0.8640	1.1844	0.9696±0.0680	0.9591 –0.9801
K_R			0.8922	1.0992	1.0022±0.0502	0.9945 –1.0100
W_R			89.223	109.921	100.224±5.017	99.448 –101.001
K_A	C	303	0.0124	0.0163	0.0143±0.0008	0.0142 – 0.0144
K_F			0.8573	1.1844	0.9440±0.0640	0.9367 – 0.9512
K_R			0.8689	1.1423	1.0017±0.0534	0.9956 – 1.0077
W_R			86.887	114.226	100.167±5.344	99.562 –100.770

M, male; F, female; C, combined sex; *n*, sample size; Min, minimum; Max, maximum; SD, standard deviation; CL, confidence limit for mean values; K_A, allometric condition factor; K_F, Fulton′s condition factor; K_R, relative condition factor; W_R, relative weight.

Condition factors

The K_A values varied from 0.0107 – 0.0134 (mean ± SD = 0.0117 ± 0.0005) for males and 0.0141 – 0.0174 (mean ± SD = 0.0158 ± 0.0008) for females (Table V). According to the Mann-Whitney U-test, K_A was significantly different between sexes (*P* < 0.0001). The K_F ranged from 0.8573 – 1.1177 (mean±SD= 0.9141±0.0403) for males and 0.8640 – 1.1844 (mean±SD= 0.9696±0.0680) for females, respectively (Table V), and the U-test showed that K_F was significantly different between genders (*P* < 0.0001). In addition, K_R ranged from 0.9162 – 1.446 (mean ± SD = 0.9993 ± 0.0406) for males and 0.8922 –1.0992 (mean ± SD = 1.0022 ± 0.0502) for females (Table V) and the U-test showed insignificant deviations between sexes (*P* = 0.7228) in our study area. Calculated W_R for males were 91.623 to 114.460 (mean ± SD = 99.933 ± 4.055) and for females were 89.223 to 109.921(mean ± SD = 100.224 ± 5.017) (Table V). According to Wilcoxon sign rank test, W_R showed no significant differences from 100 for both males (*P*= 0.6137) and females (*P*=0.6185). The relationship between TL *vs.* W_R is shown in Fig. 4, and the relationships of different condition factors (K_A, K_F, K_R, and W_R) with TL and BW are shown in Table VI. From the above four condition factors, only K_F has high significantly correlated with TL and BW (*P* < 0.001).
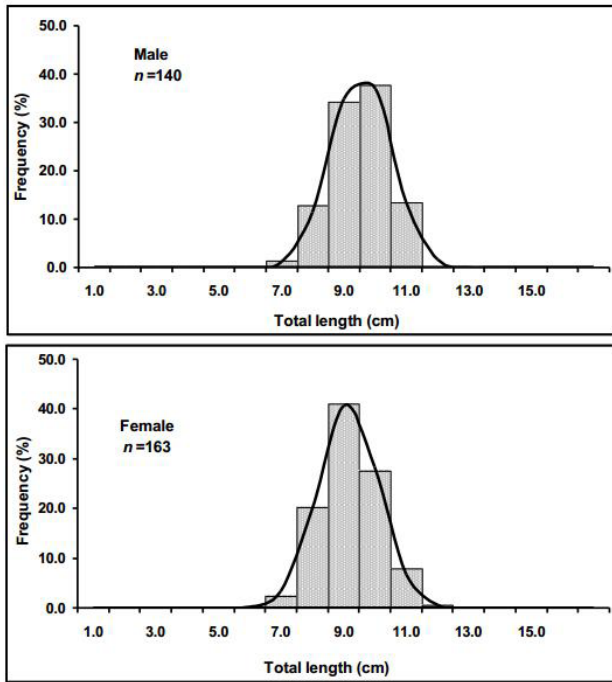
Fig. 1. The length-frequency distribution of male and female *Corica soborna* (Hamilton, 1822) in the Ganges River, northwestern Bangladesh.
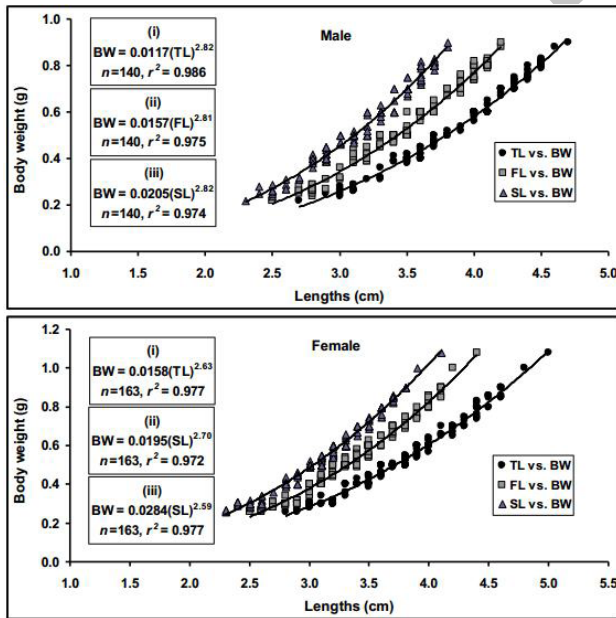

Fig. 2. Relationships (W = a × L^b) between (i) total length vs. body weight, (ii) fork length vs. body weight and (iii) standard length vs. body weight of male and female *Corica soborna* (Hamilton, 1822) in the Ganges River, northwestern Bangladesh.
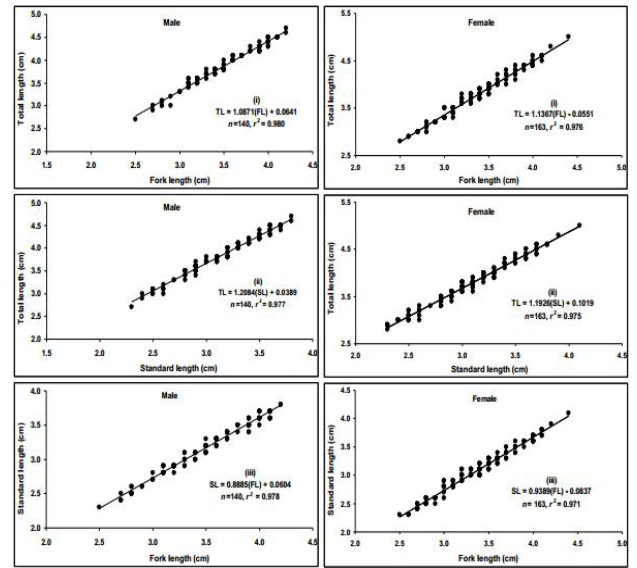

Fig. 3. Relationships (y =a+b × x) between (i) total length (TL) and fork length (FL), (ii) standard length (SL) and total length (TL), and (iii) fork length (FL) and standard length (SL) of male and female *Corica soborna* (Hamilton, 1822) in the Ganges River, northwestern Bangladesh.
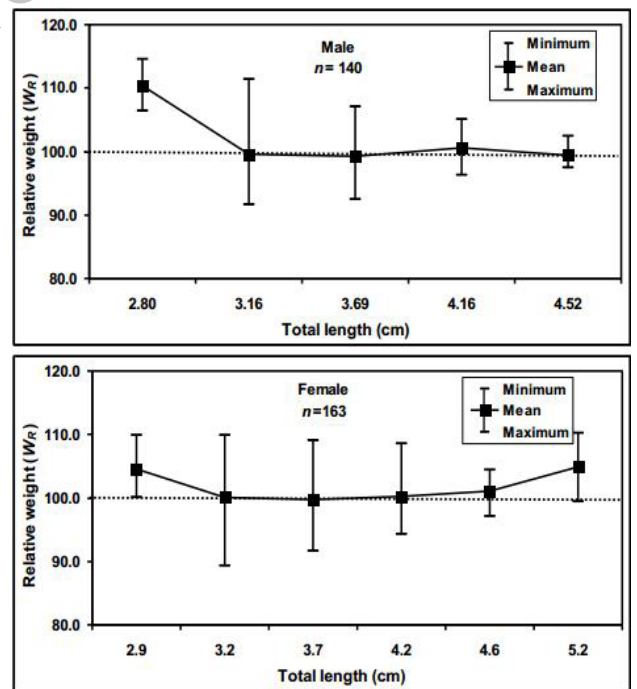

Fig. 4. The relationship between TL and W_R of male and female *Corica soborna* (Hamilton, 1822) in the Ganges River, northwestern Bangladesh.

Form factor (a₃.₀)

The calculated $a_{3.0}$ values were 0.0067, 0.0050, and 0.0054 for males, females, and combined sexes of *C. soborna,* respectively, in the Ganges River (Table VII), such values indicate that this fish is fusiform in shape. We also calculated the $a_{3.0}$ of *C. soborna* from various South Asian studies using available literature to compare with our study (Table VII).

Size at first sexual maturity (Lₘ)

The calculated L_m values for males and females were 3.14 cm (95% CL = 2.63 – 3.80 cm TL) vs. 3.32 cm TL (95% CL=2.77 – 4.02 cm TL), respectively (Table VII). Moreover, we calculated the L_m of *C. soborna* from different South Asian studies in the available literature (Fig. 5 and Table VII).
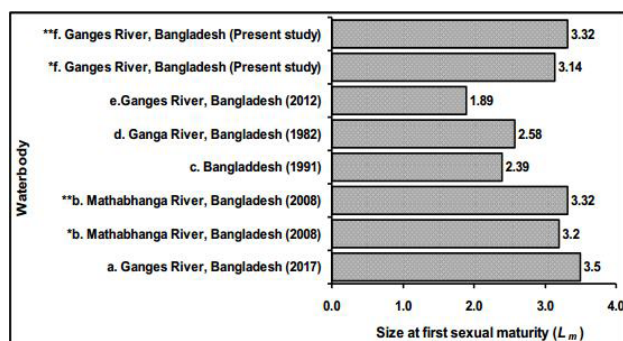
Fig. 5. Size at sexual maturity of *Corica soborna* across Bangladeshi studies (*, male; **, female).

Natural mortality (Mᵂ)

M_W for the population of *C. soborna* was estimated as 2.52 year⁻¹, irrespective of sex in the Ganges River, NW Bangladesh. However, M_W was very high for specimens under 2.4 cm TL, but it declined for bigger fish (Fig. 6). The calculated M_W for *C. soborna* in the Ganges River and other South Asian water-bodies are shown in Table VII.

DISCUSSION

Past information on population parameters of *C. soborna* is scant for Bangladesh and elsewhere in South Asia. However, Hossain *et al*. (2017a) carried out a brief study on LWR for this species from the Ganges River, NW Bangladesh. Nevertheless, a work has also been done on biological aspects of this species by Hossain *et al*. (2008) from the Mathabhanga River, southwestern Bangladesh. During the present study, 303 individuals were sampled to encompasses various body sizes (2.7–5.0 cm TL), as collected through different conventional fishing gears. We highlighted the population parameters of *C. soborna*

comprising SR, LFDs, LWRs, LLRs, condition factors (K_A, K_P, K_R and W_R), $a_{3.0}$, L_m, and M_W from the Ganges River in NW Bangladesh.
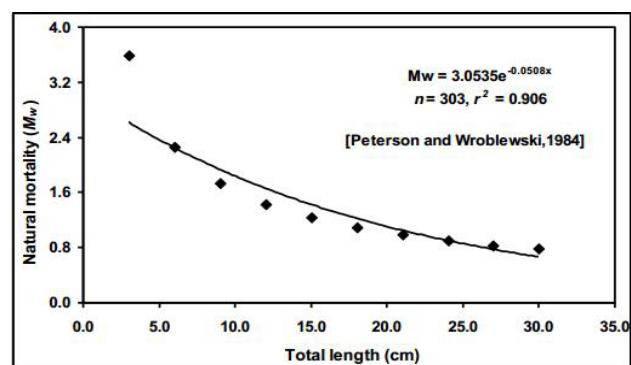
Fig. 6. The natural mortality of *Corica soborna* (Hamilton, 1822) in the Ganges River, northwestern Bangladesh.

Variation of sex ratio from 1:1 is not expected for most aquatic (fish and shellfish) species, but some finfish and prawn populations may exhibit a strong bias in this ratio (Hossain *et al*., 2013b, 2016b; Khatun *et al*., 2018). In our study, the sex ratio of male and female was 1:1.41 with female dominant over males. A similar finding was also reported by Hossain *et al*. (2008) from the Mathabhanga River, southwestern Bangladesh. During our study, the overall sex ratio varied significantly from the predictable 1:1 ratio ($df = 1$, $\chi^2 = 4.06$, $P < 0.05$), whereas Hossain *et al*. (2008) observed no noticeable variation from the expected 1:1 ratio ($df = 1$, $\chi^2 = 0.07$, $P > 0.05$) elsewhere in Bangladesh. Our LFDs showed a lack of *C. soborna* smaller than 2.7 cm in TL which might be attributed to inappropriate selection of fishing gears rather than their absence from the fishing ground; or else the fishermen did not go where smaller fish occurs (Hossain *et al*., 2015b, 2016b, 2017c; Hossen *et al*., 2016; Nawer *et al*., 2017). Hossain (2010a, b) made a similar hypothesis when studying small indigenous species from the Ganges River.

In our study, the observed maximum length of *C. soborna* was 5.0 cm TL irrespective of sex, which is higher than the reported value of (i) 2.70 cm (Sultana, 2012) from the Ganges River, Bangladesh (ii) 4.99 cm (Hossain *et al*., 2008) from the Mathabhanga River, Bangladesh (iii) 3.80 cm (Kamal, 1982) from the Ganga River, India, but lower than the maximum recorded length (TL= 5.3 cm) reported by Hossain *et al*. (2017a) from the Ganges River, NW Bangladesh. Information on maximum length is crucial for the estimation of asymptotic length and growth coefficient of fishes, as required for planning and management of fisheries resources (Hossain *et al*., 2012a, 2017d, 2018; Hossen *et al*., 2018; Khatun *et al*., 2019a).

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Table VI. Relationships of condition factor with total length (TL) and body weight (BW) of *Corica soborna* from the Ganges River, northwestern Bangladesh.

Relationships	Sex	r_s values	95% CL of r_s	P values	Significance
TL *vs.* K_A	M	0.0457	-0.1261 to 0.2148	$P = 0.592$	ns
TL *vs.* K_F		-0.3466	-0.4884 to -0.1869	$P < 0.001$	***
TL *vs.* K_R		0.0293	-0.1421 to 0.1991	$P = 0.731$	ns
TL *vs.* W_R		-0.0034	-0.1740 to 0.1675	$P = 0.968$	ns
BW *vs.* K_A		0.0442	-0.1275 to 0.2134	$P = 0.604$	ns
BW *vs.* K_F		-0.2476	-0.4013 to -0.0802	$P = 0.003$	***
BW *vs.* K_R		0.1324	-0.0392 to 0.2965	$P = 0.119$	ns
BW *vs.* W_R		0.1003	-0.0717 to 0.2665	$P = 0.238$	ns
TL *vs.* K_A	F	0.2091	0.0526 to 0.3555	$P = 0.007$	**
TL *vs.* K_F		-0.6021	-0.6942 to -0.4906	$P < 0.001$	***
TL *vs.* K_R		0.0314	-0.1274 to 0.1887	$P = 0.690$	ns
TL *vs.* W_R		0.0406	-0.1184 to 0.1976	$P = 0.607$	ns
BW *vs.* K_A		0.3051	0.1544 to 0.4420	$P < 0.001$	***
BW *vs.* K_F		-0.4896	-0.6013 to -0.3592	$P < 0.001$	***
BW *vs.* K_R		0.1647	0.0067 to 0.3148	$P = 0.036$	*
BW *vs.* W_R		0.1736	0.0158 to 0.3229	$P = 0.027$	*
TL *vs.* K_A	C	-0.2526	-0.3581 to -0.1407	$P < 0.001$	***
TL *vs.* K_F		-0.5029	-0.5848 to -0.4109	$P < 0.001$	***
TL *vs.* K_R		0.0415	-0.0748 to 0.1568	$P = 0.471$	ns
TL *vs.* W_R		0.0555	-0.0609 to 0.1704	$P = 0.336$	ns
BW *vs.* K_A		-0.1492	-0.2607 to -0.0338	$P = 0.009$	**
BW *vs.* K_F		-0.3760	-0.4715 to -0.2719	$P < 0.001$	***
BW *vs.* K_R		0.1805	0.0659 to 0.2904	$P = 0.002$	**
BW *vs.* W_R		0.1949	0.0807 to 0.3040	$P = 0.0001$	***

TL, total length; BW, body weight; K_A, allometric condition factor; K_F; Fulton′s condition factor; K_R, relative condition factor; W_R, relative weight; M, male; F, female; C, combined sex; r_S, Spearman rank-correlation values; CL, confidence limit; P, shows the level of significance; ns, not significant; * significant ($P \leq 0.005$); ** highly significant ($P \leq 0.01$); *** very highly significant ($P \leq 0.001$) (Sokal and Rohlf,1981).

Table VII. The calculated form factor ($a_{3.0}$), size at first sexual maturity (L_m) and natural mortality (M_w) of *Corica soborna* (Hamilton, 1822) across South Asian studies.

Water body	Sex	Regression parameters		L_{max}	References	$a_{3.0}$	L_m	95% CL of L_m	M_w (Y^{-1})
		a	*b*						
Ganges River, Bangladesh	U	0.0139	2.71	5.30	Hossain *et al.* (2017a)	0.0056	3.50	2.92 – 4.25	1.67
Mathabhanga River, Bangladesh	M	0.0080	2.95	4.79	Hossain *et al.* (2008)	0.0068	3.20	2.67 – 3.87	1.56
	F	0.0084	2.97	4.99		0.0076	3.32	2.77 – 4.02	1.53
Bangladesh	U	0.0069	3.05	3.50	Hossain and Afroze (1991)	0.0081	2.39	2.03 – 2.87	2.22
Ganga River, India	U	0.0061	3.69	3.80	Kamal (1982)	0.0528	2.58	2.18 – 3.10	2.06
Ganges River, Bangladesh	U	-	-	2.70	Sultana (2012)	-	1.89	1.62 – 2.25	–
Ganges River, Bangladesh	M	0.0117	2.82	4.70	Present study	0.0067	3.14	2.63 – 3.80	2.55
	F	0.0158	2.63	5.00		0.0050	3.32	2.77 – 4.02	2.50
	C	0.0143	2.69	5.00		0.0054	3.32	2.77 – 4.02	2.52

Male; F, Female; C, Combined; U, Unsexed; L_{max}, Maximum length; *a*, intercept; *b*, slope; $a_{3.0}$, form factor; L_m size at first sexual maturity; CL, confidence limit; M_w, Natural mortality.

The allometric coefficient (*b*) may fluctuate between 2 and 4, however, values stretching from 2.5–3.5 are more common for fishes (Froese, 2006). According to Tesch (1971), values of *b* close to 3 represent isometric growth and variations from 3 indicate allometric growth, either positively (> 3) or negatively (< 3) allometric. In our study, the *b* values of LWRs (TL vs. BW; FL vs. BW; SL vs. BW) were within the range of 2.81–2.82 for males and 2.59–2.70 for females, representing negative allometric growth (<3.00) for both sexes. A similar growth pattern was reported by Hossain *et al.* (2017a) (*b* = 2.71) for *C. soborna* from the Ganges River of Bangladesh. However, isometric growth was observed by Hossain and Afroze (1991) (*b* = 3.05) for combined sexes and Hossain *et al.* (2008) for males (*b* = 2.95) and females (b= 2.97) from the Mathabhanga River of SW Bangladesh, which is dissimilar to this study. Conversely, positive allometric growth was found by Kamal (1982) (*b* = 3.69) from the Ganga River, India, unlike our findings. However, this dissimilarity in growth pattern may results from numerous factors, including sex, physiology, maturation of gonads, habitat, seasonal influence, level of stomach plumpness, preservation methods and differences in the studied fish lengths (Hossain *et al.*, 2013b, 2019; Khatun *et al.*, 2019b), which we did not study. All LLRs were highly correlated ($P < 0.001$), with all r^2 values ≥ 0.971 in our study. There are no prior studies dealing with LLRs to make comparisons.

We studied four condition factors (K_A; K_F; K_R, and W_R) to assess the health and habitat condition of *C. soborna* in the Ganges River, although most of the study focused on a single condition factor. Among these condition factors, the Spearman rank correlation test found that K_F was highly significant correlated with TL and BW than for other condition factors (Table V). Hence, K_F can validly be used to evaluate the wellbeing of this species in the Ganges River and nearby water bodies. Moreover, the Wilcoxon signed-rank test showed that the W_R revealed no remarkable differences from 100 for both males (*P*= 0.6137) and females (*P*=0.6185), suggesting a balanced habitat with plenty of food access compared to predator risk (Anderson and Neumann, 1996) for *C. soborna* in the Ganges River basin. This is the first study on this aspect, so comparison with other data is not possible.

The $a_{3.0}$ values were 0.0067 and 0.0050 for male and female *C. soborna* in the Ganges River, which indicated elongated body shapes. The $a_{3.0}$ helps to appraise variation of body shape among populations or species from others (Froese, 2006). There was no literature information on the form factor of this species, so our study will provide the foundation for future studies.

L_m for males and females of *C. soborna* were 3.14 cm

vs. 3.32 cm in TL, respectively. However, Hossain *et al.* (2008) reported L_m as 4.44 cm TL for female *C. soborna* in the Mathabhanga River, SW Bangladesh, which is higher than observed for our study. This distinction may be result from differences in sample size, shrinkage in specimen body sizes from preservation in formalin, water temperature, population density, and food availability (Khatun *et al.*, 2019a), which were not considered in our study. The natural mortality (M_w) for the population of *C. soborna* was assessed as 2.52 year^{-1} for combined sexes of *C. soborna* in the Ganges River, NW Bangladesh. This is the first study on natural mortality for this species, so comparisons are impossible with other literature. It would be useful to document the causes of fish mortality in our study area.

CONCLUSION

Our findings describe the population parameters of *C. soborna* including length-frequency distribution, growth pattern based on LWRs, best-suited condition factor, relative weight, form factor, size at first sexual maturity, and natural mortality in the Ganges River. The results should be an effective tool for fishery managers, fish biologists and conservationists to formulate prompt management and regulations for sustainability of existing stocks of this species in the Ganges River and other South Asian water-bodies.

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