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RESEARCH PAPER

Temporal Variation of Hilsa, Tenualosa ilisha (Hamilton, 1822) Demographics in Bangladesh

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Abstract

Tenualosa ilisha (Hamilton, 1822) is the most significant open-water single-species fishery in Bangladesh. A study was performed to determine the length frequency distribution, length-length and length-weight relationship, form factor and condition factor of this species based on the length-weight (L-W) data comprised of 62092 specimens collected from 12 commercial landing stations of Bangladesh from January 2018 to December 2019. The total length and body weight ranged from 18.0-59.6 cm and 56.0-2532.0 g for females, and 11.0-52.5 cm and 14.0-1486.0 g for males, respectively. The length frequency distribution indicated that the percentage of females between 36.0-37.0 cm and males between 33.0-34.0 cm size groups were more abundant than other size classes. The overall allometric coefficient (b) values (b = 3.12 for females; b = 3.21 for males) denoted positive allometric growth (A^+) for both sexes. Moreover, the length-length relationship was also strongly associated ($r^2 > 0.956$; $p < 0.05$). The form factor values were 0.0103 for females and 0.0096 for males in this study. Fulton's condition factor exhibited a significant correlation with both total length and body weight, hence making it an ideal condition factor for predicting the fitness of this species. The findings from the present study will serve as a useful tool for conservationists, fish biologists and managers of fisheries to quickly formulate management plans and guidelines for the sustainability of this species in Bangladesh and its surrounding nations.

Introduction

Bangladesh has demonstrated great achievement by reaching self-sufficiency in fish production (4.62 million metric tons (MT)) (DoF, 2022). The nation today holds the third position internationally in the production of inland open water capture fisheries, which accounts for around 11% of global inland water capture (FAO, 2022). Hilsa shad, *Tenualosa ilisha* (Hamilton, 1822) is the national fish of Bangladesh and the most significant open-water single-species fishery, making a significant contribution to the nation's protein needs, economic development and foreign exchange gains. Even though the genus *Tenualosa* and *Hilsa* include three species of shad, the Bay of Bengal's hilsa fishery is dominated by *T. ilisha*, which accounts for 99% of the overall hilsa capture (Hossain et al., 2019). Currently, hilsa contributes approximately 1% to Bangladesh's GDP and 12.22% to total fish production (annual production: 565183 MT) (DoF, 2022). This fishery supports the employment of 0.45 million people directly and 2.5 million people indirectly, with an estimated non-consumptive value between 167.5-355.7 million US$ annually (Mohammed et al., 2016).

According to its life phases, hilsa is primarily an anadromous, swift-swimming, pelagic fish that lives in the estuary, marine and river habitats (Hossain et al., 2014). To feed, develop to maturity, spawn and migrate, hilsa ascends or migrates across a network of interconnected aquatic habitats. Once their life cycle is complete, the spent hilsa returns to marine waters with the juveniles (Milton and Chenery, 2003; Hossain et al., 2016). The world's average yearly output of hilsa is 0.72 million tons, with Bangladesh contributing the lion's share of around 50-60%, followed by Myanmar 20-25%, India 15-20%, and some other countries (i.e., Iraq, Kuwait, Malaysia, Thailand and Pakistan) contributing 5-10% (Rahman et al., 2010; Sahoo et al., 2018). Hilsa may be found in both freshwater and marine environments, from Sumatra to Kuwait (AL-Baz and Grove, 1995; Blaber et al., 2001; Bhaumik et al., 2013). The Department of Patents, Designs and Trademarks (DPDT), Ministry of Industries designated hilsa as the "Geographical Indicator" (GI) product of Bangladesh on August 6, 2017, taking into account its enormous potential in the country's economy and worldwide production share.

Length-length (LLRs) and length-weight (LWRs) relationships are essential tools in fisheries biology, physiology, ecological stock assessment (Rahman et al., 2020; Ullah and Mredul, 2022) and to assess the stock condition because they may be utilized for synchronized development of a species in a variety of habitats (Díaz de Astarloa et al., 2011). LWRs enable morphological and life history assessments between various fishes or between fish samples from various habitats and/or regions (Petrakis and Stergiou, 1995). Fish weight and length data are essential for determining the population dynamics, age and length distributions, growth and death rates and health of the species (Mishra et al., 2009; Saha et al., 2019). LWRs are used to gather data, such as length frequency from biomass (Ullah and Mredul, 2022) and fish status (Petrakis and Stergiou, 1995) for evaluation of stock and population monitoring of fish (Muchlisin et al., 2017) and to evaluate the growth history of the fish population from different places (Petrakis and Stergiou, 1995). The condition factor is a quantifiable parameter of the fish's state of well-being (Le Cren, 1951) and it includes indicators of fatness or degree of wellness, as well as a health condition that represents recent feeding state. The condition factor assesses the suitability of a particular water environment for fish growth by measuring an organism's deviation from the average weight in a given sample (Oluwatoyin et al., 2013; Batubara et al., 2019).

A large number of research on population dynamics and stock assessment of hilsa from various water bodies in Bangladesh have been published (Rahman et al., 1998; Amin et al., 2000; Haldar et al., 2001; Amin et al., 2004; Ahmed et al., 2008; Flura et al., 2015; Rahman et al., 2018; Nima et al., 2020; Islam et al., 2021; Das et al., 2022; Flura et al., 2022 and Flura et al., 2023). However, all of these studies were performed with a small number of samples and didn't cover all the locations where hilsa is abundant. Therefore, present study was performed with a large number of samples to determine length frequency distribution, growth patterns based on length-length and length-weight relationship, form factor and condition factors of hilsa.

Materials and Methods

Sampling area and period

From January 2018 to December 2019, monthly length-weight (L-W) data of hilsa were collected from 12 commercial landing centers in Bangladesh. In the year of 2018, L-W data of 50122 (38307 female and 11815 male), and in the year of 2019, L-W of 11970 (9432 female and 2538 male) hilsa specimens were collected. Figure 1 and Table 1 provide the geographic map and GPS coordinates for each sampling site. Data from the specimens were gathered and combined in an Excel spreadsheet for analysis. Using a measuring scale, the total and standard lengths were measured with a precision of around 0.01 cm. For each fish, the total weight was recorded using a digital balance (Acculab Sartorius Group, 0.01 g accuracy) (Colton Road, East Lyme, CT, USA). An external observation was used to identify the gender of hilsa.

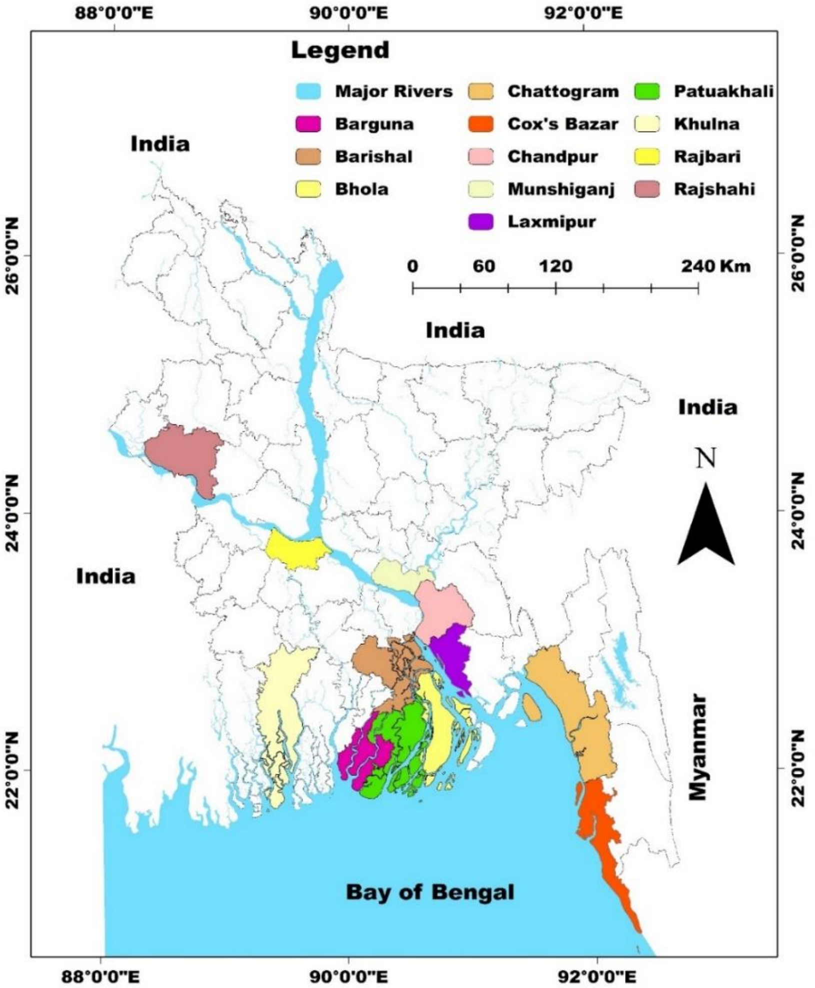

Figure 1. Sampling sites of hilsa from 12 commercial landing centers of Bangladesh.

Table 1. GPS coordinates of all sampling locations of Bangladesh.

Sl No.	Districts	Source	Sampling sites	GPS position	
1	Cox's Bazar	Bay of Bengal	BFDC Landing Station	N: 21º27'07.26"	E: 91º58'05.42"
2	Chattogram	Bay of Bengal	BFDC Landing Station	N: 22º19'09.18"	E: 91º50'19.56"
3	Laxmipur	Meghna river	Alexander	N: 22º39'16.47"	E: 90º54'24.23"
		Meghna river	Ramgoti	N: 22º38'47.07"	E: 90º55'53.57"
		Meghna river	Monpura	N: 22°15'26.16"	E: 90°57'41.21"
4	Bhola	Meghna river	Dalautkhan	N: 22°35'38.33"	E: 90°45'19.28"
5	Barisal	Meghna, Tetulia, Paira, Kirtonkhola, Arialkhan	BFDC Landing Station	N: 22°41'36.00"	E: 90°22'23.62"
6	Borguna	Bishkhali river and Bay of Bengal	Patharghata Landing Station	N: 22°3'6.59"	E: 89°58'19.81"
7	Patuakhali	Andarmanik river and Bay of Bengal	Mohipur	N:21°5'23.89"	E:90°7'21.24"
			Khepupara	N: 21°58'56.86"	E: 90°13'29.61"
8	Khulna	Kocha, Shibsha, Rupsha, Poshur rivers and Sundarban areas	BFDC Landing Station	N: 22°48'31.26"	E: 89°34'42.46"
9	Rajshahi	Padma and Mohananda rivers	Gudagari	N: 24°27'25.54"	E:88°19'39.06"
10	Rajbari	Padma river	Dalutdia	N 23°45'53.38"	E 89°46'55.38"
11	Munshiganj	Padma	Mawa	N:23°27'57.08"	E:90°16'46.98"
12	Chandpur	Meghna	Boro Station	N: 23°13'47.34"	E: 90°38'35.93"
			Horina Ghat	N: 23°09'50.94"	E: 90°38'44.09"

Length frequency distribution (LFD)

The length frequency distributions of hilsa were constructed using 1.0 cm intervals of the total length. The normal frequency distribution was converted into the total length frequency distribution using the computer program PAST (version 4.03, Palaeontological Association, Oslo, Norway).

Growth parameters and form factor

The length-weight relationship (LWR) of the fish was computed using the formula $W= aL^b$ (Le Cren, 1951), where W = weight of fish (g), L = length of fish (cm), a = intercept (describe the rate of change of weight, g with length, cm), and b = slope (weight, g at unit length, cm). The b value denotes isometric growth (I) if it is equal to 3, positive allometric growth (A^+) if it is greater than 3, and negative allometric growth (A^-) if it is lower than 3. The length-length relationship (LLR) between total length and standard length was calculated using the least-squares approach to fit a linear regression model as Y = a + bX, where Y is standard length, X is total length, a is the regression's intercept and b is the regression coefficient (slope). Form factor ($a_{3.0}$) of hilsa was calculated according to Froese (2006) using the equation: $a_{3.0} = 10^{\log a - s(b-3)}$; where a and b are the LWR's regression parameters and S is the regression slope of ln a vs. b. The researchers utilized a mean slope S = -1.358 to calculate the form factor.

Conditional indices

To determine the condition of the fish species in the current study, the relative condition factor (K_R) was computed using a modified version of Le Cren's (1951) model. K_R is calculated using the formula $K_R = W/(aL^b)$, where W is the body weight (g), and L is the overall length (cm). According to Fulton (1904), the formula for calculating Fulton's condition factor (K_F) is $K_F = 100 \times (W/L^3)$, where W is the fish's weight in grams and L is its total length in centimeters.

Statistical analysis

The Statistical Package for the Social Sciences (SPSS, version 25), Paleontological Statistics (PAST, version 4.03) and Microsoft Excel (Office 365) were used to conduct the statistical analyses. The presentation of means was as Mean ± Standard Deviation of the mean. Analysis of variance (ANOVA) was performed to examine if there were any significant variation in the slopes and intercepts between the associations (Saha et al., 2019). At a 5% ($p < 0.05$) level of significance, all statistical analyses were deemed significant.

Results

Length frequency distribution (LFD)

The length frequency distribution (LFD) of hilsa revealed that the size range was 18.0-59.6 and 11.0-52.5 cm total length for females and males, respectively. Further, the length frequency distribution showed that the 36.0-37.0 cm size group was dominant among females and the 33.0-34.0 cm group was dominant for the males, respectively (Figure 2). In this study, the body weight ranged from 52.0-2532.0 g for the females and 14.0-1486.0 g for males (Table 2).

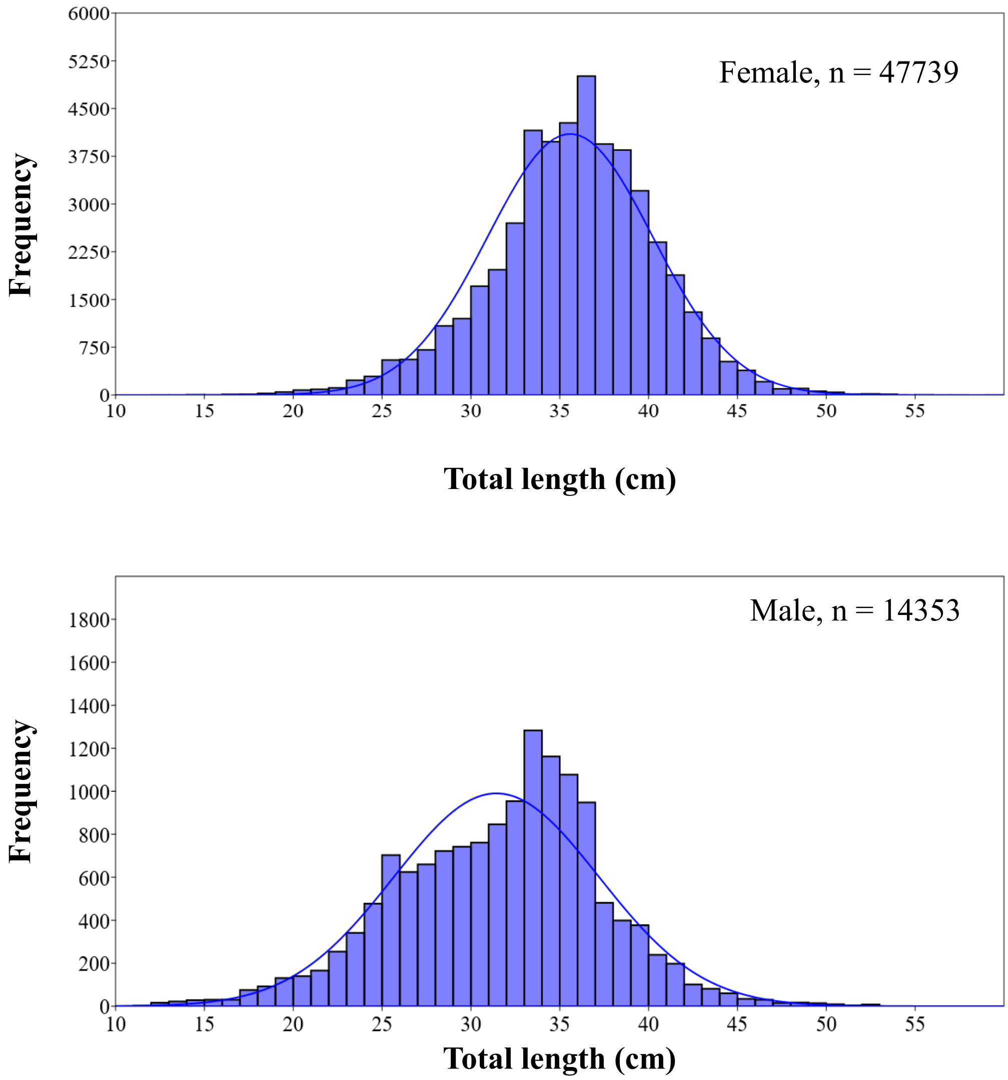

Figure 2. Length frequency distributions for female and male hilsa from 12 commercial landing centers of Bangladesh.

Table 2. Descriptive statistics of length (cm) and weight (g) measurements of hilsa from 12 commercial landing centers of Bangladesh.

Month	Sex	n	Total length range (cm)			Weight range (g)		
			Min	Max	Mean+SD	Min	Max	Mean+SD
January	F	4627	20.6	52.3	34.4±4.4	52.0	1316.5	455.6±179.6
	M	891	15.1	41.3	28.7±5.6	34.4	760.0	263.9±148.9
February	F	3371	19.7	52.6	35.7±4.9	78.3	1354.4	491.1±182.4
	M	745	19.2	42.9	30.2±3.9	48.3	702.8	282.1±106.7
March	F	4822	21.2	48.1	36.1±4.0	95.0	1180.6	535.6±185.2
	M	699	21.5	39.8	31.9±3.6	95.2	657.4	349.9±122.8
April	F	3635	19.5	49.3	36.0±4.9	61.3	1320.2	516.0±227.0
	M	755	14.5	43.3	27.9±5.4	32.7	830.8	243.4±134.2
May	F	6202	18.0	52.1	36.0±3.8	65.0	1571.7	521.1±192.6
	M	1534	11.0	49.0	29.6±6.0	14.0	1244.9	296.9±179.1
June	F	3707	23.4	59.6	37.0±4.0	114.8	2532.0	561.6±206.9
	M	851	20.5	52.5	33.7±5.6	86.4	1075.5	426.9±217.5
July	F	4821	22.4	53.1	35.5±3.8	100.5	1450.3	519.7±185.7
	M	800	17.7	43.5	31.3±3.7	78.6	900.5	325.2±126.3
August	F	2888	23.5	52.6	35.3±3.7	124.9	1501.1	535.8±184.6
	M	2921	18.0	50.5	34.2±4.4	76.6	1309.4	477.8±203.6
September	F	2527	23.1	51.3	36.4±3.8	100.4	1555.8	567.6±185.8
	M	2750	20.5	51.0	35.0±5.3	46.6	1486.0	519.8±238.8
October	F	2938	18.3	48.5	37.0±4.3	58.5	1350.6	584.0±194.7
	M	897	13.1	46.3	28.4±4.3	28.2	1000.5	425.3±174.8
November	F	3544	19.3	57.5	35.9±3.9	56.8	2007.6	490.6±160.0
	M	664	19.1	46.5	32.5±6.1	52.8	1004.4	375.1±242.5
December	F	4656	20.3	45.6	33.7±4.2	77.4	999.8	437.9±180.3
	M	846	14.5	43.5	29.9±4.5	35.7	750.4	273.2±102.9

Growth parameters and form factor

Overall b value for both female (b = 3.12) and male (b = 3.21) population in the LWR specified positive allometric growth (b > 3.00) (Figure 3). Females were found to grow larger than the males. The variances in the “b” value were observed from 2.13 to 3.36 with the correlation coefficient (r^2) of 0.75 to 0.99 for all LWRs. The regression parameters a and b of the LWRs, 95% confidence limits and coefficients of determination (r^2) of hilsa has been presented in Table 3. Statistically, a significant correlation ($p < 0.05$) was observed for all LWRs.

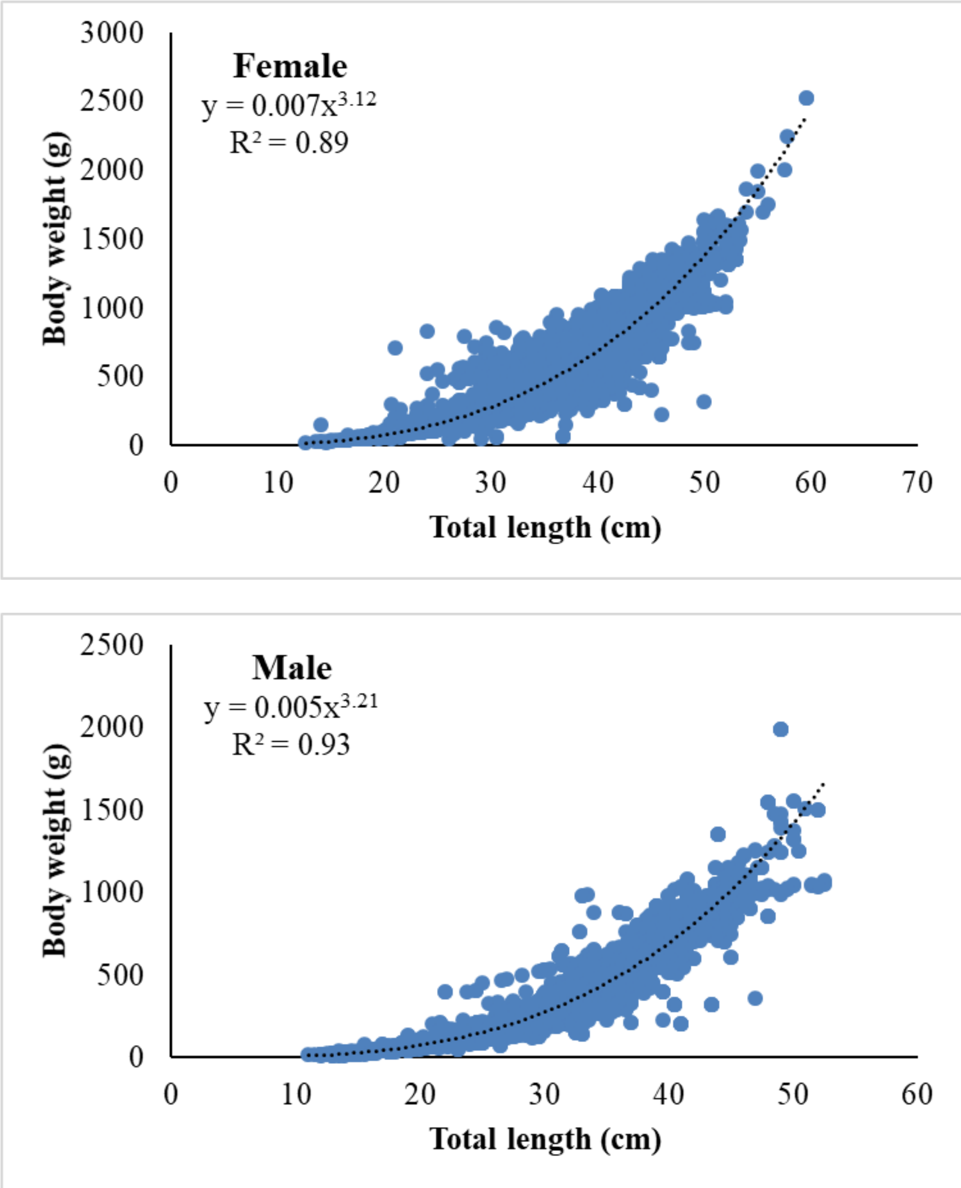

Figure 3. Growth patterns through the length-weight relationship of hilsa from 12 commercial landing centers of Bangladesh.

Table 3. Descriptive statistics on length-weight relationship and growth patterns of hilsa from 12 commercial landing centers of Bangladesh.

Month	Sex	Regression parameters		95% CI of b	r^2	Growth type
		a	b			
January	F	0.009	3.03	2.99 to 3.06	0.91	I
	M	0.007	3.10	3.06 to 3.14	0.97	A^+
February	F	0.005	3.16	3.12 to 3.20	0.91	A^+
	M	0.010	2.97	2.89 to 3.06	0.91	A^-
March	F	0.007	3.11	3.07 to 3.15	0.87	A^+
	M	0.008	3.05	3.01 to 3.09	0.99	I
April	F	0.004	3.23	3.18 to 3.29	0.93	A^+
	M	0.006	3.12	3.07 to 3.16	0.96	A^+
May	F	0.003	3.30	3.23 to 3.36	0.88	A^+
	M	0.011	2.96	2.90 to 3.01	0.91	A^-
June	F	0.008	3.07	3.02 to 3.11	0.86	I
	M	0.018	2.83	2.74 to 2.91	0.88	A^-
July	F	0.007	3.09	3.04 to 3.14	0.87	I
	M	0.008	3.04	2.89 to 3.19	0.81	I
August	F	0.006	3.14	3.08 to 3.21	0.87	A^+
	M	0.010	2.99	2.87 to 3.12	0.90	I
September	F	0.006	3.14	3.09 to 3.20	0.88	A^+
	M	0.001	3.36	3.23 to 3.49	0.95	A^+
October	F	0.007	3.09	3.04 to 3.19	0.90	I
	M	0.002	3.24	3.16 to 3.32	0.95	A^+
November	F	0.052	2.54	2.44 to 2.64	0.75	A^-
	M	0.006	3.05	2.88 to 3.22	0.91	I
December	F	0.004	3.28	3.21 to 3.34	0.86	A^+
	M	0.018	2.13	1.96 to 2.31	0.93	A^-

A^+ = Positive allometric; A^- = Negative allometric; I = Isometric

The length-length relationship (LLR) means the relations between total length and standard length with regression parameters a and b, and 95% confidence limit of b with the coefficient of determination (r^2). The results of LLR has been presented in Table 4. All LLRs were highly correlated with the coefficient of determination values ≥0.956. The assessed form factor ($a_{3.0}$) values in this investigation for hilsa were 0.0103 for females and 0.0096 for males. The form factor (a3.0) for hilsa was calculated using the equation of Froese (2006).

Table 4. Descriptive statistics on the length-length relationship of the hilsa from 12 commercial landing centers of Bangladesh.

Month	Sex	Regression parameters		95% CI of b	r^2
		a	b		
January	F	0.517	1.14	1.10 to 1.19	0.974
	M	1.232	1.19	1.17 to 1.21	0.988
February	F	0.553	1.08	1.01 to 1.13	0.961
	M	0.614	1.14	1.08 to 1.19	0.983
March	F	0.507	1.05	0.99 to 1.10	0.969
	M	0.789	1.09	1.04 to 1.14	0.985
April	F	0.474	1.23	1.17 to 1.29	0.997
	M	0.277	1.08	1.03 to 1.12	0.995
May	F	-0.411	1.13	1.09 to 1.18	0.986
	M	0.533	1.01	0.98 to 1.07	0.987
June	F	0.768	1.14	1.11 to 1.17	0.978
	M	0.518	1.11	1.08 to 1.14	0.989
July	F	1.584	1.07	1.02 to 1.12	0.985
	M	0.493	1.12	1.10 to 1.15	0.989
August	F	0.509	1.15	1.12 to 1.18	0.980
	M	-0.491	1.12	1.09 to 1.15	0.984
September	F	0.514	1.10	1.03 to 1.16	0.980
	M	0.581	1.15	1.10 to 1.19	0.977
October	F	0.604	1.12	1.08 to 1.17	0.956
	M	0.638	1.02	0.98 to 1.06	0.976
November	F	0.527	1.15	1.10 to 1.21	0.969
	M	1.484	1.08	1.04 to 1.14	0.982
December	F	0.507	1.14	1.12 to 1.17	0.981
	M	0.440	1.11	1.07 to 1.16	0.989

Conditional indices

Relative condition factor (K_R) values were found between 0.17-2.70 for females and 0.13-2.60 for males. Fulton's condition factor (K_F) values varied between 0.33-3.83 for females and 0.32-2.89 for males (Table 5). However, K_F was found statistically significant with the total length for both sexes (Table 6).

Table 5. Relative (K_R) and Fulton's (K_F) condition factors of hilsa from 12 commercial landing centers of Bangladesh.

Month	Sex	Relative condition factor				Fulton's condition factor			
		Min	Max	Mean±SD	95% CL	Min	Max	Mean±SD	95% CL
January	F	0.26	2.04	1.0±0.2	0.9-1.1	0.6	2.7	1.1±0.3	1.0-1.2
	M	0.21	1.90	1.0±0.1	0.9-1.2	0.4	2.4	1.1±0.1	1.0-1.2
February	F	0.32	1.99	1.0±0.1	0.9-1.1	0.6	2.7	1.1±0.1	1.0-1.2
	M	0.24	1.81	1.0±0.1	0.9- 1.1	0.3	1.5	1.1±0.1	1.0-1.2
March	F	0.49	2.70	1.1±0.1	1.0-1.1	0.5	3.6	1.1±0.2	1.0-1.2
	M	0.19	1.57	0.9±0.1	0.9-1.0	0.4	2.6	1.0±0.1	1.0-1.1
April	F	0.60	1.62	1.0±0.1	0.9-1.1	0.6	1.9	1.1±0.2	1.0-1.1
	M	0.22	1.54	0.9±0.1	0.9-1.0	0.6	1.5	1.0±0.1	1.0-1.1
May	F	0.20	1.86	1.0±0.1	0.9-1.1	0.3	2.2	1.1±0.1	1.0-1.1
	M	0.21	1.82	1.0±0.1	0.9-1.1	0.5	2.3	1.0±0.1	0.9-1.1
June	F	0.18	1.74	1.1±0.1	0.9-1.1	0.3	2.9	1.0±0.1	1.0-1.1
	M	0.26	2.51	1.0±0.1	0.9-1.1	0.4	2.9	1.0±0.2	0.9-1.1
July	F	0.73	1.66	1.1±0.1	1.1-1.2	0.6	2.2	1.1±0.2	1.0-1.2
	M	0.89	1.53	1.0±0.1	0.9-1.1	0.6	2.2	1.1±0.2	1.0-1.1
August	F	0.63	2.05	1.1±0.2	1.0-1.2	0.5	3.0	1.1±0.2	1.0-1.2
	M	0.65	1.36	1.0±0.1	0.9-1.1	0.7	2.8	1.2±0.5	1.1-1.2
September	F	0.52	1.56	1.0±0.1	0.9-1.1	0.6	3.8	1.1±0.1	1.0-1.2
	M	0.75	1.40	1.0±0.1	1.0-1.2	0.7	2.5	1.1±0.1	1.0-1.2
October	F	0.32	1.72	1.1±0.1	1.0-1.2	0.5	2.7	1.2±0.1	1.1-1.3
	M	0.21	2.60	1.1±0.2	1.0-1.2	0.5	1.9	1.1±0.2	1.0-1.1
November	F	0.36	1.42	1.0±0.2	0.9-1.2	0.4	2.8	1.1±0.2	1.0-1.1
	M	0.22	1.78	0.9±0.2	0.9-1.1	0.4	2.1	1.0±0.2	0.9-1.0
December	F	0.17	2.55	1.0±0.2	1.0-1.1	0.4	2.6	1.1±0.2	1.0-1.1
	M	0.13	2.05	1.0±0.1	0.9-1.1	0.6	1.5	1.1±0.2	1.0-1.1

Table 6. Relationships of condition factors with total length and body weight of hilsa from 12 commercial landing centers of Bangladesh.

Correlation	Sex	r_s values	95% CL of r_s	p-value	Level of significance
TL vs. K_R	Female	0.0235	0.0121 - 0.0349	0.1431	ns
	Male	0.0008	-0.0256 - 0.0272	0.9509	ns
BW vs. K_R	Female	0.2913	0.2808 - 0.3017	< 0.0001	***
	Male	0.0097	-0.0168 - 0.0364	0.0025	**
TL vs. K_F	Female	0.0212	0.0110 - 0.0230	< 0.0001	***
	Male	0.0005	-0.0256 - 0.0272	0.0031	**
BW vs. K_F	Female	0.1939	0.2808 - 0.1131	< 0.0001	***
	Male	0.0076	-0.0024 - 0.0262	< 0.0001	***

Note: TL, total length; BW, body weight; K_R, relative condition factor; K_F; Fulton's condition factor; r_s, Spearman rank-correlation values; CL, confidence limit; p, shows the level of significance; ns, not significant;
* significant ($p < 0.05$);
** highly significant ($p < 0.01$);
*** very highly significant ($p < 0.001$).

Discussion

In order to formulate an effective management plan for any aquatic habitat, knowledge of the fish population structure, growth and development trend is very crucial. We found a maximum total length of 59.6 cm in this study, which was smaller than the study of Amin et al., (2004), but all other studies (Amin et al., 2002; Bhaumik et al., 2011; Roomiani and Jamili, 2011; Flura et al., 2015; Mohanty and Nayak, 2017; Sarkar et al., 2017; Rahman et al., 2018; Bhakta et al., 2019; Das et al., 2022 and Flura et al., 2022) found the body length smaller than that of the present study. The overfishing of hilsa in Bangladesh's territorial waters or the mesh size of the net may be the cause of the absence of individuals greater than 59.6 cm in the sampling locations in this research.

Particularly for the species that are vulnerable to overexploitation, LWRs are excellent for setting a foundation for conservation initiatives. Hilsa's length and weight were found to be significantly correlated in the present study throughout the year, showing isometric and positive allometric growth while only a few observations exhibited negative allometric growth. According to Carlander (1969), the allometric coefficient (b) can have a value between 2 and 4, however; values between 2.5 and 3.5 are more frequent (Froese, 2006). According to Tesch (1971), b values close to 3 indicate isometric growth, whereas variations from 3 indicate either positive (>3) or negative (<3) allometric growth. In the current study, the b values of LWRs ranged from 2.54 to 3.12 for females and 2.13 to 3.35 for males, demonstrating a negative (<3.0) to positive (>3.0) allometric patterns of growth for both sexes. Similar growth patterns for the hilsa population have been noted by Flura et al. (2015), Bhakta et al. (2019), Das et al. (2022) and Flura et al. (2022). In contrast to the current observation, Ahmed et al. (2008), Mohanty and Nayak (2017), Rahman et al. (2018) and Islam et al. (2021) found negative allometric growth (b < 3.00) of hilsa population. By comparing results from the past and present research, it can be stated that variations in the value of the regression coefficient or exponent "b" can be linked to variations in sampling season, sample size, or length ranges.

In our investigation, all LLRs had r^2 values more than 0.956 and all LLRs were significantly associated ($p < 0.05$). There were no comparable previous investigations with LLRs. Variations in animal physiology, ecological factors, or both may contribute to differences in length-length correlations (Ullah et al., 2022a). In this study, the measured form factor values for males and females were 0.0096 and 0.0103, respectively. This value is frequently used to detect whether an individual's body shape varies from that of other fish species in a certain fish population or species (Froese, 2006). However, no form factor reference value for hilsa in the literatures were found for Bangladesh. Therefore, the present form factor results will be a useful starting point for subsequent comparisons.

The condition factor of a fish describes the physiological factors and feeding circumstances interactions that result in physical and biological conditions and variations (Le Cren, 1951). This also reflects changes in food reserves and markers of the general health of fish. Understanding condition factors are essential for management because it gives the producer exact knowledge about the conditions under which organisms are growing (Araneda et al., 2008; Ullah et al., 2022b). Additionally, to evaluate the population's health at various life stages of cycle, the condition factor is an index that shows interactions between biotic and abiotic elements of the fish's physiological condition (Froese, 2006). To determine a fish's overall condition, the condition factor was generated using values based on the fish's present biophysical conditions and it was subject to be influenced by the interactions between feeding conditions, pathogenic infections, physiological parameters, and food reserves. Relative condition factor (K_R) is an important condition factor that can show a person's or a population's nutritional and physiological state. Most often, it is viewed in terms of energy reserves and life history traits like growth and reproduction (Gubiani et al., 2020). Froese (2006) recommended utilizing K_R to compare the health state of fish population within the same sample or population. The deviation of K_R from 1, where $K_R > 1$ signifies excellent general condition and $K_R < 1$ indicates the opposite situation, provides information on variations in food availability and the effects of physico-chemical characteristics on the life cycles of fish species (Le Cren, 1951). According to our research, both male and female population had K_R levels greater than 1, indicating a sign of excellent health. The difference in K_R levels might be explained by how much food each gender consumes (Ambily and Nandan, 2010). Both female and male population of hilsa had Fulton's condition factor (K_F) values greater than 1, which indicates that they are in excellent condition. Conversely, a value of less than 1 indicates that the fish are not in good health (Froese, 2006). The K_F values found in the present study of the both sexes of hilsa indicates that a healthy environment and a home with an ample food supply still exits in the water shed of Bangladesh. According to Barnham et al. (2003), the K_F in females diminishes swiftly after the eggs are discharged, and is significantly impacted by the stage of development of the reproductive organs. In contrast to the other condition variables, only K_F showed a significant association with TL and BW for both sexes, according to the Spearman rank correlation test. As a result, this study showed that K_F may be used to evaluate hilsa’s well-being in Bangladesh’s waters and its surrounding nations.

Conclusions

The overall findings from the present study can be outlined as follows:

- There is size discrepancies and variation of LLRs, LWRs and condition factors among male and female hilsa and significant correlation ($p < 0.05$) was observed for all LLRs and LWRs.
- Fulton’s condition factor exhibited a significant correlation with both total length and body weight.
- The b values of LWRs for females and males demonstrated a negative to positive allometric growth patterns.

- Variations in the values of the regression coefficient or exponent "b" were linked to variations in sampling seasons, sample size, or length ranges.
- Both male and female hilsa had K_R levels greater than 1, indicating excellent health condition.

Our research describes the demographic characteristics of hilsa from several water bodies in Bangladesh, including length frequency distribution, length-length, length-weight relationships, form factor and condition factors. These findings will serve as a useful tool for conservationists, fish biologists, managers and policy planners to quickly formulate management plans and adopt different interventions for the sustainable management of hilsa resources in Bangladesh.

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Ethical approval

This research had been approved by the Ethics Committee of Bangladesh Fisheries Research Institute, Bangladesh.

Informed consent

Not available.

Conflicts of interest

There is no conflict of interests for publishing of this study.

Data availability statement

The authors declare that data are available from authors upon a reasonable request.

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Author contribution

Mohammad Ashraful Alam: Writing original draft, Conceptualization, Data curation, Formal analysis, and Project administration.
Md. Moniruzzaman: Data curation, Methodology, Software, Writing an original draft.
Flura: Data curation, Methodology, Writing an original draft.

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