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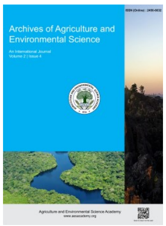

ORIGINAL RESEARCH ARTICLE

CrossMark

Length frequency distribution, length-weight relationship and condition factors of Hilsa Shad, *Tenualosa ilisha* from Bangladesh

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ABSTRACT

Hilsa shad, *Tenualosa ilisha*, a cherished and economically vital species, thrives in the waters of Bangladesh. It holds a prominent role in bolstering the nation's food security and influencing the ecological dynamics of aquatic ecosystems along the Bangladeshi coast and estuaries. This comprehensive study encompasses data collection efforts on the Hilsa fish species, conducted at 12 commercial landing centers throughout Bangladesh over the course of 2020. The study describes some fundamental components, including length frequency distribution, length-weight relationships, and condition factors, offers invaluable insights into the growth, health, and overall well-being of Hilsa population. Notably, the length-weight relationship analysis revealed size ranges of 11.5-59.2 cm and 11.0-49.0 cm total length for females and males, respectively. The observed b values indicated positive allometric growth (b > 3.00) for female population and negative allometric growth (b < 3.00) for male population in the length-weight relationship. Among the condition factors scrutinized, Fulton's condition factor emerged as the most reliable indicator for assessing the health and condition of the Hilsa population. This study offers valuable insights for biologists, aiding in the assessment of the species' status and providing essential information for fishery biologists and conservation biologists. Such insights are instrumental in the management and ultimate conservation of this iconic species in Bangladesh.

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INTRODUCTION

Tenualosa ilisha, commonly referred to as the Hilsa shad, is an economically vital species deeply ingrained in the waters of Bangladesh. Its revered status in the culture is further accentuated by its delectable taste and rich nutritional profile, rendering it an essential component of the Bangladeshi diet. This iconic fish species, known for its distinctive flavor and cultural significance, not only plays a critical role in bolstering the nation's food security but also exerts a profound influence on the ecological dynamics of the aquatic ecosystems along the Bangladeshi coast and estuaries (Flura *et al*., 2022). In Bangladesh, where the Hilsa shad is affectionately christened the "King of Fish," gaining a comprehensive understanding of the key biological and ecological parameters of this species holds paramount importance (Alam *et al*., 2023). Notably, among these pivotal parameters, the length frequency distribution, length-weight relationship, and condition factors emerge as fundamental components that furnish invaluable insights into the growth, health, and overall well-being of the Hilsa population (Saha *et al*., 2019). Length-weight relationships (LWRs) represent pivotal metrics, enabling an exploration of how a fish's weight varies in relation to its length. This relationship serves as a valuable lens through which to assess the overall health and growth patterns of fish population, contributing to our understanding of their ecological dynamics (Yamamoto *et al*., 2006; Ullah and Mredul, 2022; Manon *et al*., 2023). LWRs are particularly instrumental for evaluating diverse factors, including nutrition, habitat quality, and the potential impact of environmental stressors on a fish's condition (Froese, 2006). This information holds profound importance in the assessment of the life history of fish species and their intricate roles within the complex network of aquatic ecosystems (Rahman *et al*., 2023). Condition factors (CF) emerge as essential indicators for assessing a fish's overall well-being and the quality of its environment. These factors take into account various measurements, including weight, length, and sometimes even age, in order to determine whether an individual fish is experiencing optimal growth and health conditions (Froese, 2006; Kassem *et al*., 2021). In doing so, they provide valuable insights into the interplay between a fish's physiological status and the surrounding ecological context.

This manuscript embarks on a comprehensive investigation of pivotal aspects of *Tenualosa ilisha* within the context of Bangladesh. By delving into the length frequency distribution, length-weight relationship, and condition factors of the Hilsa shad, our objective is to make a substantial contribution to the foundational knowledge required for well-informed and sustainable fisheries management. This endeavor not only elucidates the growth, health, and ecological significance of the Hilsa but also carries profound implications for the conservation and responsible utilization of this culturally and economically significant species in Bangladesh. Through this research, we aspire to augment our comprehension of the Hilsa and fortify the initiatives aimed at ensuring its enduring presence in the waters of Bangladesh.

MATERIALS AND METHODS

Sampling area and period

In the year 2020, a comprehensive data collection initiative was executed, with a focus on the length and weight of the Hilsa fish species, encompassing 12 strategically chosen commercial landing centers across Bangladesh. Figure 1 and Table 1 within this study provide both visual representations and precise GPS coordinates for each of the strategically selected sampling locations. For precise measurements, a measuring scale was employed to determine the total length (TL) and standard length (SL) of each fish. Additionally, an electronic balance (Acculab, Sartorius Group, Colton Road, East Lyme, CT, USA) was used to measure the entire body weight with an accuracy of 0.01 cm and 0.01 g precision, respectively. Gender determination of the Hilsa fish in our study was based on external observations.

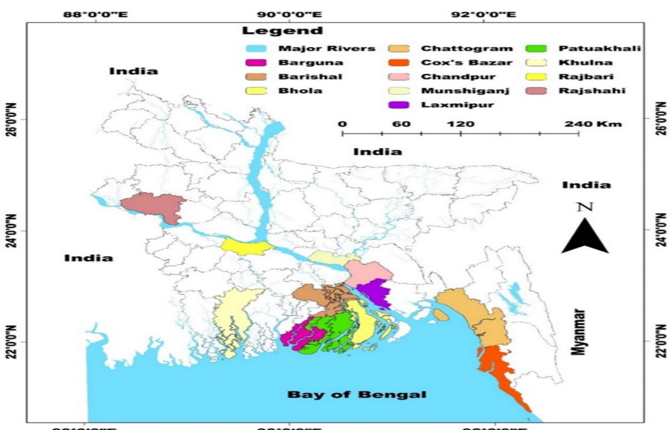

Figure 1. *Sampling sites of Hilsa from 12 commercial landing centers of Bangladesh.*

Length frequency distribution (LFD)

Length frequency distribution (LFD) for this species was constructed, considering the different collection areas. These distributions were created using normal frequency distribution based on the total length of the specimens. This analytical methodology served as a means to visually depict and scrutinize the variations in total length across the diverse geographic regions under investigation.

Length-weight relationship (LWR)

The data collected was subjected to rigorous analysis to establish a potential relationship, employing the formula for length-weight relationships as proposed by Le Cren (1951): $W = aL^b$. In this formula, 'W' represents the weight of the fish in grams (g), 'L' denotes the length of the fish in centimeters (cm), signifying the intercept and characterizing the rate of change of weight concerning length, while 'b' signifies the slope, describing the weight at unit length. To facilitate further analysis, the parabolic equation, $W = aL^b$, was transformed into a linear equation through a logarithmic transformation: $\text{Ln } W = \text{Ln } a + b \text{ Ln } L$. This conversion into a linear representation enhanced the accessibility and comprehensiveness of the analysis concerning the length -weight relationships of the fish, contributing to a deeper understanding of this fundamental aspect of their biology.

Form factor

The 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 In a vs. b. The researchers utilized a mean slope S = -1.358 to calculate the form factor.

Condition factors

Fulton's Condition Factor (K_F) is computed by dividing the weight of a fish by the cube of its length. The formula for Fulton's Condition Factor is expressed as $K_F = 100 \times W / L^3$ (Fulton, 1904), where 'K_F' denotes Fulton's condition factor, 'W' signifies the weight of the fish, and 'L' represents the length of the fish. The Relative Condition Factor (K_R) serves as a metric to evaluate how a fish's weight compares to the anticipated weight for a fish of the same length. The formula for the Relative Condition Factor is defined as $K_R = W / (a \times L^b)$ (Le Cren, 1951), where 'K_R' represents the Relative Condition Factor, 'W' stands for the weight of the fish, and 'a' and 'b' denote the parameters derived from the length-weight relationship.

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

S. No.	Districts	Source	Sampling sites	GPS position	
1.	Cox's Bazar	Bay of Bengal	BFDC Landing Station	N: 21°27´07.26´´	E: 91°58´05.42´´
2.	Chattogram	Bay of Bengal	BFDC Landing Station	N: 22°19´09.18´´	E: 91°50´19.56´´
3.	Laxmipur	Meghna river	Alexander	N: 22°39´16.47´´	E: 90°54´24.23´´
		Meghna river	Ramgoti	N: 22°38´47.07´´	E: 90°55´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´´

Statistical analysis

The Statistical Package for the Social Sciences (SPSS, version 25), Minitab (version 18, Pennsylvania State University, USA), and Microsoft Excel (Office 365) were used to conduct the statistical analyses at 5% ($p < 0.05$). 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 variations in the slopes and intercepts between the relationships.

RESULTS AND DISCUSSION

Length frequency distribution (LFD)

The length frequency distribution (LFD) analysis of the Hilsa fish indicated that the size range for females was between 11.5 and 59.2 cm in total length, while for males, it ranged from 11.0 to 49.0 cm. Furthermore, the LFD data showed that among females, the 41.0-42.0 cm size group was the most common, while among males, the 25.0-26.0 cm group was predominant (Figure 2). In this research, the body weight of female Hilsa fish ranged from 18.0 to 2360.0 g, while for males, it varied from 13.0 to 1500.0 g (Table 2). Length-frequency distributions constitute a pivotal source of information, offering valuable insights into the population structure of fish, thereby contributing to the foundations of effective fisheries management. A comprehensive understanding of the size composition of fish populations is of utmost importance, shedding light on crucial facets of their growth, development, reproduction, and recruitment dynamics. Notably, changes in size serve as early indicators of environmental disturbances. In our study, a maximum total length of 59.2 cm was observed, a size notably smaller than those reported in previous investigations by Amin *et al.* (2004) and Alam *et al.* (2023). However, it is worth noting that other research conducted by Bhaumik *et al.* (2013), 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) consistently indicated body lengths smaller than those observed in our present study. The absence of individuals larger than 59.2 cm at our sampling locations could potentially be attributed to overfishing of the Hilsa fish species in the territorial waters of Bangladesh or constraints associated with the mesh size of the fishing nets employed in our research efforts.

Length-weight relationships (LWRs)

A descriptive analysis of length-weight relationships including regression parameters of a and b of the LWR, and 95% confidence limit of b with the coefficient of determination (r^2) has been depicted in Table 3. The variances in the "b" values were observed from 2.21 to 3.59 with a correlation coefficient (r^2) of 0.65 to 0.98. Overall b value for female (b = 3.07) population in the LWR specified positive allometric growth (b > 3.00) and male (b = 2.97) population in the LWR specified negative allometric growth (b < 3.00) (Figure 3). The assessed form factor ($a_{3.0}$) values in this investigation for Hilsa were 0.01032 for females and 0.0099 for males. The form factor ($a_{3.0}$) for Hilsa was calculated using the equation of Froese (2006). The parameter 'b,' often referred to as the slope, represents a critical indicator of allometric or isometric growth rate in fish populations, primarily

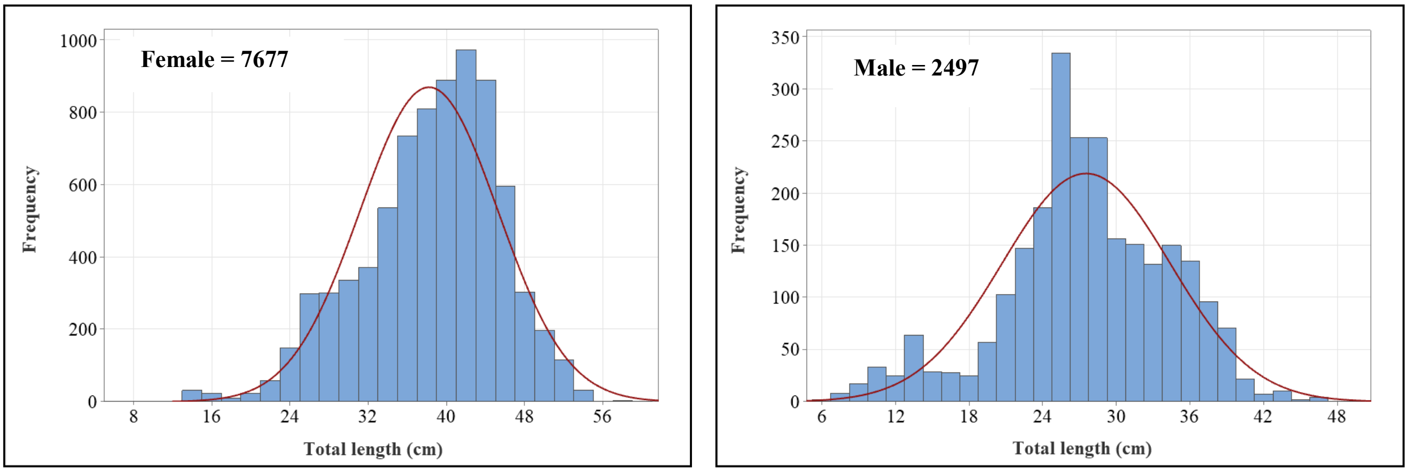

Figure 2. *Length frequency distributions of Hilsa from 12 commercial landing centers of Bangladesh.*

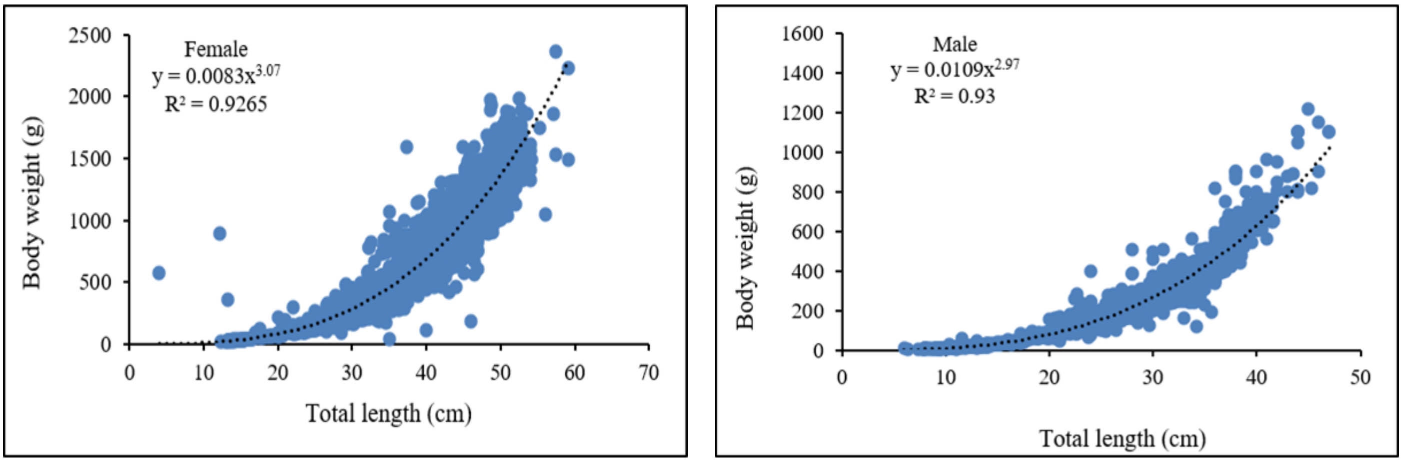

Figure 3. *Growth patterns through the length-weight relationship of Hilsa from 12 commercial landing centers of Bangladesh.*

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	861	17	50.9	36.8±6.35	48	1600.0	600±311.5
	M	310	11.6	43	26.3±4.5	42	802	210.3±105.1
February	F	575	12.1	51.5	39.2±5.8	160	1526	739.8±322.8
	M	134	11	43	30.3±5.3	13	877	309.8±158.9
March	F	155	23.4	51.6	36.9±6.1	130	1423	584.8±289.9
	M	152	12.5	36	27.4±5.9	22	480	221.9±105.5
April	F	67	12.3	24	15.9±2.8	18	150	44.7±30.3
	M	206	11	30.3	13.6±3.5	19	290	29.8±29.6
May	F	242	26.5	48.6	38.6±5.3	175	1890	724.7±350.6
	M	27	16.5	46	33±8.1	43	1500	523.2±418.3
June	F	350	26	54	40.1±5.7	181	1610	678.5±304
	M	90	17.2	41	28.1±4.8	76	605	231.6±125.6
July	F	635	11.5	59.1	39.4±5.9	102	2360	752.2±351.3
	M	244	20.6	44	31.8±5.2	93	1049	363.1±164.5
August	F	1784	19	57.2	37.7±7.6	60	1891	659.9±387.2
	M	743	18	47	28.9±5.7	61	1216	270.7±177.9
September	F	190	25.2	53.6	37.3±6.6	145	1862	673.5±387.5
	M	110	19.5	37.6	28.6±3.9	75	522	253.7±103.6
October	F	1104	16.6	52.2	40.7±5.5	50	1870	780.5±302.1
	M	92	18	49	32.3±5.8	80	1260	390.5±236.6
November	F	1450	19.8	59.2	37.7±7.6	40	1531	622.4±346.4
	M	247	17	47	28.3±6.3	40	1100	256.6±185.9
December	F	264	29	49.1	39.2±4.6	275	1305	710.8±231.4
	M	142	15	39	29±4.7	320	830	608.3±213.5

underpinned by genetic factors. When the value of 'b' maintains stability, hovering around 3.0, it signifies that an individual's shape and ontogenetic growth remain relatively consistent. In our current study, we observed 'b' values of 3.07 for females and 2.97 for males within the Hilsa population. These values fall well within the expected range, typically between 2.5 and 3.5, as established by prior studies (Froese, 2006; Rahman *et al*., 2020; Ullah *et al*., 2022). Conventionally, in an ideal fish, this value approximates 3.0 and remains relatively constant (Carlander, 1969), although occasional deviations from this standard, as noted by Hile (1936), may occur. Acceptable variations in allometric growth typically range from 2.0 to 4.0, as documented by Hile (1936) and Tesch (1971). In our current investigation, it was observed that female Hilsa exhibited positive allometric growth, while male Hilsa displayed negative allometric growth. Previous studies have reported instances of positive allometric growth within the Hilsa population, as documented by Flura *et al*. (2015), Bhakta *et al*. (2019), Das *et al*. (2022), Flura *et al*. (2022), and Alam *et al*. (2023). In contrast, Ahmed *et al*. (2008), Mohanty and Nayak (2017), Rahman *et al*. (2018), and Islam *et al*. (2021) reported occurrences of negative allometric growth (b < 3.00) within the Hilsa population.

The variations observed in the exponent 'b' or regression coefficient can be attributed to a multitude of factors, encompassing differences in sampling methodologies, seasonal variations, sample size, and length ranges. Additionally, localities, habitats, sex (Hossain, 2010; Hossen *et al*., 2017; Ullah and Mredul, 2022), temperature fluctuations, feeding rates, overfishing, and food competition (Tesch, 1971; Rahman *et al*., 2012) may influence these 'b' values. Furthermore, factors such as fish behavior (active or passive swimming), ecological aspects (availability of forage organisms) (Le Cren, 1951), preservation techniques, disparities in the observed length ranges of captured specimens (Hossain *et al*., 2012), water flow, maturity levels, stages of maturity, metamorphosis, seasonal effects, gonadal development, growth phases, and trophic potential within rivers and ponds of aquatic organisms (Garcia, 2010; Alam *et al*., 2012) are recognized as additional influencers on these 'b' values. Literature on form factor is not available for those species. Estimated form factor and their comparisons are snapshot pictures of which is useful for fisheries management. The form factor assessment appears consistent with Alam *et al*., 2023. Minute variances observed may be linked to factors such as body plumpness and the developmental stage of gonads.

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

Months	Sex	Regression parameters		95% CI of b	r^2	Growth type
		a	b			
January	F	0.008	3.08	3.02 to 3.13	0.93	-A
	M	0.028	2.71	2.59 to 2.84	0.86	+A
February	F	0.01	3.03	2.93 to 3.14	0.85	A
	M	0.008	3.06	2.99 to 3.14	0.98	-A
March	F	0.003	3.32	3.24 to 3.39	0.97	+A
	M	0.019	2.80	2.73 to 2.88	0.92	A
April	F	0.005	3.18	3.13 to 3.23	0.65	+A
	M	0.043	2.42	2.25 to 2.59	0.90	-A
May	F	0.003	3.41	3.24 to 3.58	0.87	+A
	M	0.001	3.59	3.31 to 3.88	0.97	+A
June	F	0.005	3.17	3.09 to 3.25	0.95	+A
	M	0.019	2.79	2.64 to 2.94	0.94	-A
July	F	0.206	2.21	2.08 to 2.33	0.66	-A
	M	0.025	2.75	2.60 to 2.88	0.86	-A
August	F	0.005	3.19	3.16 to 3.22	0.96	+A
	M	0.008	3.07	3.02 to 3.11	0.95	+A
September	F	0.002	3.46	3.35 to 3.57	0.95	+A
	M	0.010	2.98	2.84 to 3.14	0.93	-A
October	F	0.007	3.12	3.06 to 3.17	0.91	A
	M	0.043	2.57	2.31 to 2.79	0.83	-A
November	F	0.008	3.06	3.02 to 3.10	0.93	A
	M	0.009	3.01	2.93 to 3.09	0.96	-A
December	F	0.007	3.10	3.01 to 3.20	0.91	A
	M	0.144	2.88	2.77 to 3.00	0.94	-A

Table 4. 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	0.17	2.46	1.02±0.15	1.01-1.03	0.18	1.83	1.10±0.16	1.09-1.11
	M	0.46	2.95	1.02±0.23	0.99-1.04	0.48	1.84	1.09±0.28	1.06-1.12
February	F	0.68	1.61	1±0.12	0.92-1.23	0.77	1.81	1.13±0.14	1.05-1.39
	M	0.75	1.31	1±0.09	0.98-1.02	0.76	1.32	1.02±0.09	1-1.03
March	F	0.81	1.42	1.02±0.09	1-1.03	0.77	1.42	1.05±0.11	1.04-1.07
	M	0.57	1.3	1.01±0.11	0.99-1.02	0.53	1.3	0.98±0.12	0.96-1
April	F	0.51	4.55	1.32±0.93	1.09-1.54	0.84	1.49	1±0.09	0.98-1.03
	M	0.41	2.43	1.03±0.25	0.99-1.06	0.45	3.70	1.01±0.31	0.97-1.06
May	F	0.60	2.66	1±0.22	0.97-1.03	0.68	3.06	1.17±0.25	1.13-1.19
	M	0.77	1.49	1.03±0.19	0.95-1.11	0.83	1.87	1.11±0.28	0.99-1.22
June	F	0.68	1.55	1.01±0.12	1-1.02	0.66	1.53	0.99±0.11	0.98-1.01
	M	0.85	1.56	1.04±0.14	1.01-1.06	0.81	1.63	0.96±0.14	0.94-0.99
July	F	0.50	1.79	1.01±0.20	0.99-1.02	0.53	1.97	1.13±0.17	1.11-1.14
	M	0.29	2.58	1.01±0.20	0.99-1.04	0.29	2.89	1.06±0.22	1.03-1.09
August	F	0.38	2.37	1.02±0.13	1.01-1.02	0.38	2.49	1.08±0.15	1.07-1.08
	M	0.58	2.08	1.01±0.13	0.99-1.01	0.56	1.99	0.98±0.13	0.97-0.99
September	F	0.77	1.44	1.03±0.14	1.01-1.05	0.76	1.61	1.15±0.18	1.11-1.17
	M	0.75	1.55	1±0.11	0.98-1.02	0.76	1.6	1.02±0.11	1-1.04
October	F	0.39	1.35	1.02±0.16	1.01-1.03	0.41	1.39	1.09±0.17	1.08-1.10
	M	0.79	1.52	1±0.12	0.98-1.03	0.78	1.58	1.03±0.13	0.99-1.06
November	F	0.12	3.07	1.13±0.18	1.13-1.14	0.09	2.74	1.03±0.17	1.02-1.04
	M	0.44	1.71	1.01±0.14	0.99-1.02	0.43	1.65	0.97±0.13	0.96-0.99
December	F	0.75	1.38	0.99±0.09	0.98-1.01	0.79	1.45	1.04±0.09	1.02-1.05
	M	0.61	1.27	1.01±0.11	0.99-1.02	0.59	1.23	0.98±0.11	0.96-1

Table 5. Relationships of condition factors with total length and body weight of Hilsa from 12 commercial landing centers of Bangladesh in 2020.

Correlation	Sex	r_s values	95% CL of r_s	p-value	Level of significance
TL vs. K_R	Female	0.0926	0.0695 - 0.1155	< 0.0001	****
	Male	0.0530	0.0116 - 0.0941	0.0097	**
BW vs. K_R	Female	0.1911	0.1687 - 0.2133	< 0.0001	****
	Male	0.1052	0.0641 - 0.1460	< 0.0001	****
TL vs. K_F	Female	0.1805	0.1580 - 0.2028	< 0.0001	****
	Male	0.0468	0.0054 - 0.0880	0.0224	*
BW vs. K_F	Female	0.3108	0.2897- 0.3316	< 0.0001	****
	Male	0.1129	0.0718 - 0.1535	< 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 ($p < 0.001$).

Condition factors

The estimated Fulton's Condition Factor (K_F) and Relative Condition Factor (K_R) are shown in Table 4. The K_R value ranged from 0.12 to 4.55 (Table 4). The Spearman rank correlation test, exhibited highly significant relationships between TL vs. K_R (r_s = 0.0926 and $p < 0.0001$) for females, significant relationships between TL vs. K_R (r_s = 0.0530 and $p < 0.0097$) for males, and highly significant relationships between both BW vs. K_R (r_s = 0.1911 and $p < 0.0001$) for females, and BW vs. K_R (r_s = 0.1052 and $p < 0.0001$) for males, respectively (Table 5). The K_F value ranged from 0.18 to 3.70 (Table 4). According to the Spearman rank correlation test, there were highly significant relationships between TL vs. K_F (r_s = 0.1805 and $p < 0.0001$) for females, significant relationships between TL vs. K_F (r_s = 0.0468 and $p < 0.0224$) for males, and highly significant relationships between both BW vs. K_F (r_s = 0.3108 and $p < 0.0001$) for females, as well as BW vs. K_F (r_s = 0.1129 and $p < 0.0001$) for males, respectively (Table 5). The condition factor of a fish encapsulates a multifaceted interplay between physiological factors and feeding conditions, resulting in variations in the physical and biological state of the fish (Le Cren, 1951). It serves as an indicator of fluctuations in food reserves and provides insights into the overall health of the fish (Offem *et al*., 2007; Ullah *et al*., 2022). Furthermore, the condition factor is a fundamental tool in fisheries management, offering precise information concerning the environmental conditions impacting an organism's growth (Froese, 2006). It serves as an index to assess the health of a fish population across various life stages, shedding light on how both biotic and abiotic elements affect the fish's physiological state (Ogunola and Onada, 2017). The Relative Condition Factor (K_R) is an invaluable instrument in fisheries biology, providing a means to assess the overall health of fish populations and elucidating the intricate interplay between fish and their environment (Froese, 2006). It aids in making well-informed decisions for the sustainable management of fisheries resources. The K_R value, typically sought close to 1, acts as a crucial indicator of the health and condition of fish populations. When K_R deviates from this equilibrium, with $K_R > 1$ indicating excellent condition and $K_R < 1$ indicating less favorable conditions, it offers valuable insights into variations in food availability and the impact of physico-chemical factors on the life cycles of fish species (Le Cren, 1951; Kumar *et al*., 2013).

In our study, both male and female populations exhibited K_R values equal to or greater than 1, indicating excellent health. Variations in K_R levels may be attributed to differences in feeding behavior between the genders (Ambily and Nandan, 2010). Importantly, our study revealed that both female and male Hilsa populations displayed Fulton's Condition Factor (K_F) values equal to or exceeding 1, signifying their robust health and well-being (Froese, 2006; Muchlisin *et al*., 2017). The K_F values observed for both sexes of Hilsa in this investigation reflect the presence of a thriving environment and abundant food resources within the waters of Bangladesh. Among the condition factors examined, K_F emerged as the most reliable indicator for evaluating the well-being of the Hilsa population. Notably, it displayed significant correlations with both TL and BW, underscoring the effectiveness of K_F as a valuable metric for assessing the health and condition of Hilsa within the studied regions. Consequently, our study underscores the practicality of employing K_F as a valuable metric for assessing the health and condition of Hilsa within the waters of Bangladesh and its neighboring regions.

Conclusion

The length-frequency distribution, length-weight correlations, and condition indices derived from our investigation offer invaluable insights into both the population dynamics of the Hilsa species and the strategies for its fisheries management. Our analysis of the length-weight relationship revealed positive allometric growth for female Hilsa, while males displayed a negative allometric trend. The assessment of Fulton's condition factor and relative condition factors consistently yielded values equal to or exceeding 1, indicating a favorable state of health among the Hilsa population. This research contributes significantly to our understanding of the Hilsa's current status, serving as a valuable resource for fishery biologists and conservationists seeking effective strategies for the management and preservation of this fish species.

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Authors contribution

Conceptualization, M.A.A. and M.R.U.; methodology, M.A.A. and F.; software, M.H.R. and M.M.; validation, M.A.A., M.T. and M.A.I.; formal analysis, M.A.A., M.T. and M.R.U.; investigation, M.Z.A.; resources, M.A.A.; data curation, M.A.A., F. and M.M.; writing—original draft preparation, M.R.U; writing—review and editing, M.A.A.; visualization, M.A.A. and M.A.I.; supervision, M.A.I. and M.Z.A.; project administration, M.A.A.; funding acquisition, M.A.A. All authors have read and agreed to the published version of the manuscript.

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