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Comparative length-weight relationship and condition factor of hilsa shad *Tenualosa ilisha* (Hamilton, 1822) from freshwater, estuarine and marine environments in India

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ABSTRACT

The hilsa shad *Tenualosa ilisha* (Hamilton, 1822), is a commercially important and highly relished food fish. This paper presents the length-weight relationships (LWR) and condition factor of hilsa, throughout its geographical distribution in India. A total of 910 samples of *T. ilisha*, comprising 404 males and 288 females collected from various locations of east and west coasts of India were used for analyses. Heterogeneity in the LWR of males, females and pooled population was noticed. The regression coefficient (b) ranged from 2.07-3.68 for pooled, 0.75-3.03 for males and 1.78-2.97 for females. The coefficient of determination (R^2) varied between 0.72-0.98 in pooled, 0.73-0.94 in males and 0.76-0.97 in females. Fulton's condition factor (K) ranged from 0.47-3.05 in pooled, 0.47-1.63 in male and from 0.77-3.05 in female samples whereas relative condition factor (Kn) varied from 0.48-2.51 in pooled population, from 0.47-1.56 in males and 0.76-2.33 in females. Mean Fulton's condition factor (K) ranged from 0.7-1.33 in pooled population, 0.92-1.28 in males and from 0.95-1.39 in females whereas the mean relative condition factor (Kn) varied between 0.98-1.04 in pooled population, 0.98-1.04 in males and 0.98-1.03 in females. These parameters (b, K, Kn) have been found useful in evaluating the well-being of different populations of this species. Most of the populations under study showed concordance to ideal value of b, thereby indicating isometric growth. However, significant negative allometric growth was observed for pooled samples from Padma, Hoogly and males from Padma and significant positive allometric growth was observed in the pooled samples collected from Hoogly. Comparative study of recent data with the decadal old data (1999-2000) revealed differences in mean size of the fish. This study also indicates overexploitation of the species in the recent years, which might be due to intensive fishing efforts.

Keywords: Condition factor, East and west coasts of India, Hilsa shad, Length-weight relationships, *Tenualosa ilisha*

Introduction

Tenualosa ilisha (Hamilton 1822), commonly known as hilsa shad, belongs to the sub-family Alosinae, under the family Clupeidae (Talwar and Jhingran, 1991). It has a wide range of distribution and occurs in marine, estuarine and riverine ecosystems. The fish is reported in the Persian Gulf, Red Sea, Arabian Sea, Bay of Bengal, Vietnam Sea and China Sea (Bhaumik, 2013). Hilsa shad is one of the highly valued fishes of the Indo-Pacific region. This clupeid species is of tremendous fishery importance due to its culinary excellence, particularly in Bangladesh, north-eastern and eastern India. Hilsa shad sustained a lucrative fishery in the middle stretch of Ganga which showed declining trend after the commissioning of Farakka Barrage in 1972 (Sinha, 2000; Saha *et al.*, 2011).

Hilsa is the dominant constituent of fishery in the Hooghly-Bhagirathi river system accounting for about 20-25% of total fish landing (Ahsan *et al.*, 2014). During the pre-Farakka Barrage period (1957-1974), the annual landings of this species varied between 114 and 6573 t, with an average of 1427.6 t. But the level of yield increased during the post-barrage period. However, in the recent years, hilsa capture fisheries is at stake due to overexploitation of adults, juveniles and fry (20 mm). Habitat degradation, construction of dams and water diversions, as obvious from the dwindling catches of 15799 t in 2000 to 5530 t in 2010 in the Hooghly estuarine system (Puvanendran, 2013). This necessitated the exercise on the relationship between length and weight with condition factor of this species from various locations for sustainable fisheries management.

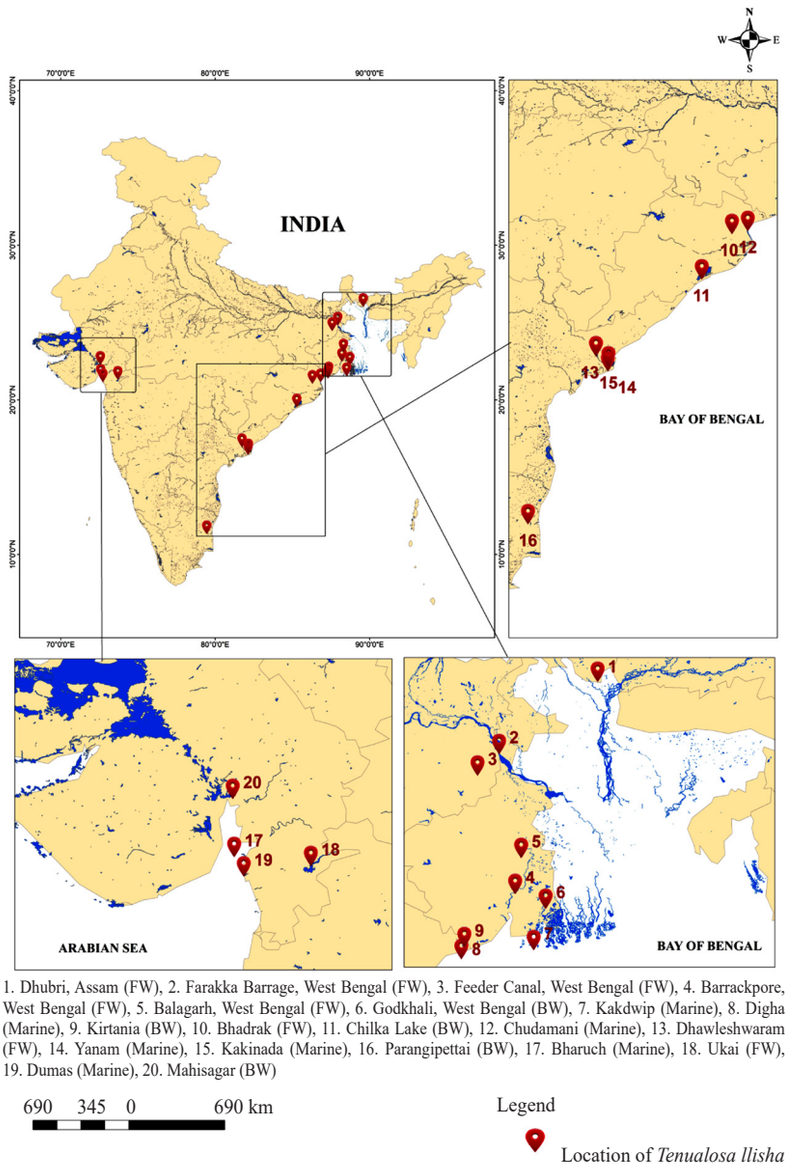
The study on length-weight relationship (LWR) of fish is a practical index appropriate for understanding their survival, growth, maturity, reproduction and general well-being (Le Cren, 1951). The Fulton's condition factor (K) and relative condition factor (Kn) are the important parameters which display the suitability of a specific water

body for growth dynamics of the fish population (Le Cren, 1951). The LWR of *T. ilisha* has been studied by many workers (Ramakrishnaiah, 1972; Shafi and Quddus, 1974; De and Dutta, 1990; Nurul Amin *et al.*, 2005; Bhaumik *et al.*, 2011; Flura *et al.*, 2015). However till date, a comprehensive study on the comparison of LWR among the populations of *T. ilisha* covering its entire geographical distribution range from India is lacking. Therefore, an attempt has been made to compare LWR and condition factor of *T. ilisha* from different locations of freshwater, estuarine and marine environments from the east and west coasts of India.

Materials and methods

Sample collection

The present study is based on the pooled data of 910 *T. ilisha* specimens (404 males and 288 females) from a total of 20 marine, estuarine and freshwater locations, across its distributional range (Fig. 1, Table 1) collected during October - November 1999 and from January 2013 to February 2016. The data studied for October - November 1999 collections were from Lal *et al*. (2004). Small sized fish were also included in the present study as hilsa attains its shape and maturity very early,



1. Dhubri, Assam (FW), 2. Farakka Barrage, West Bengal (FW), 3. Feeder Canal, West Bengal (FW), 4. Barrackpore, West Bengal (FW), 5. Balagarh, West Bengal (FW), 6. Godkhali, West Bengal (BW), 7. Kakdwip (Marine), 8. Digha (Marine), 9. Kirtania (BW), 10. Bhadrak (FW), 11. Chilka Lake (BW), 12. Chudamani (Marine), 13. Dhawleshwaram (FW), 14. Yanam (Marine), 15. Kakinada (Marine), 16. Parangipettai (BW), 17. Bharuch (Marine), 18. Ukai (FW), 19. Dumas (Marine), 20. Mahisagar (BW)

Fig. 1. Sample collection sites of *Tenualosa ilisha* (For exact GPS coordinates, refer to Table 1)

Table 1. Description of collection localities, number of samples and size statistics of *T. ilisha* (Pooled including male and female; N = number of samples)

Ecosystem	Site	Coordinates	Time of collection	Sex	N	Length (mm)		Weight (g)	
						Range	Mean±SD	Range	Mean±SD
Brahmaputra River	Dhubri, Assam (FW)	N 26° 01', E 89° 58'	Nov. 2015	Female	09	285.00-320.00	297.56±13.09	239.00-370.00	277.44±39.45
Padma River	Farakka Barrage, West Bengal (FW)	N 24° 80', E 87° 93'	Nov. 1999	Pooled	90	225.00-510.00	381.94±66.62	150.00-1450.00	661.67±320.73
				Male	35	225.00-435.00	350.71±57.34	150.00-850.00	470.00±209.06
				Female	55	260.00-510.00	401.82±64.89	200.00-1450.00	783.64±321.03
			Dec. 2013	Male	29	210.00-335.00	254.72±31.56	105.00-348.00	157.79±61.92
			Nov. 2015	Pooled	85	165.00-300.00	204.52±25.02	40.00-280.00	81.41±33.19
				Male	82	167.00-300.00	204.73±24.88	44.00-280.00	81.40±32.93
				Female	03	165.00-233.00	198.67±34.00	40.00-135.00	81.67±48.56
Hooghly River	Feeder Canal, West Bengal (FW)	N 24° 44', E 87° 57'	Oct. 1999	Pooled	50	270.00-490.00	383.10±62.48	200.00-1500.00	719.00±329.17
				Male	18	270.00-410.00	345.83±48.64	200.00-800.00	491.67±201.65
				Female	32	285.00-490.00	404.06±60.11	300.00-1500.00	846.88±319.51
	Barrackpore, West Bengal (FW)	N 22° 46', E 088° 20'	Oct. 1999	Pooled	95	272.00-566.00	356.26±53.75	200.00-2100.00	550.53±290.20
				Male	32	272.00-445.00	333.78±43.60	225.00-900.00	414.06±184.47
				Female	63	275.00-566.00	367.68±55.10	200.00-2100.00	619.84±310.12
	Balagarh, West Bengal (FW)	N 23° 06', E 88° 30'	April 2013	Pooled	12	280.00-380.00	331.83±31.00	245.00-685.00	447.08±143.92
				Male	07	280.00-345.00	313.71±23.77	245.00-450.00	349.43±75.87
				Female	05	325.00-380.00	357.20±20.38	440.00-685.00	583.8090.94
			April 2015	Pooled	22	230.00-395.00	273.59±36.46	103.00-475.00	202.77±88.92
				Male	17	230.00-308.00	263.29±21.80	103.00-298.00	173.94±52.67
				Female	05	262.00-395.00	308.60±55.63	184.00-475.00	300.80±121.92
	Godkhali, West Bengal (BW)	N 22° 21', E 88° 71'	Aug. & Sep. 2013	Pooled	71	245.00-505.00	296.59±38.31	163.00-1438.00	292.07±165.58
				Male	68	245.00-387.00	292.32±28.42	163.00-614.00	269.38±84.88
				Female	03	320.00-505.00	393.33±98.28	421.00-1438.00	806.33±551.44
			March-April 2015	Pooled	32	178.00-394.00	263.34±35.23	52.00-753.00	212.65±117.91
				Male	21	178.00-310.00	252.43±28.68	52.00-281.00	159.71±55.81
				Female	11	240.00-394.00	278.09±41.57	146.00-753.00	271.54±166.87
Bay of Bengal	Kakdwip (Marine)	N 21° 52', E 88° 51'	February 2016	Pooled	28	220.00-340.00	259.82±27.37	98.00-348.00	182.21±57.67
				Male	20	220.00-340.00	256.50±31.21	98.00-348.00	170.00±60.84
				Female	8	240.00-290.00	268.12±11.63	150.00-276.00	212.75±35.90
	Digha (Marine)	N 21° 37', E 87° 30'	August 2013	Pooled	25	223.00-420.00	266.72±52.87	120.00-933.50	252.98±210.05
				Male	04	241.00-355.00	279.75±51.94	150.00-530.00	270.00±178.26
				Female	07	223.00-420.00	300.29±81.45	120.00-933.50	397.50±342.04
	Kirtania (BW)	N 22° 28', E 87° 04'	August 2013	Pooled	36	200.00-350.00	282.42-36.63	152.00-537.00	304.03±107.41
				Male	13	240.00-340.00	299.08±35.26	160.00-537.00	354.08±114.75
				Female	20	200.00-350.00	275.20±36.40	152.00-522.00	288.55±94.27
Baitrani River	Bhadrak (FW)	N 21° 03', E 86° 29'	June 2014	Pooled	25	278.00-368.00	315.08±20.60	284.00-526.00	363.04±55.86
				Male	04	278.00-315.0	297.50±16.05	284.00-367.00	319.25±35.42
				Female	21	285.00-368.00	318.43±19.92	300.00-526.00	371.38±55.67
Estuary	Chilka Lake (BW)	N 19° 51', E 85° 28'	March 2015	Pooled	25	105.00-249.00	212.56±32.63	9.50-115.00	71.58±27.31
Bay of Bengal	Chudamani (Marine)	N 21° 08', E 86° 47'	June 2013	Pooled	27	272.00-365.00	318.70±24.21	250.00-495.50	375.61±74.45
				Male	20	283.00-363.00	320.15±19.31	261.00-495.50	383.18±62.27
				Female	04	272.00-365.00	316.25±40.80	250.00-493.00	365.75±106.00
			February 2014	Pooled	18	335.00-445.00	365.11±27.40	428..00-878.00	566.89±100.69
				Male	5	340.00-445.00	372.40±42.76	500.00-627.00	552.8±54.72
				Female	08	335.00-410.00	366.88±25.06	428.00-878.00	582.38±145.54
Godavari River	Dowleswaram (FW)	N 16° 56', E 81° 45'	April 2013	Pooled	23	210.00-390.00	344.30±46.08	91.00-723.00	530.15±180.60
				Female	10	345.00-390.00	369.5±14.42	658.00-723.00	658.00±51.83
	Yanam (Marine)	N 16° 43', E 82° 13'	April 2013	Pooled	55	182.00-242.00	201.63±11.46	76.00-170.00	102.35±18.69
	Kakinada (Marine)	N 16° 59', E 82° 15'	May 2013	Female	05	375.00-415.00	397.00±15.25	587.00-817.00	738.40±92.39
			August 2014	Pooled	20	210.00-490.00	305.43±7.09	75.00-1530.50	335.55±346.69
Vellar Estuary	Parangipettai (BW)	N 11° 30', E 79° 45'	April 2014	Pooled	26	320.00-450.00	391.88±31.68	341.00-982.00	692.65±165.44
				Male	06	410.00-430.00	419.17±7.48	709.00-908.00	804.00±78.35
Narmada Estuary	Bharuch (Marine)	N 21° 42', E 72° 59'	January 2013	Pooled	27	88.00-160.00	135.85±18.41	6.00-41.00	28.89±10.31
			September 2014	Pooled	25	282.00-440.00	354.88±31.08	245.00-1000.00	505.10±143.14
				Male	23	282.00-380.00	349.00±23.97	245.00-665.00	471.22±79.63
				Female	02	405.00-440.00		789.5-1000	
Tapti River	Ukai (FW)	N 21° 14', E 73° 34'	January 2013 & January 2015	Pooled	46	83.00-275.00	169.83±33.33	5.00-222.00	51.70±37.34
Arabian Sea	Dumas (Marine)	N 21° 06', E 72° 42'	September 2014	Female	14	350.00-450.00	402.50±30.05	625.00-975.00	821.57±102.26
Mahisagar Estuary	Mahisagar (BW)	N 23° 11', E 73° 33'	January 2013	Pooled	41	132.00-174.00	141.15±7.30	22.00-54.00	28.83±5.44

*BW - Brackishwater, FW- Freshwater

at approximately 20 cm total length (Bhaumik and Sharma, 2012). For each individual, total length (from the tip of snout to the extended tip of the caudal fin) was measured using digital calipers (Mitutoyo, America, USA) close to 0.01 mm and body weight was taken on a digital balance (Acculab Sartorius Group, 0.01 g accuracy). The size of fish ranged from 83 to 566 mm and 5 to 2100 g. Sex was identified by observing the gonads after dissecting the fish at the site of collection.

Statistical analysis

The length-weight relationship (LWR) between total length (mm) and body weight (g) was determined through the parameters, a and b, estimated by linear regression on the transformed equation (Le Cren, 1951). The coefficient of determination (R^2) was calculated following standard statistical procedure (Snedecor and Cochran, 1967). One-way ANOVA was performed on log data of length and weight for each location. The Fulton's condition factor (K) is an index of well being of fish (Fulton, 1904).

The relative condition factor (Kn) compensates for changes in form or condition with increase in length, and was calculated following Le Cren (1951). All the calculations were done using Microsoft Office Excel (2010) and SPSS 16 (IBM, 2013). Paired t-test was done in SPSS 16 to test the significance of b value.

Results

Length-weight relationships (LWR), Fulton's condition factor (K) and relative condition factor (Kn) estimated for sexes pooled (comprised indeterminate and both sexes) and separately for males and females are shown in Table 2. Samples from a few sites were not used in the analysis due to insufficient sample size of male or female fish. The coefficient of determination calculated from linear regressions of different populations were highly significant ($p<0.01$), except in pooled samples of Chudamani (February 2014).

The overall value of R^2 ranged from 0.72-0.98 in pooled, 0.73-0.94 in males and 0.76-0.97 in females. In freshwater, high correlation ($R^2>0.9$) was observed in pooled samples of Padma River (Farakka, November 1999), Feeder Canal (October 1999) and Hoogly (Barrackpore, October 1999 and Balagarh, April 2015). In males, high R^2 value was observed in Feeder Canal (October 1999) and Hoogly (Barrackpore, October 1999) whereas in females from Padma River (Farakka, November 1999), Feeder Canal (October 1999) and Hoogly (Barrackpore, October 1999).

In east coast, high correlation was observed in pooled samples of Godakhali (March-April, 2015), Digha (August 2013), Chilka Lake (January 2015), Chudamani (June 2013), Godavari (Dowleswaram, April 2013) and Kakinada (August 2014). In males, high R^2 value was noticed in Godakhali (March-April, 2015). Similarly, from west coast, pooled samples of Narmada River (Bharuch, January 2013) and Ukai Reservoir (January 2013 and January 2015) showed high correlation.

The regression coefficient (b) ranged from 2.07-3.68 for pooled, 0.75-3.03 for males and 1.78-2.97 for females. Samples from majority of riverine, brackishwater and marine locations showed isometric growth (b=3), except in five populations. In freshwater, four populations were noticed to be significant ($p<0.01$) for negative allometric growth ($b<3$) in paired t-test, *i.e.,* in pooled population of Padma (Farakka, November, 1999 and 2015), Hoogly (Godakhali, August-September, 2013) and males from Padma (Farakka, November, 2015). Significant positive allometric growth ($b>3$) was observed in the pooled samples collected from Hoogly (Barrackpore, October 1999).

Fulton's condition factor (K) ranged from 0.47-3.05 in pooled, 0.47-1.63 in male and from 0.88-3.05 in female samples whereas relative condition factor (Kn) varied from 0.48-2.51 in pooled population, from 0.47-1.56 in males and 0.76-2.34 in females. Mean Fulton's condition factor (K) ranged from 0.7-1.33 in pooled population, 0.92-1.16 in males and from 1.13-1.39 in females whereas the mean relative condition factor (Kn) varied between 0.98-1.04 in pooled population, 0.98-1.04 in males and 0.98-1.03 in females. Analysis of variance (ANOVA) of mean K and mean Kn revealed that samples of different locations are not significantly different in pooled, male and female samples. Linear regression plot on LWR also supports the results of K and Kn, which clearly indicates that pooled, male and female samples of different locations are not significantly different (Fig. 2).

Seasonal variation in b value

The variations in *'b'* values for pooled and males in different populations during winter and monsoon seasons is displayed in Fig. 3. The values of monsoon and winter runs of Chudamani from east coast and Bharuch from west coast did not deviate from 3, while that of Godkhali from monsoon run only showed negative allometry ($b<3$, $p<0.01$, Table 2).

Spatial and temporal variation in growth parameters

For a few locations, *i.e.,* Padma at Farakka Barrage, and Hoogly at Barrackpore, a comparison of present data with past data has also been done. Pooled samples from Farakka Barrage showed significant negative allometric growth ($b<3$, $p<0.01$) in both the samples collected during November 1999 as well as November 2015 samples.

Table 2. Parameters of length-weight relationship and condition factor among various populations of *T. ilisha* (*on b denotes significance from 3 (** on R^2 denotes significance, $p<0.01$). Analyses of LWR, K and Kn were done only for the samples for which sample size was deemed sufficient

Ecosystem	Site	Time of collection	Sex	Length-weight relationship			Fulton's condition factor (K)		Relative condition factor (K_n)	
				a	*b*	R^2	Range	Mean±SD	Range	Mean±SD
Padma River	Farakka Barrage, West Bengal	Nov. 1999	Pooled	0.00001288	2.97*	0.94**	0.66-1.51	1.09±0.15	0.62-1.38	1.01±0.13
			Male	0.00006166	2.69	0.89**	0.66-1.51	1.03±0.17	0.68-1.36	1.02±0.16
			Female	0.00001380	2.97	0.97**	0.93-1.35	1.13±0.11	0.80-1.17	0.98±0.09
		Dec. 2013	Male	0.00067608	2.22	0.73**	0.58-1.63	0.94±0.19	0.66-1.56	1.04±0.17
		Nov. 2015	Pooled	0.00006456	2.63*	0.88**	0.47-1.13	0.92±0.10	0.59-1.33	1.02±0.11
			Male	0.00008317	2.58*	0.87**	0.47-1.13	0.92±0.10	0.61-1.37	1.03±0.11
Hooghly River	Feeder Canal, West Bengal	Oct. 1999	Pooled	0.000011749	3.00	0.95**	0.87-1.42	1.19±0.13	0.74-1.21	1.01±0.11
			Male	0.000019054	2.91	0.90**	0.87-1.41	1.13±0.16	0.79-1.24	1.01±0.14
			Female	0.000025704	2.87	0.97**	0.94-1.42	1.22±0.10	0.81-1.21	1.03±0.08
	Barrackpore, West Bengal	Oct. 1999	Pooled	0.000008128	3.05*	0.91**	0.80-2.72	1.13±0.20	0.74-2.52	1.04±0.19
			Male	0.000012882	2.96	0.92**	0.80-1.23	1.06±0.11	0.77-1.18	1.01±0.11
			Female	0.000015488	2.95	0.90**	0.88-2.72	1.17±0.23	0.76-2.34	1.02±0.19
	Balagarh, West Bengal	April 2015	Pooled	0.000012303	2.95	0.92**	0.77-1.14	0.95±0.10	0.84-1.22	1.02±0.11
	Godakhali, West Bengal	Aug. & Sep. 2013	Pooled	0.000025704	2.84*	0.88**	0.49-1.29	1.06±0.11	0.48-1.26	1.03±0.11
			Male	0.000093324	2.62	0.82**	0.49-1.29	1.06±0.11	0.47-1.22	0.98±0.10
		March-April 2015	Pooled	0.002570396	3.39	0.93	0.81-1.27	1.03±0.13	0.81-1.25	1.00±0.12
			Male	0.057543994	3.03	0.94	0.81-1.15	0.95±0.08	0.80-1.25	1.00±0.09
Bay of Bengal	Kakdwip	February 2016	Pooled	0.000162181	2.50	0.78**	0.73-1.37	1.02±0.14	0.74-1.30	1.01±0.13
			Male	0.000275423	2.40	0.84**	0.73-1.26	0.99±0.14	0.77-1.19	1.01±0.12
	Digha	August 2013	Pooled	0.000005128	3.15	0.98**	0.96-1.48	1.16±0.10	0.82-1.25	0.98±0.08
	Kirtania	August 2013	Pooled	0.000338844	2.42	0.82**	1.00-3.05	1.33±0.31	0.77-1.94	1.02±0.19
			Female	0.003388442	2.02	0.76**	1.20-3.05	1.39±0.40	0.80-1.62	0.99±0.17
Baitrani River	Bhadrak	June 2014	Pooled	0.002454709	2.07	0.84**	0.97-1.32	1.16±0.10	0.89-1.15	0.99±0.06
			Female	0.002511886	2.06	0.80**	0.97-1.32	1.15±0.10	0.92-1.19	1.03±0.07
Estuary	Chilka lake	January 2015	Pooled	0.0000107152	2.92	0.96**	0.54-0.86	0.70±0.08	0.77-1.23	1.01±0.11
Bay of Bengal	Chudamani	June 2013	Pooled	0.000128825	2.58	0.91**	1.01-1.30	1.15±0.08	0.88-1.14	1.00±0.06
			Male	0.000120226	2.59	0.87**	1.04-1.30	1.16±0.08	0.94-1.15	1.03±0.06
		February 2014	Pooled	0.0004295	2.75	0.77	1.04-1.36	1.18±0.10	0.84-1.37	1.03±0.14
Godavari River	Dowleswaram	April 2013	Pooled	0.00000354813	3.21	0.95**	0.95-1.46	1.23±0.14	0.81-1.28	1.02±0.12
	Yanam	May 2013	Pooled	0.0000331131	2.81	0.82**	1.08-1.60	1.24±0.09	0.89-1.32	1.02±0.08
	Kakinada	August 2014	Pooled	0.00000051286	3.50	0.98**	0.74-1.30	0.92±0.14	0.87-1.21	1.04±0.10
Vellar Estuary	Parangipettai	April 2014	Pooled	0.000025704	2.86	0.82**	0.96-1.48	1.13±0.13	0.85-1.32	1.02±0.12
Narmada Estuary	Bharuch	January 2013	Pooled	0.000000380189	3.68	0.93**	0.64-1.34	1.08±0.18	0.74-1.29	1.01±0.16
		September 2014	Pooled	0.0000446684	2.76	0.88**	0.88-1.30	1.11±0.10	0.82-1.14	1.02±0.09
			Male	0.000398107	2.39	0.82**	0.88-1.30	1.10±0.10	0.83-1.14	0.98±0.08
Tapti River	Ukai	January 2013 & January 2015	Pooled	0.0000026915	3.24	0.97**	0.65-1.22	0.92±0.12	0.76-1.26	1.00±0.12
Estuary	Mahisagar	January 2013	Pooled	0.0000251189	2.82	0.72**	0.87-1.22	1.02±0.09	0.85-1.17	0.99±0.09

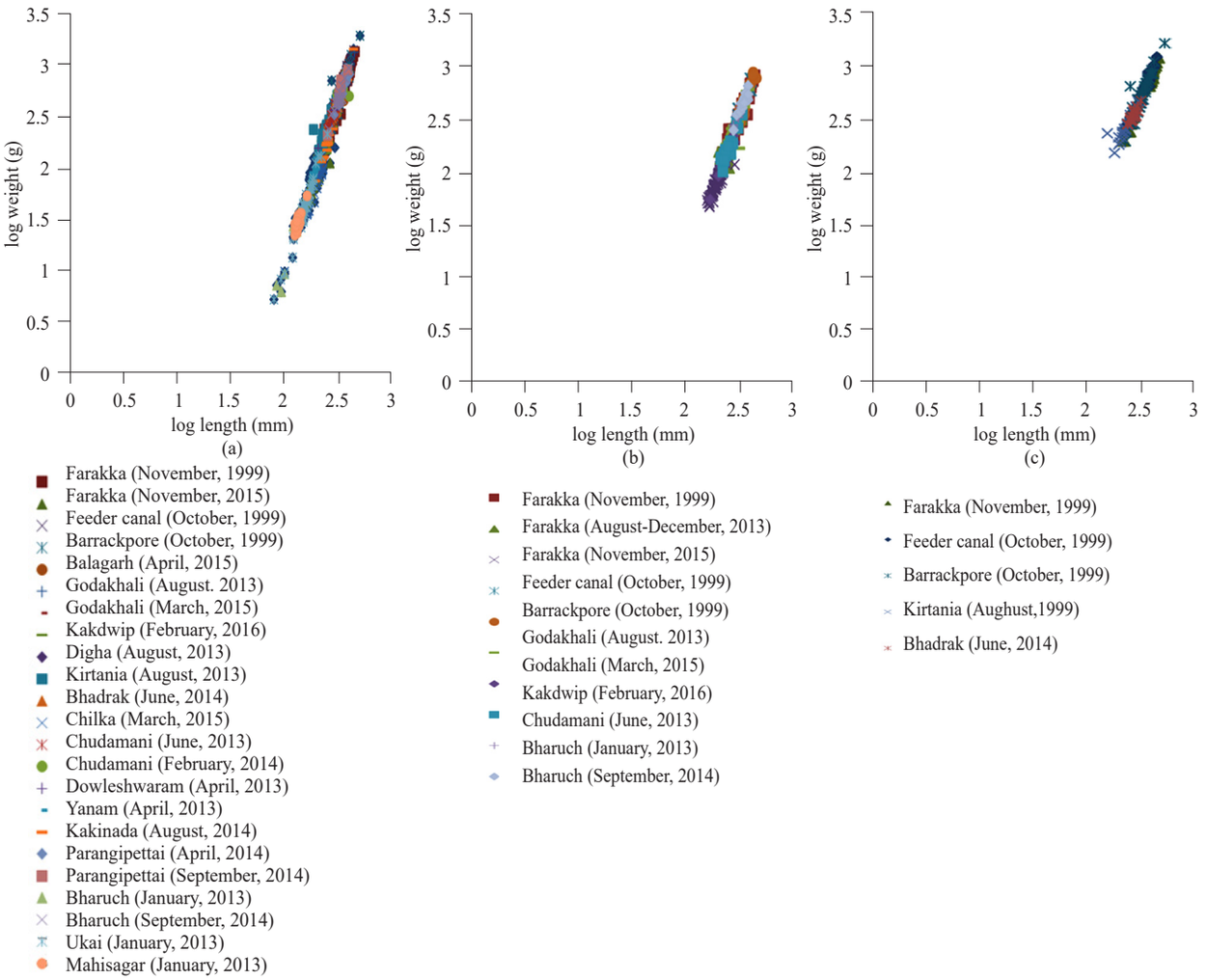


Fig. 2. Least-squares regression of $\log_{10}W$ $\log_{10}TL$ of (a) pooled, (b) male and (c) female of *Tenualosa ilisha* in freshwater, estuarine and marine ecosystems of India

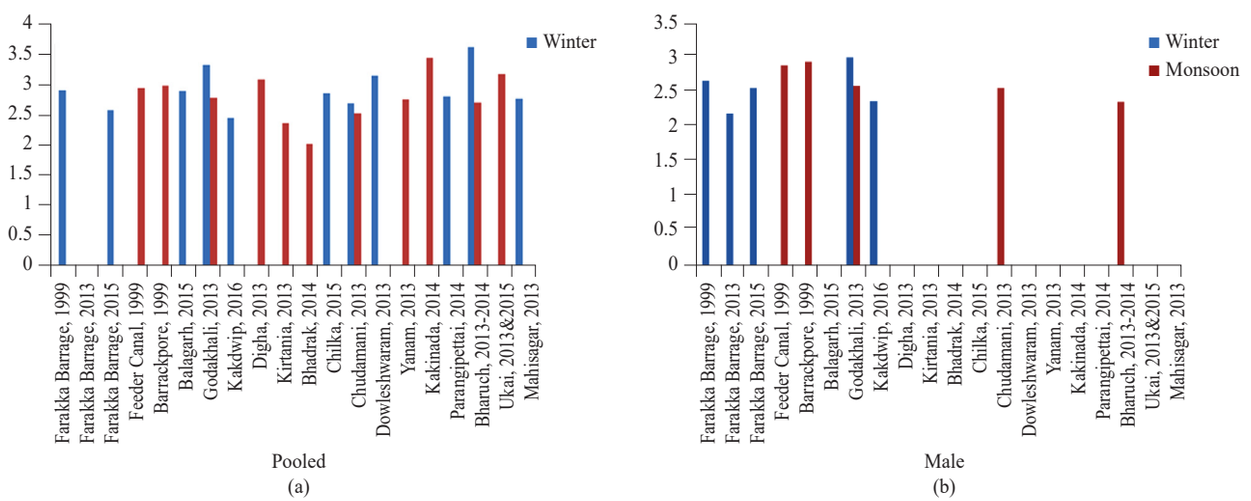


Fig. 3. Growth equation changes in 'b' values of (a) pooled and (b) male of *Tenualosa ilisha* in freshwater, estuarine and marine environments of India

From two locations for Hoogly River, *i.e.,* pooled samples from Feeder canal collected during October 1999 showed isometric growth (b=3.00) whereas significant positive allometric growth was noted in Barrackpore (b=3.05, p<0.01) in pooled samples collected during October 1999.

Discussion

The study of LWR is a widely applied approach in fisheries management as it provides information on stock condition (Bagenal and Tesch, 1978). Although a good number of fragmented studies have been documented, comparative study on LWR and K among several wild populations of hilsa shad from India is lacking. In this study, heterogeneity in the LWR was noticed in pooled populations, males and females. Exponential value '*b*' of the LWR normally falls between 2.5 and 4.0 (Martin, 1949). In terms of growth pattern, a value close to three follows the cube law indicating that the fish grows isometrically and other values indicate allometric growth (Bagenal and Tesch, 1978). In the present study, most of the populations showed concordance to ideal value of 'b', thereby indicating isometric growth indicating the fish is maintaining a constant body shape (Sunil Kumar *et al.*, 1999). However, negative allometric growth was observed for pooled samples from Padma (Farakka, November, 1999; 2015), Hoogly (Godakhali, August-September 2013) and males from Padma (Farakka, November 2015). Significant positive allometric growth (b>3) was observed in the pooled samples collected from Hoogly (Barrackpore, October 1999). According to Ricker (1958), such deviations are common. The observation of seasonal variation, *i.e.,* negative allometric condition of monsoon runs of Godakhali samples as compared to that of winter run may be attributed to the maturity stages, in peak spawning season (Nurul Amin *et al.*, 2005).

The R^2 values for most of the sites from east coast revealed the proper fit of the model for growth. High correlation R^2 (>0.9) demonstrated a strong relationship between the length and weight, which was observed in many populations of this species. Values of 'b' and R^2 from the Padma at Farakka collected in November 1999 and November 2015 are concordant to the values of b=3.04 and R^2 =0.90 reported from river Meghna in Bangladesh by Flura *et al.* (2015) as well as to the values of b=3.38 and R^2=0.93 reported from different landing centers of Bangladesh by Nurul Amin *et al.* (2005). The possible reason could be that hilsa migrates from the Bay of Bengal to upstream rivers: the Padma, Meghna and other rivers of Bangladesh for breeding (Miah, 2015). However, values of 'b' and R^2 of male samples from Farakka (November, 2015) showed negative allometric growth, which can be related to the peak spawning period of *T. ilisha* and the collection site was the spawning ground in Padma River. De and Datta (1990) reported value of 'b' as 2.81-2.91 and R^2 as 0.98 and Bhaumik *et al.* (2011) observed the value of 'b' to be 2.57; 3.20 and 3.11 and R^2 to be 0.88; 0.95 and 0.93 for male, female and pooled samples, respectively from river Hooghly, which is in agreement with that of different populations of the river Hooghly, in the present study.

Pooled data of Narmada (Bharuch, January 2013) showed b value of 3.68 and R^2 of 0.93 whereas in September 2014, 'b' value of 2.76 and R^2 of 0.88 was detected. This may be correlated with the variation in sizes and maturity stages during two time periods of collection, *i.e.,* in January 2013, mean weight was 135.85 g and were immature, while in September 2014, mean weight was 354.88 g and were mature. Similar results were reported by Roomiani *et al.* (2014) in the studies of length-weight relationship of hilsa from landing centers of Persian Gulf as well as from Arvand and Bahmanshir rivers in Iran.

Mean Fulton's condition factor (K) for all populations except for the pooled data of Chilka Lake was above 0.9, whereas mean relative condition factor (Kn) was above 0.98. Most of the populations showed Kn value greater than 1 which indicates good general condition of fish (Le Cren, 1951). Minimum mean K was observed for Chilka Lake (March 2015) which might be attributed to small sample size. Better growth condition was observed in various populations for sexes pooled data and for females of Kirtania (August 2013), which might be attributed to better environmental conditions, feeding intensity, maturity and spawning periodicity (Le Cren, 1951). Welcome (1979) opined that condition factor decreases with decline in length and is also influenced by the reproductive cycle in fish. The 'condition' or well-being of fish is determined by Kn-factor is based on the hypothesis that heavier fish for a given length are in better condition (Bagenal and Tesch, 1978).

Temporal variation in growth parameters

A comparative study of recent data with past data (1999-2000) revealed that pooled samples from Farakka Barrage showed significant negative allometric growth in both the samples collected during November 1999 as well as November 2015 samples which may be attributed to the spawning season in both the collection period. However, differences in mean size of the fish from both collection were observed, *i.e.,* comparatively bigger size samples were available during November 1999 than those collected during November 2015. Moreover, there was a good number of female samples during November 1999. Probably, this also indicates overexploitation of the species

in the recent years, which might be due to intensive fishing efforts (BOBLME, 2010; Bhaumik and Sharma, 2012). The mean length of hilsa has also been reported to drop from 356 mm in 1960s to 300 mm or even less in 2000s, as a result of increased efforts, displaying over-fishing (Bhaumik and Sharma, 2012).

The LWR and K are crucial parameters for understanding the well-being of the fish species in a particular habitat. This study provides the first comprehensive information on length-weight parameters for *T. ilisha*, all across its distribution range in India. The indication of overexploitation due to intensive fishing efforts demands management strategies, including its stock assessment for sustainable hilsa fishery in the region.

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