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Studies on length-weight relationship, condition factors and length-length relationship of *Anguilla bengalensis bengalensis*, Gray, 1831 (Actinopterygii, Anguillidae) collected from River Mayurakshi, Siuri, Birbhum, West-Bengal, India

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Abstract
Length-weight, length-length relationships and condition factors are the most important aspects to assess the growth, maturity and well-being of fish population. These are also helpful for scientific management of fisheries and stock assessment.

To assess the above mentioned criteria, length-weight relationship was studied in size groups of *Anguilla bengalensis bengalensis*, a freshwater catadromous mottled eel of Indian subcontinent. The results show highly significant relationship in all the size groups. The 'b' value of the exponential equation shows positive allometric growth in all the three juvenile size groups while negative allometric growth is observed in the largest size group.

Results of regression analysis of total length vs. anodorsal length and total length vs. head length show highly positive significant correlation. Multivariate regression analysis of body weight on anodorsal and total length shows a perfect significant linear relationship.

Condition factor, relative condition factor and modified condition factor of all the size groups shows that the earlier stages of *A.bengalensis bengalensis* are in good condition in respect to growth but in the largest size group, weight gain is minimum relative to growth.

From the entire study it is to be concluded that like all non-migratory fishes the results of juvenile stages of *A. bengalensis bengalensis* show normal allometric growth and hence the fishes are in good condition. But due to unavailability of spawning ground, far reaches from sea, this catadromous fish lacks gonadal differentiation and development and hence negative allometric growth is observed in the largest size group.

Keywords: Allometric growth, anodorsal length, 'b' value, catadromous migration, multivariate regression

Introduction
Anguilla bengalensis bengalensis, Gray, 1831, a freshwater mottled eel is widely distributed in the Indian subcontinent [1-7]. This fish has an endangered status in India [8, 9], hence the present workers feel a need to study for adequate management of the species concern, where length-weight relationship along with condition factor, length-length relationship and growth are considered as important tools, as these tools were considered by a good section of eminent research workers for any fish [6, 10-15].

Computing mathematical relationship between length and weight of fish is an important aspect of applied fishery biology [16-18]. Length-weight relationship is used on commercial scales in population assessments [19, 20]. So several authors were interested in studying the length-weight relationship on various fish species [21-27].

As *Anguilla bengalensis bengalensis* is the most common eel in Indian inland water [28] and has a high commercial value due to high export markets for both live elvers (eel larvae) and large eels [5, 29], used as food fish [5] and have high nutritional value [29], the present workers badly need to study the length-weight analysis along with condition factors, length-length relationship of the above mentioned species for understanding of well-being of population, their biology for scientific management of fisheries and stock assessment.

Materials and Methods

Fifty-two specimens of different size-groups (168-340 mm. in length) were collected from Tilpara Barrage on Mayurakshi river at Siuri (87°32′00″E, 23°55′00″N) (Fig.1.), district Birbhum, West-Bengal, India during the rainy season, 2017. Due to incessant rain at Siuri and in the upper reaches of river Mayurakshi, freshwater mottled eels were collected by a local fisherman from the massive influx of water and the present workers collected the specimens in living condition from that very fisherman. The specimens were then preserved in 8% formaldehyde solution. After that measurements were taken within four days of preservation.

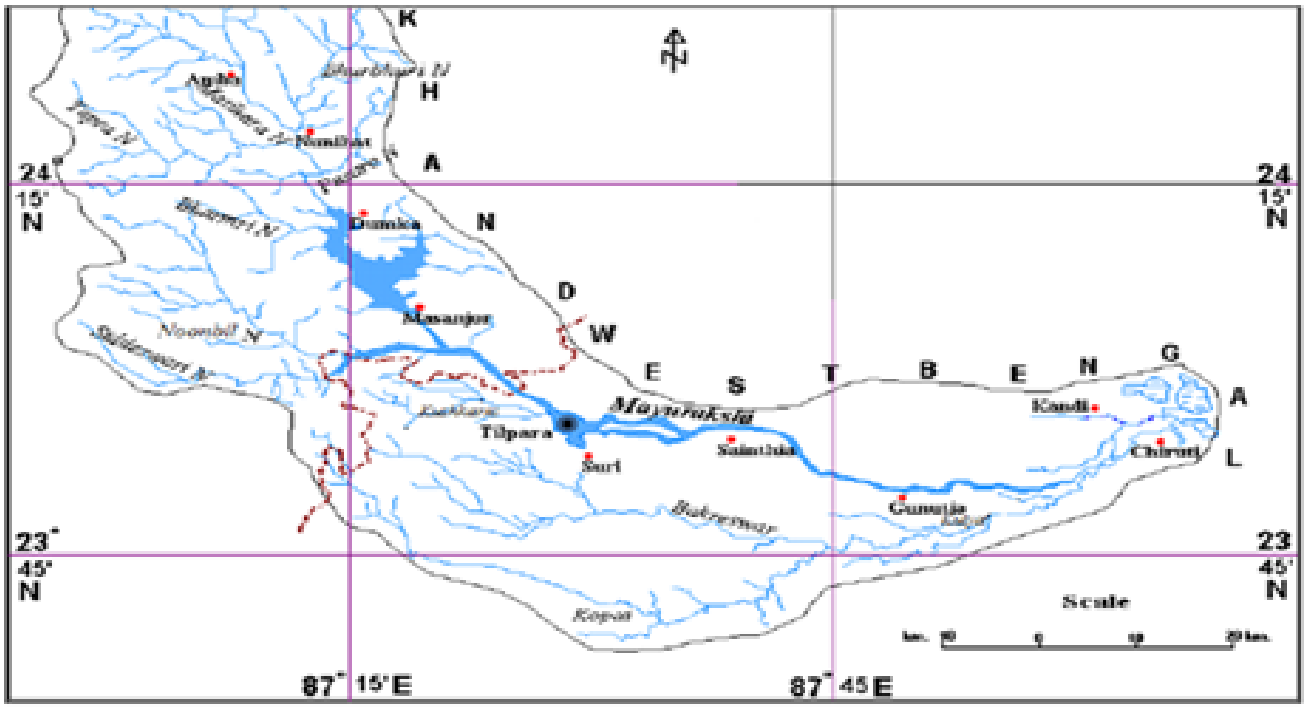

Fig 1: Collection site at Tilpara Barrage on Mawrakshi River.

Length-weight ratio of *Anguilla bengalensis bengalensis* was determined from the general formula,

$W = aL^b$

in its logarithmic form, viz. Log W = log a + b log L

where, W = weight in gram,

L = length in mm.

a = coefficient related to body form

and b = exponent.

The condition factor, K and the relative condition factor, K_n were calculated from the equation of LeCren [30],

$K = W \times 100/L^3$

$K_n = W/w$

Where, W = weight in grams.

L = length in mm.

And w = calculated weight of fish in grams.

Modified condition factor was also determined to assess the expected growth of fish.

I_{FD} is considered to be specific and key character for discrimination for *Anguilla* sp. [31], so correlation in between anodorsal length and total length was considered along with head length and total length.

Statistical analyses were done to find out correlations in between different parameters.

Bivariate regression analyses were done on length-weight relationship. A multivariate regression was also designed to know the relationship in between dependent variable weight and two independent variables i. e. anodorsal length (ADL) and total length (TL). Here, weight is predictant and two lengths are predicators. Bivariate regression analyses were also determined in between TL and ADL and in between TL and HL (head length) to correlate length-length relationship.

Results

In the present study, a total number of fifty-two specimens (sample size) were categorized into four major groups: Gr.1. (up to 199 mm i.e. elvers), Gr.2. (200-249mm), Gr.3. (250-299mm) and Gr.4.(>300mm). Regression analyses were done in between logarithm of total length (TL) and logarithm of weight (Wt) of each group and of pooled data of the sample. Graphical representations were given (Fig 2, 3, 4, 5 and 6) and the results of the regression analyses were given in Table 1. All the analyses showed significant variations.

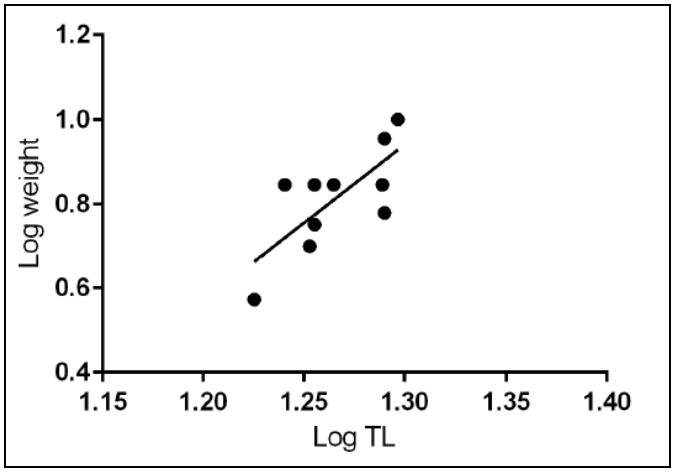

Fig 2: Regression of log weight on log length in size Group 1(r^2=0.5435).

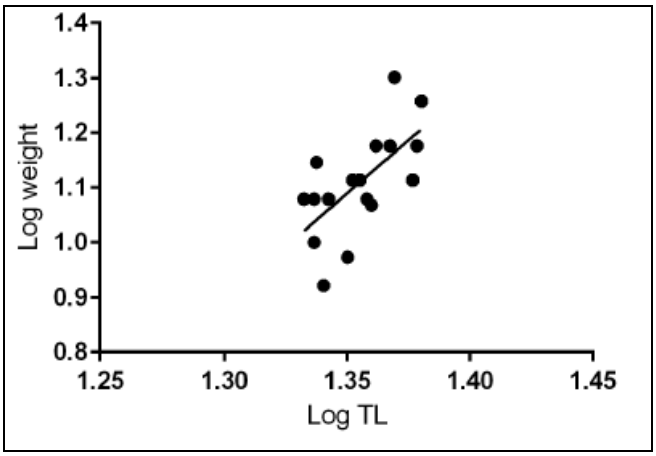

Fig 3: Regression of log weight on log length in size Group 2 (r^2= 0.4164).

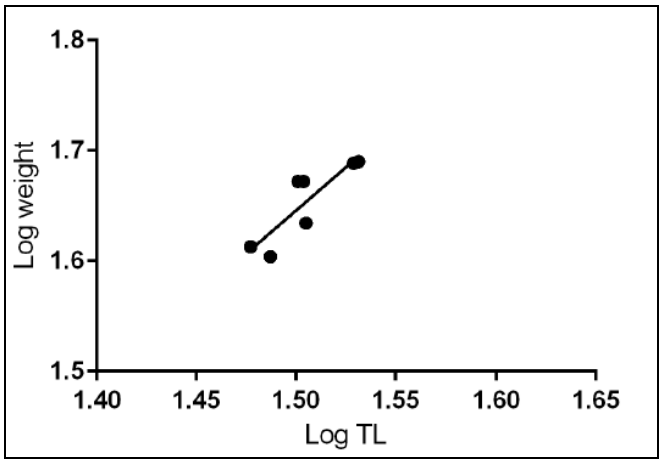

Fig 5: Regression of log weight on log length in size Group 4 (r^2= 0.7541).

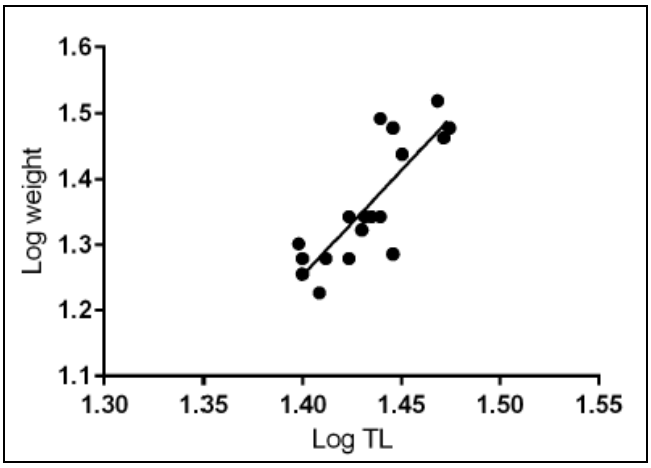

Fig 4: Regression of log weight on log length in size Group 3 (r^2= 0.6810).

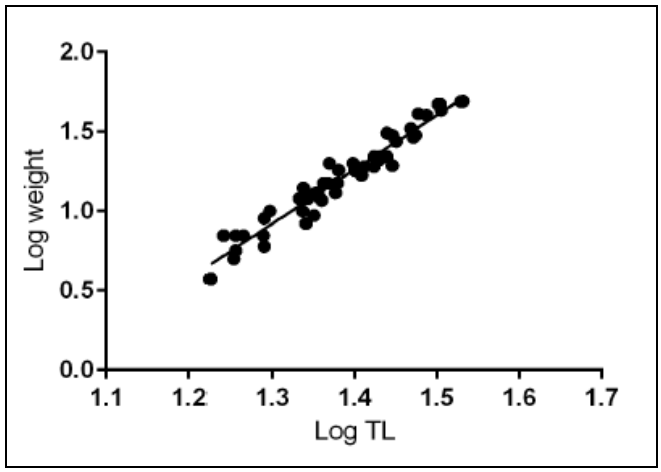

Fig 6: Regression of log weight on log length of pooled data (r^2= 0.9450).

Table 1: Statistical data of length-weight relationship of *A. bengalensis bengalensis*.

Parameters	Size group				Pooled data
	1	2	3	4	
Exponential equation	Wt= 0.000132(TL)$^{3.71}$	Wt=0.0000692(TL)$^{3.89}$	Wt= 0.000631(TL)$^{3.18}$	Wt= 0.1995(TL)$^{1.57}$	Wt= 0.000302(TL)$^{3.41}$
Regression equation	logW=3.708logTL− 3.880	logW=3.887logTL− 4.158	logW=3.184logTL− 3.204	logW=1.565logTL− 0.7014	logW=3.414logTL− 3.516
Regression coefficient	0.5435	0.4164	0.6810	0.7541	0.9450
Regression probability	P<0.0150	P<0.0051	P<0.0001	P<0.0112	P<0.0001

Comparative analyses of condition factor, relative condition factor and modified condition factor of the four groups are presented in Table 2. and a graphical representation is given in Fig. 7.

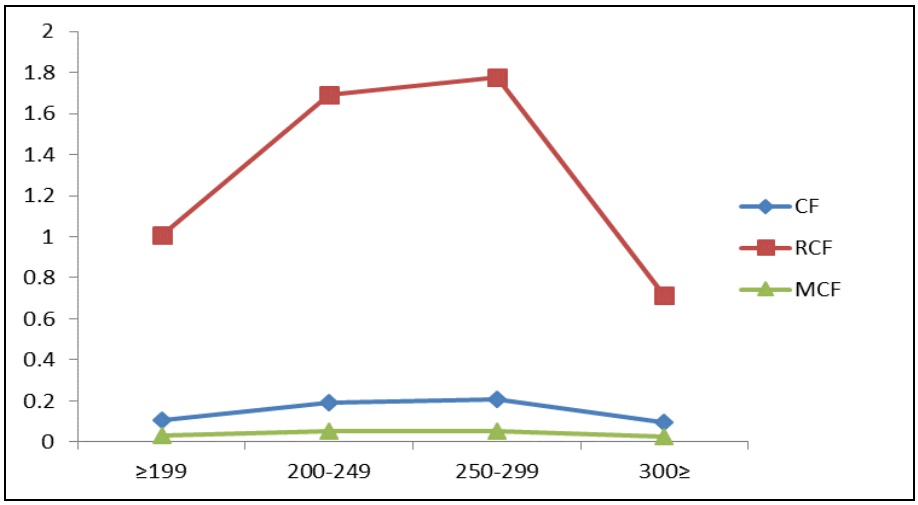

Fig 7: Graphical representation of condition factor (CF, K), relative condition factor (RCF, K_n) and modified condition factor (MCF) of the four groups of *A. bengalensis bengalensis*.

Table 2: Values of condition factor, relative condition factor and modified condition factor of the four groups *A. bengalensis bengalensis*.

Group	Condition factor(K)	Relative condition factor (K_n)	Modified condition factor
Gr.1.	0.1054	1.0083	0.0315
Gr.2.	0.1908	1.6937	0.0524
Gr.3.	0.2081	1.7765	0.0511
Gr.4.	0.0965	0.7142	0.02303

Results of all length-length relationships indicated that the values were highly significant in both the cases. (Fig.8. and 9.).

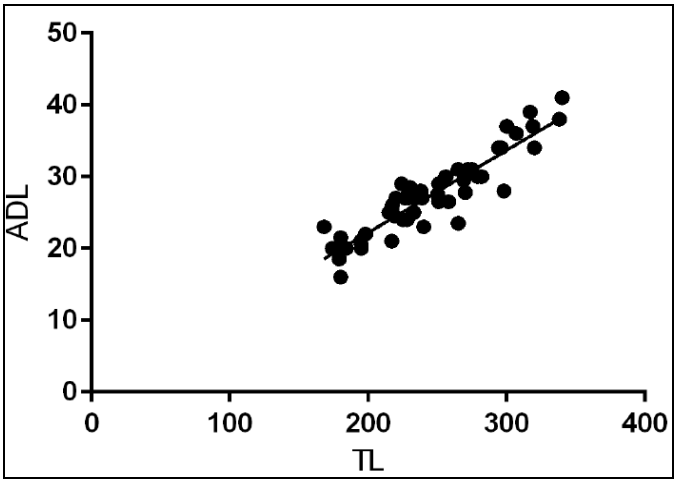

Fig 8: Regression of ADL on TL of pooled data (Y= 0.117X─ 0.7314, r^2= 0.8420)

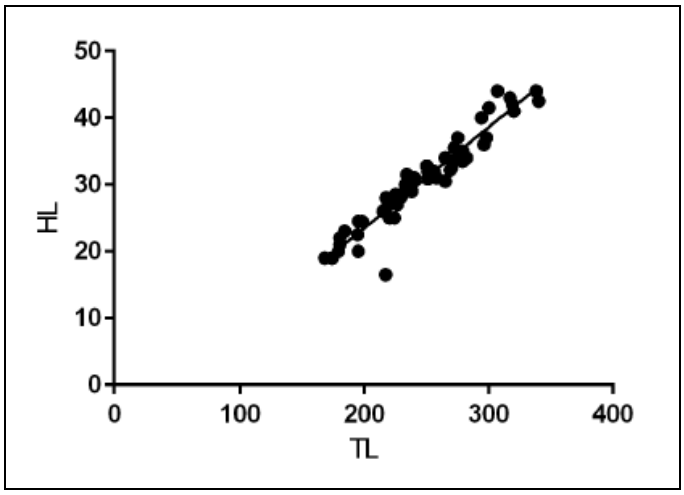

Fig 9: Regression of HL on TL of pooled data (Y= 0.1512X─ 6.730, r^2= 0.9135).

The multiple regression equation of body weight on ADL and TL is

$Y= 0.56846X_1+0.19901X_2-44.99891$

where, Y=Body weight, X_1=ADL and X_2=TL. (Fig. 10 and Table 3).

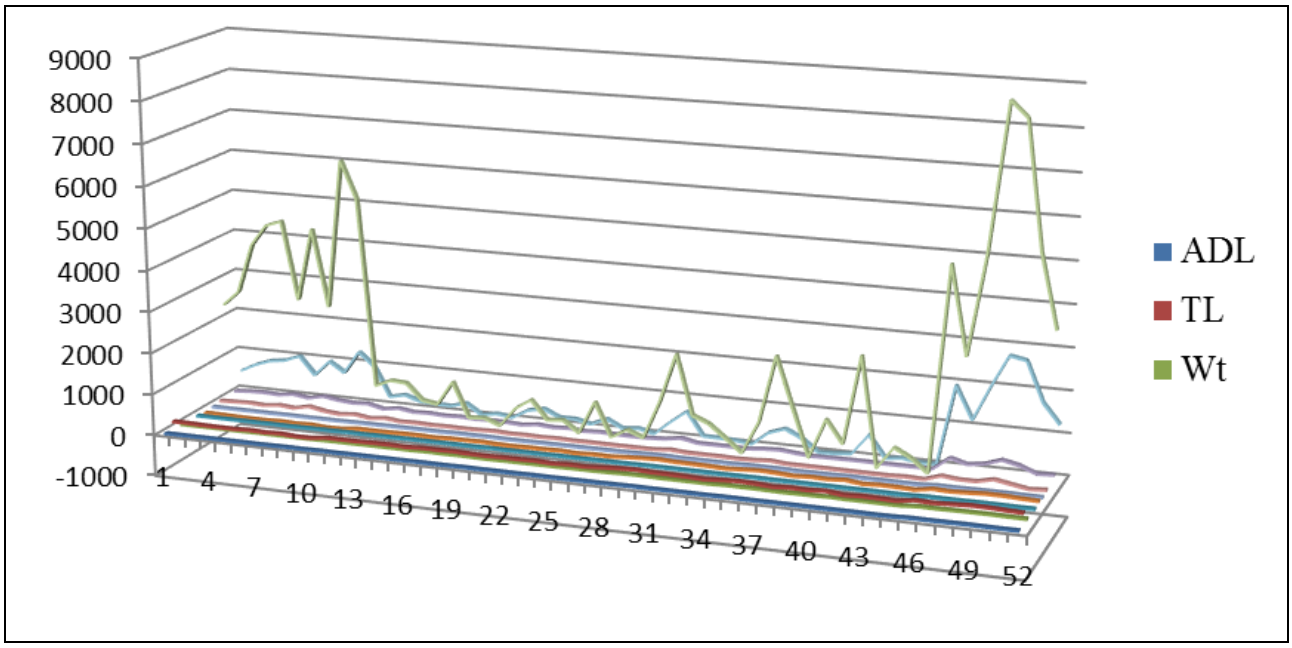

Fig 10: Three dimensional model of multivariate regression analysis of body weight on ADL and TL (R= 0.9610).

Table 3: ANOVA table of multiple regression analysis.

Due to	df	SS	MS	F value
Regression	3	7140.74	2380.25	1375.86*
Residual	48	82.85	1.73	

*highly significant

Discussion

Length-length relationships are highly significant in the present study. Similar findings were observed in different fishes by a number of authors [12, 21, 22, 32].

The R (0.9610) value of multivariate regression analysis indicates that there exist almost a perfect linear association between weight and the independent variables ADL and TL. The F value also shows significant relationship between weight and ADL and TL.

In relation to growth pattern, 'b' value is an important criterion that indicates isometric or allometric growth. When 'b' value is exactly 3.0, it indicates isometric growth [33]. Wooten [34] pointed out that when 'b' value is significantly larger or smaller than 3.0 indicates positive or negative allometric growth. In the present study 'b' value of length-weight relationship of 52 specimens is 3.414 which indicates

that overall growth of *Anguilla bengalensis bengalensis* is positively allometric. Ye *et al.* [35], Subba *et al.* [36], and Mousavi-Sabet *et al.* [22] showed negative allometric growth in different species of fishes (b<3). Shakir *et al.* [23], Subba and Adhikaree [37] and Moradinasab *et al* [32] reported positive allometric growth in different species. Allen [38] suggested that for ideal fish following 'cube law' the value of 'b' remains constant at '3'. But Martin [39] illustrated that the value of 'b' usually ranges from 2.5 to 4.0 and in majority of cases 'b' is not equal to '3'. Various authors reported different values of exponent 'b' like Johal and Tandon [40] in *Tor putitora* (b=3.38), Gupta *et al.* [41] in the same species (b=3.68 in mature and 1.41 in immature), Torres [42] in *Labeo altivelis* and *L. cylindricus* (as 2.976 and 3.325 respectively), Ranval *et al.* [43] in *L. dero* (b=2.98), Pawar and Supugade [44] in *L. rohita* (b= 2.664 in male and 2.695 in female. So 'b' value of *A. bengalensis bengalensis* is of no exception.

There is a general expectation that the weight increases as a cube of the length [45]. But as the fish grows through several stages, the simple cube law does not hold well throughout the life span and regression coefficient 'b' shows certain variation [39]. Therefore, to draw the exact picture of growth in *A. bengalensis bengalensis*, size wise 'b' value of length-weight relationship were calculated. The first and second size group shows positive allometric growth (b=3.71 and 3.88 respectively) while third group shows nearly isometric growth (b=3.18).In the largest size group (>300mm) growth pattern shows strong negative allometry (b=1.565). Gandotra *et al.* [46] reported 'b' values as 1.43, 2.86, 2.94 and 3.07 in 0+, 1+, 2+ and 3+ age groups respectively in *Aspidoparia morar*. Gandotra *et al.* [50] reported 'b' values as 2.756, 3.149 3.319 and 2.524 in the age group 0+, 1+, 2+ and 3+ respectively in *L. dero*. Gupta *et al.* [41] observed 'b' values as 1.41 in immature and 3.68 in mature stages of *T. putitora*. In the present study, *A. bengalensis bengalensis* shows normal trend of somatic growth in immature stages which is very similar to other species of fishes but in largest size group the picture is totally reverse and not in concurrence with other species of adult fishes. All the previous studies on length-weight relationship are of non-migratory fish but no report is available on migratory fish like *Anguilla* sp. As a rule, in migratory fish, reproductive tissue and gonad development takes place when the fishes reach their spawning area or desired destination. *A. bengalensis bengalensis* is a catadromous fish that migrate from river to sea for spawning [47]. Here development of reproductive tissue and gonad in the riverine largest size group (>300mm) is not observed as they are restricted to river. So they show negative allometric growth unlike other non-migratory fish in which positive allometric growth is a common phenomenon [41].

As reported by various authors 'b' value depends on various factors like feeding [30], state of maturity [48], sex [49] and for different population of a particular species [43] and [50] in *L. dero*). Moreover, on the basis of present study, another important factor that comes to our notice is migration which should be incorporated along with other factors.

In the field of fishery science, condition factor or 'K' is used to know the condition fitness, or wellbeing of a particular species of fish. The 'K' is always important in understanding the life cycle of fish species, thus contributing to the management of the species and maintaining the equilibrium in the ecosystem [51]. 'K' is also a useful index for monitoring of feeding intensity, age and growth rates of fish [52]. It is strongly influenced by both biotic and abiotic environmental conditions and can be used as an index to assess the status of the aquatic ecosystem in which the fish lives [53]. According to Nikos [54] fishes sufficiently fed would have 'K' ≥1 but when undernourished 'K' is less than 1. According to Lizama *et al.* [55]. the fluctuation of 'K' values between the species as well as within the species is due to feeding difference, climate and environmental conditions. Blackwell *et al.* [56] commented that high condition factor values indicate favourable environmental conditions and low values indicate less favourable environmental condition. Mousavi-Sabet *et al.* [22] showed month-wise variation of condition factor in his study. In the present study, the mean value of 'K' is 0.1502 which is far less than 1 and not in concurrence with any other fresh water fish so far reported. Bennet [57] commented that fishes with condition factor value above 0.56 are considered as in good condition. This hypothesis is not acceptable in case of *A. bengalensis bengalensis* as it is a migratory fish with different body morphology. Here size wise condition factors are 0.1054, 0.1908, 0.2081 and 0.0965. The increasing trends in 'K' value with advancement of sizes indicate that there is more weight gain in comparison to the cube length. But in largest size group (>300mm), the lower value of 'K' indicates less weight gain relative to length. Pantulu [6] calculated 'K' value of *A. bengalensis* in different months of the year that ranges from 0.134 to 0.165 which is also exceptionally low compared to other species of fishes. Sudden marked fall of 'K' values in larger size ranges is also observed by Pantulu. This supports our findings. Moreover, lower value of 'K' is also reported by Macgregor [58], Johal and Tandon [40], Zakaria *et al.* [59], Olurin and Aderibigbe [60], Gupta *et al.* [41], Kanwal and Pathani [61] and Pawar and Supugade [44].Evaluation of the conditions at different body lengths can give valuable information regarding the maturation and spawning in the life span of the fish. Fluctuations in 'K' value might be either related to other parameters like breeding cycle [30, 62, 63]. Condition factor is influenced by reproductive cycle in fish [64]. Hart [65] commented that declining trends of 'K' value with increase of length is a good indication of length at which sexual maturity starts. In the present study, low 'K' value of largest size group indicates start of sexual maturity.

LeCren [30] proposed relative condition factor in preference to condition factor as the latter is influenced by many environmental and biological factors. Condition factor measures deviation from a hypothetical ideal fish whereas relative condition factor measures the deviations from the average weight or the length of fish. Relative condition factor above 1 or close to 1, indicates that the fish is in good condition. In the present study, in the first three size groups, the values of relative condition factor is in increasing order that reflects that all these stages are in good condition, but in the largest size group, relative condition factor is below 1 (0.7142) indicates poor average of weight gain. Similar trend was observed in the case of modified condition factor. Values in all the size groups of *A. bengalensis bengalensis* (the values of 'K', 'K_n' and modified condition factor) appear to remain constant if the value of 'b' equals to 3 but it fluctuates with the body weight gain compared to length. Results obtained by all the three methods are almost complementary. It indicates that generally *A. bengalensis bengalensis* is in good condition throughout its juveniles. Comparing all these data of *A. bengalensis bengalensis* with other species of fishes, it can be concluded that growth and condition of *A. bengalensis bengalensis* in this water body is quite normal in the earlier stages but largest size range is an exception in all

respect. This is due to lack of reproductive growth i.e. maturation of gonad and other reproductive structures before spawning.

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