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Comparison of length-weight progression for Japanese threadfin bream, *Nemipterus japonicus* (Bloch, 1791) from different regions along Indian coast using selected regression models

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Variation in standard length (SL) and weight parameters based on the selected regression models for *Nemipterus japonicus* is carried out in this study. Comparison of nonlinear regression model coefficients have executed employing sum of squared reduction test. Fitted models have shown differences with respect to coast, location, sex, locations within a coast. Sex wise difference was evident in east coast while the difference was not significant in west coast. Pooled, male and female length weight relationships have followed the isometric growth pattern while coastwise and location wise analysis showed an allometric pattern of growth. Strong negative allometric pattern of growth in east coast may be attributed to the fluctuating and diluted aquatic environment in the Bay of Bengal.

[Keywords: Length weight relationship, nonlinear model, allometric growth, sum of squared reduction test**]**

Introduction

Length and weight data are standard results of fish sampling programs[1]. In fishes, size is biologically relevant than age, mainly because several ecological and physiological factors are more size-dependent than age-dependent. Consequently, variability in size has important implications for diverse aspects of fisheries science and population dynamics[2]. One of the most commonly used analyses of fisheries data is length-weight relationship[3]. Length weight relationships give information on the condition and growth patterns of fish[4]. Fish are said to exhibit isometric growth when length increases in equal proportions with body weight for constant specific gravity. The regression coefficient for isometric growth is ‘3’ and values significantly greater or lesser than ‘3’ indicates allometric growth[5].

The length weight relationships are usually estimated from the formula, $W= a L^b$, where ‘W’ is the total body weight (g), ‘L’ the total length (cm), ‘a’ and ‘b’ are the coefficients of the functional regression between W and L[6]. In order to confirm whether ‘b’ values obtained in the linear regressions are significantly different from the isometric value (b=3), t-tests with appropriate degrees of freedom are used[7]. Statistical significance of ‘b’ values, and their inclusion in the isometric range (b=3) or allometric ranges (negative allometric: b<3 or positive allometric>3). An ANCOVA is used to determine if there were significant differences in the length weight relationships between sexes[8]. The transformed length fitted over weight gave linear growth indicating the three dimensional growth structures of most fish species[9]. Values of length exponent in the length weight relationship being isometric imply that the fish species did not increase in weight faster than cube of their total lengths.

The length weight relationship for *Nemipterus japonicus* was reported from Veraval[10] (northwest coast) and negative allometric growth observed in males and isometric growth in females (Table 1) and pooled relationship was negative allometric. Isometric growth for male, female and pooled length weight relationships was observed from Madras[11]. The study on the length weight relationship for this species in Jizan region of Red sea, revealed that the growth in both sexes are negative allometric in nature[12] (Table 1).

Table 1—The Compiled data on the important research attempts in studying the length- weight relationships (Natural log transformation on weight and length) on *Nemipterus japonicus* stocks

Serial no	Length-weight relation	Region (Reference)

*Corresponding author

	a	b	length (cm)	weight(g)	
Male	4.0595	2.6616	7.5-24.5	.	Veraval (Gopal and Vivekanandan, 1991)
Female	-4.6173	2.9066	7.5-27.5	.	
Pooled	-4.257	2.7488	6.5-27.5	.	
Male	-4.8057	2.9654	..	.	Madras (Vivekanadan and James, 186)
Female	-4.978	2.9665	…	.	
Pooled	-4.8665	2.9661	..	.	
Male	-1.079	2.428	…		Jizan region of Red sea (Bakhsh, 1994)
Female	-1.159	2.469	…		
Pooled	..	..	3.5-22		
Male	0.0183	2.9924	9.4-27.3 (FL	14.04-351.89	North Persian gulf (Kerdgari *et al.,* 2009)
Female	0.0178	3.0073	11-26.3 (FL)	21.7-325.65	
Pooled	0.0181	3.0001	9.4-27.3 (FL)	14.04-351.89	
Male	-4.83473	2.99499	5.5-31.4 (TL)	1.5-510	Veraval (Raje, 2002)
Female	-4.9586	3.04463	6.9-27.2 (TL)	3.9-283	
Pooled	4.88606	3.00437	5.5-31.4 (TL)	1.5-510	
Male	-3.65045	2.43025	7.1-25.1	6-184	Kakinada (Murty, 1984)
Female	-4.78737	2.95688	6.9-21.8	5-139	
Pooled	-4.1345	2.69579	6.9-25.1	5-184	

FL- Fork length, TL- Total length

The different length-length relationships of the morphometric characters, length-weight relationship and various meristic traits for *N. japonicus* were studied along Bombay coast[14]. The values for 'a' and 'b' in length weight relationship

Immature and mature males and immature and mature females and concluded that there is no differences in the slopes[15]. Significant difference between male and female length weight relationships for *N. japonicus* was reported along Andhra-Orissa coast[16]. Length weight relationship of *N. japonicus* along Ratnagiri coast of Maharashtra indicated significant departure from isometric growth[17]. Growth rate was highest in indeterminate fishes, followed by males and females. Result obtained for *N. japonicus* indicate that there is no significant difference between the sexes.

Materials and Methods

Nemipterus japonicus was identified by following the description given by FAO species identification sheets[18]. 389 numbers of samples were collected randomly from commercial fish landing centres (Table 2). Fish samples were

b = slope

L = Standard length of the fish

of males and females were 0.00003535, 2.8069 and 0.000009922, 3.0634 respectively. Analysis of length weight relationships of *N. japonicus* along Kerala coast was carried out in order to find out the differences in slopes for collected from 4 selected locations; Mumbai, Cochin, Kakinada and Chennai between August 2010 to April 2011 (Fig. 1).

Table 2—Details of samples of *Nemipterus japonicus* collected from various locations in east and west coast of India

Coast	West coast		East Coast	
Location	Cochin	Mumbai	Chennai	Kakinada
Sample size (n)	86	89	102	112
	175		214	
Total	389			

Here we used three regression models for finding out the length weight relationships.

Various models used in the present study are

1) Linear regression model

$$W = a + b (L) \quad \text{Eq… (1)}$$

W = Weight of the fish in grams

a = intercept

2) Natural log transformed linear regression model

$$Ln (W) = a + b \, Ln (L) \quad \text{Eq… (2)}$$

3) The nonlinear model fit using the following model

$$W = a L^b \quad \text{Eq… (3)}$$

The models are estimated separately for different coasts, locations, males and females.

Fig. 1—The location map of the sampling stations for the Japanese threadfin bream, *Nemipterus japonicus* along Indian coast.

Standard length of the fish is defined as the length of the fish from the snout tip to the base of the caudal fin rays. From the fresh samples, standard length (SL) and body weight (W) were measured to the nearest accuracy of 0.1 cm and 0.01 g respectively. Three models linear model, nonlinear model and natural log transformed linear models were tested using ANOVA using PROC GLM procedure of SAS[19]. The PROC NLIN procedure of SAS was used for fitting the non linear model while PROC REG procedure was used in other two models. In order to confirm whether 'b' values obtained in the regression models were significantly different from the isometric value (b=3), t-tests with appropriate degrees of freedom were used. For testing the difference in the regression lines, the analysis of covariance and its standard error for the regression coefficients in the models were checked to obtain and check the significance (α=0.05) of t-value (obtained by subtracting 3 from the regression coefficient and dividing the result by the standard error).

To compare two or more treatments in a nonlinear model problem, we proceed similarly as in the case of standard analysis of variance. First, we assess whether there are any differences between the treatments. If there are, we try to find out these differences by a sum of square reduction test[20]. This is a very general procedure that can be used to test all kinds of hypotheses. The idea is to fit two versions of the model as full model or fitted model and reduced model. One is considered as the full model with all the parameters for different groups. Reduced model with few parameters or the parameters is given the same value for all the groups, is a constrained version of the full model. You arrive at the reduced model by constraining some of the parameters of the full model. Hence, the reduced model uses same parameters for different groups. To perform the sum of squares reduction test, you need to fit both the full and reduced models. Then, calculate the test statistic,

$$F_R = \{(SSRR-SSRF) / (DFRR-DFRF)\}/MSRF \quad ...(4)$$

Where F_R = F- test statistic

SSRR = Reduced Model Residual Sum of Squares

SSRF = Full Model Residual Sum of Squares

DFRR = Reduced Model Residual Degrees of Freedom

DFRF = Full Model Residual Degrees of Freedom

MSRF = Full model Residual Mean Sum of Squares

Comparison of the F_R value has to be carried out with the F- table value with numerator degrees of freedom, NDF and denominator degrees of freedom, DDF.

$$NDF = DFRR-DFRF \quad ...(5)$$

$$DDF = DFRF \quad ...(6)$$

Results and Discussion

Three different models were used to fit length weight relationship and comparison of the models has been carried out using the R square fit statistic. Comparison of various groups with respect to location, sex and coast were also carried out with the best selected model in order to test for significant difference among them. Pattern of growth for different groups was also considered with a view to find out the isometric and allometric (positive or negative) patterns of progression among them.

Fitted nonlinear regression plots for pooled and for different groups (coast, location and sex) are given in Fig. 2 to 9. Comparison of the regression

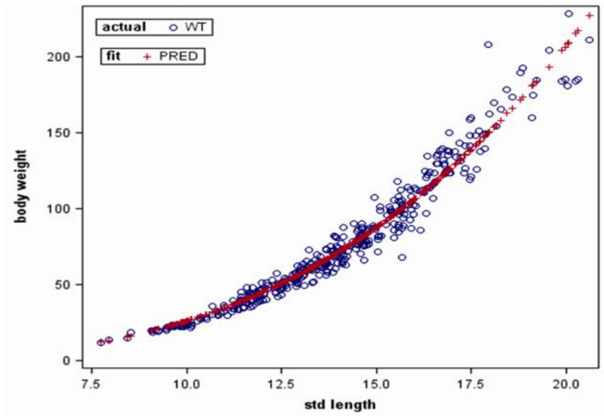
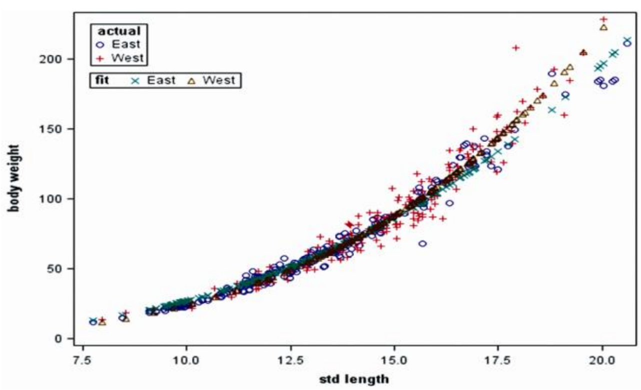


Fig. 2—Overall nonlinear regression fit plot of body weight on standard length



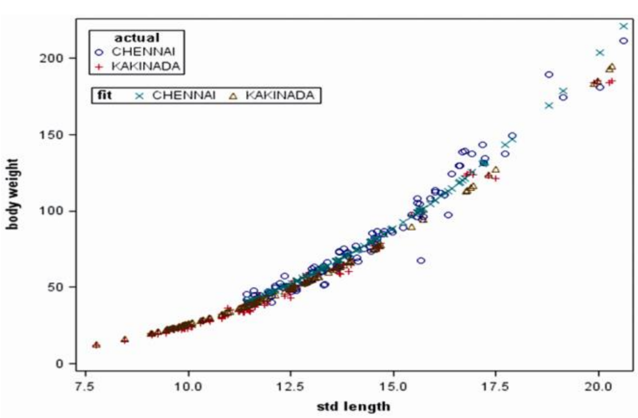


Fig. 6—Location wise nonlinear regression fit plot of body

Fig. 3—Coast wise nonlinear regression fit plot of body weight on standard length

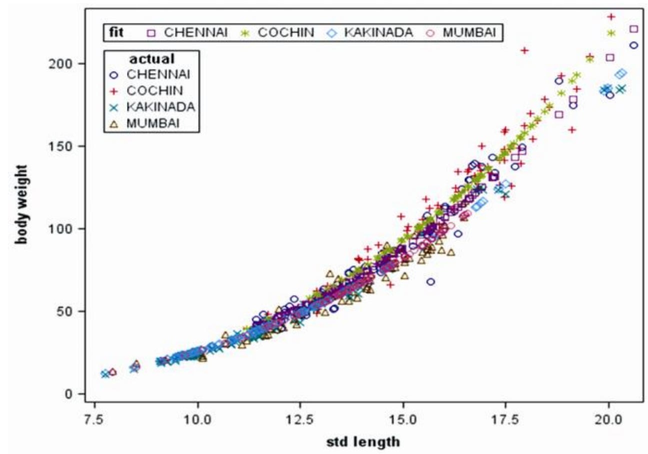


Fig. 4—Location wise nonlinear regression fit plot of body weight on standard length

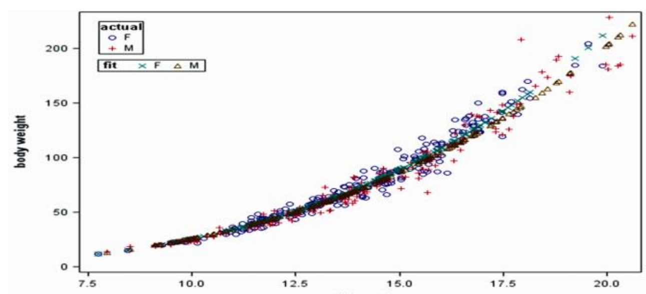


Fig. 5—Sex wise nonlinear regression fit plot of body weight on standard length

weight on standards length for east coast

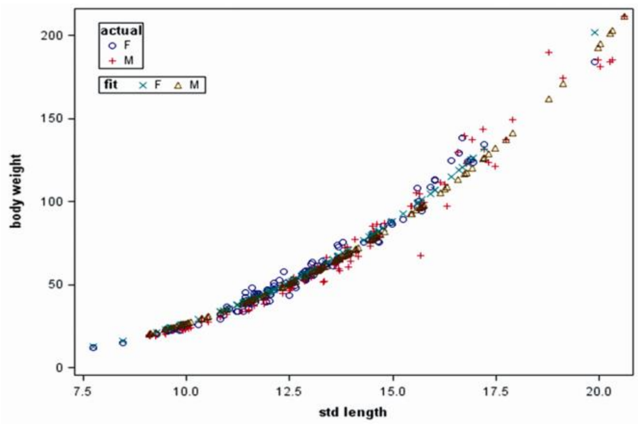


Fig. 7—Sex wise nonlinear regression fit plot of body weight on standards length for east coast

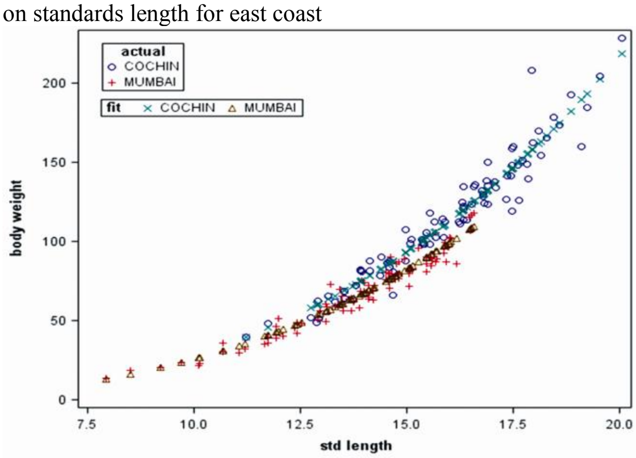


Fig. 8—Location wise nonlinear regression fit plot of body weight on standards length for west coast

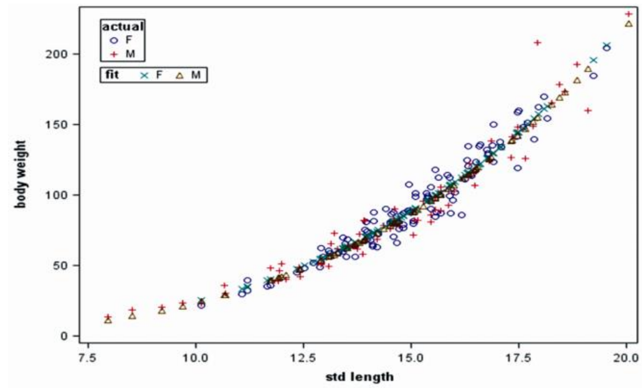


Fig. 9—Sex wise nonlinear regression fit plot of body weight on standards length for west coast

coefficients in nonlinear models have been carried out through the F_R statistic obtained between the fitted (full) and reduced nonlinear models. The coast wise analysis have shown significant difference (F_R = 26.13863, P=<0.001) among them. Location wise (F_R = 30.569, P=<0.001) and sex wise difference (F_R = 8.349, P=0.00028) was also evident in the analysis. Locations within east coast (F_R = 27.096, P=<0.001) and west coast (F_R =27.64, P=<0.001) was not significantly different. Sex wise analysis among east coast (F_R = 5.511, P=0.0046) have detailed the significance while there was no significant difference among sexes along west coast (F_R = 0.616, P=0.5412). There was no significant difference among the sexes from Mumbai (F_R = 1.49, P=0.2312) and Cochin (F_R = 0.4836, P=0.6183) regions. However the Chennai (F_R = 3.4143, P=0.0368) and Kakinada (F_R = 12.077, P=0.000018) samples have depicted significant difference among the sexes.

The non linear model fitted using the iterative procedure with the help of the NLIN programme of SAS found to have superior R square values compared to other conventional models in the study. Results of the regression models analyzed in the present study have presented in the tables 3 to 6.

Nonlinear regression plots with predicted weight values for standard length for pooled and for different groups (coast, location, locations within a coast, sex, sex within a coast) presented in Fig. 2-9. Overall length weight relationship showed isometric (Table 3) growth pattern (b=2.988) with no significant difference (t=0.36) of regression coefficient from 3 which followed the cubic law. East coast individuals followed a negative allometric growth pattern (b=2.8601, t=4.53) with initial fast progression of weight with the length and later slow pace of growth (Table 3). West coast individuals followed a positive allometric pattern of growth (b=3.2, t=3.11) with slow initial growth and fast growth in the later stages.

Location wise analysis revealed that Chennai (b=2.8764, t=2.27) and Kakinada (b=2.84, t=6.96) followed negative allometric growth pattern with the slow progression of growth in the later stages of life. Mumbai (b=2.93, t=0.75) and Cochin (b=2.88, t=1.28) individuals followed isometric pattern of growth based on the‘t’ statistic.

Sex wise analysis for east coast (Table 5) depicted isometric growth pattern for females (b=2.9388, t=1.5) and negative allometric growth pattern for males (b=2.8639, t=2.94). West coast sex wise growth pattern were positive allometric for female (b=3.1925, t=2.2) and male (b=3.22, t=2.28) individuals (Table 5). Male (Chennai (b=2.88, t=1.4), Cochin (b=3.03, t=0.16)) and female (Chennai (b=3.06, t=0.85), Cochin (b=2.87, t=1.24)) individuals from Chennai and Cochin have shown isometric growth pattern while negative allometric pattern was followed by both the sexes (female (b=2.9, t=3.02), male (b=2.84, t=5.72)) from Kakinada (Table 6). Sex wise analysis of Mumbai samples detailed that isometric growth pattern was fitted with both the sexes (female (b=2.73, t=1.9), male (b=2.96, t=0.32))

Table 3—Overall and coast wise results on the regression models fitted, of body weight on standard length.

OVERALL

MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9225	4606.2	<.001	-145.67	15.9895	.
NONLINEAR MODEL	0.9910	21201.1	<.0001	0.0269	2.9880	.
LOGLINEAR REGRESSION	0.9776	16868.1	<.0001	-3.8499	3.0720	0.0213

COAST WISE

EAST COAST

MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9446	3615.11	<.0001	-132.77	15.03	.
NONLINEAR MODEL	0.9935	16235.4	<.0001	0.0373	2.8601	.
LOGLINEAR REGRESSION	0.9842	13230.9	<.0001	-3.7552	3.0335	0.0234

WEST COAST

MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.8913	1418.27	<.0001	-171.9	17.73	.
NONLINEAR MODEL	0.9910	9528.06	<.0001	0.0152	3.2003	.
LOGLINEAR REGRESSION	0.9584	3989.9	<.0001	-3.9673	3.1174	0.0189

Table 4—Location wise and sex wise results on the regression models fitted, of body weight on standard length

LOCATION WISE

CHENNAI

MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9452	1725.5	<.0001	-169.5	17.547	.
NONLINEAR MODEL	0.9936	7736.08	<.0001	0.0367	2.8764	.
LOGLINEAR REGRESSION	0.9622	2542.1	<.0001	-3.4506	2.9285	0.0317

COCHIN

MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9171	929.55	<.0001	-209.3	20.396	.
NONLINEAR MODEL	0.9930	5947	<.0001	0.0336	2.9287	.
LOGLINEAR REGRESSION	0.9462	1476.9	<.0001	-3.5239	2.974	0.0295

KAKINADA

MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A

LINEAR REGRESSION	0.9513	2148.38	<.0001	-118.03	13.88	.
NONLINEAR MODEL	0.9971	19143.9	<.0001	0.0377	2.8393	.
LOGLINEAR REGRESSION	0.9914	12735	<.0001	-3.6283	2.9725	0.0266
MUMBAI						
MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9195	994.38	<.0001	-100.5	12.21	.
NONLINEAR MODEL	0.9939	7101.94	<.0001	0.0337	2.8812	.
LOGLINEAR REGRESSION	0.9622	2216.61	<.0001	-3.4418	2.8991	0.0320
SEX WISE						
FEMALE						
MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9261	2545.65	<.0001	-145.8	15.99	.
NONLINEAR MODEL	0.9928	14010.6	<.0001	0.0216	3.0739	.
LOGLINEAR REGRESSION	0.9755	8078.07	<.0001	-3.9341	3.1090	0.0196
MALE						
MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9197	2083.55	<.0001	-145.5	15.98	.
NONLINEAR MODEL	0.9898	8864.65	<.0001	0.0281	2.9666	.
LOGLINEAR REGRESSION	0.9805	9147.62	<.0001	-3.7836	3.0413	0.0227

Table 5—Sex wise results on the regression models fitted, of body weight on standard length for east and west coasts

			COAST WISE			
			EAST COAST			
FEMALE						
MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9478	1833.96	<.0001	-122.2586	14.221	.
NONLINEAR MODEL	0.9957	11777.7	<.0001	0.0308	2.9388	.
LOGLINEAR REGRESSION	0.9847	6481.69	<.0001	-3.823	3.0688	0.0219
MALE						
MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.944	1836.31	<.0001	-139.370	15.501	.
NONLINEAR MODEL	0.9927	7384.11	<.0001	0.0365	2.8639	.
LOGLINEAR REGRESSION	0.986	7650.67	<.0001	-3.7772	3.0343	0.0229
			WEST COAST			
FEMALE						
MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9142	1064.84	<.0001	-195.692	19.2475	
NONLINEAR MODEL	0.9919	6133.59	<.0001	0.0156	3.1925	
LOGLINEAR REGRESSION	0.9459	1749.85	<.0001	-4.4349	3.2909	0.0119
MALE						
MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.8798	519.44	<.0001	-156.419	16.773	.
NONLINEAR MODEL	0.9899	3464.57	<.0001	0.014	3.2244	.
LOGLINEAR REGRESSION	0.9695	2259.05	<.0001	-3.6883	3.0121	0.0250

The well-known general concept on the length weight relationship is that the weight of the fish would vary as the cube of its length. But as the specific gravity and the shape or body outline of the fish are subject to changes, the cubic law needs not hold good always[21]. Significant departure from the cubic law in the case of *Sardinella albella* and *Sardinella gibbosa* was reported[22]. Also, it is well known that the functional regression 'b' value represents the body form, and it is directly related to the weight affected by the ecological factors such as temperature, food supply, spawning conditions and other factors, such as sex, age, fishing time and area and fishing vessels[6]. Negative allometric progression in case of males and isometric progression for females were reported along Veraval region of northwest coast[10]. Pooled relationship was eventually of negative allometric pattern in nature. The investigation on the same species from Madras coast detailed isometric progressions for male, female and pooled length weight relationships[11]. Length weight relationship for this species from Kakinada reported isometric growth pattern for females and negative allometric growth pattern for males and pooled relationship[23]. Isometric relationship for *N. japonicus* was reported from Veraval for both the sexes[24].This shows that, the same region has shown isometric and allometric patterns during different chronological periods. Hence it can be concluded that there will be spatial and time scale influences on the biology of the species in an ecosystem. Regression coefficients of the length weight relationships in *Nemipterus japonicus* for the Kerala and Andhra-Orissa coasts seem to show difference especially in the males[15]. But in the current study there was isometric growth pattern followed by both the sexes. Present study was also conducted in order to understand the pattern of length weight progression in *Nemipterus japonicus* from different locations and resulted in variations or negative allometric patterns especially from Kakinada and Chennai.

The change in morphometric progression may be attributed to the water velocity variation in turbulent waters[25]. Kakinada is a region where the northern most distributary of river Godavari enters and brings about great changes in salinity of the sea water over a wide area[26]. This dilution of salinity may affect the population of Kakinada and as a result the distinct population may be explained[27]. Lower salinity influencing the morphometric traits also reported in *Scomberomorus guttatus*[28]. Morphometric progression depends on the environmental condition in early life history stages, morphological differentiation may be attributed to the life of fish in separate regions[29].

Table 6—Sex wise results on the regression models fitted, of body weight on standard length for different locations

LOCATION WISE

CHENNAI

FEMALE

MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9553	1047.91	<.0001	-147.0432	16.02	.
NONLINEAR MODEL	0.9966	7141.28	<.0001	0.0228	3.0608	.
LOGLINEAR REGRESSION	0.9687	1518.59	<.0001	-3.5618	2.9781	0.0284

MALE

MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9481	894.64	<.0001	-196.486	19.2294	.
NONLINEAR MODEL	0.9925	3252.51	<.0001	0.036	2.8793	.
LOGLINEAR REGRESSION	0.9533	1000.02	<.0001	-3.6254	2.9869	0.0266

COCHIN

FEMALE

MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9322	741.9	<.0001	-202.23	19.934	.
NONLINEAR MODEL	0.995	5373.4	<.0001	0.0402	2.867	.
LOGLINEAR REGRESSION	0.9404	851.96	<.0001	-3.592	3.0008	0.0275

MALE

MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9027	259.9	<.0001	-216.721	20.887	.
NONLINEAR MODEL	0.9900	1381.49	<.0001	0.0251	3.0293	.
LOGLINEAR REGRESSION	0.9543	585.32	<.0001	-3.466	2.9494	0.0312

KAKINADA

FEMALE

MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9444	849.37	<.0001	-112.0898	13.412	.
NONLINEAR MODEL	0.9978	11115.6	<.0001	0.0328	2.9011	.

LOGLINEAR REGRESSION	0.9915	5798.39	<.0001	-3.7135	3.0143	0.0244
MALE						
MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9563	1268.61	<.0001	-121.9962	14.1779	.
NONLINEAR MODEL	0.9976	12008.2	<.0001	0.0375	2.8352	.
LOGLINEAR REGRESSION	0.9931	8309.86	<.0001	-3.5842	2.948	0.0278
			MUMBAI			
FEMALE						
MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9346	628.71	<.0001	-112.654	12.9526	.
NONLINEAR MODEL	0.9946	4042.88	<.0001	0.0496	2.7328	.
LOGLINEAR REGRESSION	0.9442	743.85	<.0001	-3.9220	3.0768	0.0198
MALE						
MODEL	R SQUARE	F VALUE	Pr>F	A	B	antilog A
LINEAR REGRESSION	0.9216	482	<.0001	-96.888	12.072	.
NONLINEAR MODEL	0.9937	3243.32	<.0001	0.0276	2.9601	.
LOGLINEAR REGRESSION	0.9716	1401.77	<.0001	-3.3138	2.8546	0.0364

However, variation in morphometric characters may be affected by genetic and environmental factors[30]. This may be attributed to the non migratory demersal life status of the fish gives rise to unique location specific isolated stocks. Isolation of the east and west coast stocks may be due to the geographical barrier, there may not be a possibility of genetic exchange and there exists two ecologically different environments which may have an impact on the morphology of the two stocks. Similarly as the exploitation of this species has crossed the optimum value, all the factors like catchability, size, age, longevity and differences in growth along different geographical locations might have resulted in the generation of stocks of different characteristics. East coast individuals are distributed in a very turbulent and diluted environment, the Bay of Bengal which receives heavy rainfall and river runoff in comparison with the Arabian Sea or west coast counterparts. Thus there are chances of the relative differences in the length weight progression of the individuals in a disturbed less saline and diluted environments. Even though the pooled data don't follow allometry in the populations, the location wise considerations do follow the same. The influence of the environment plays a certain role in the geometric progression and weight expansion during fish growth with respect to the length.

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