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ESTIMATION OF THE GROWTH CURVE PARAMETERS IN *Macrobrachium rosenbergii*

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ABSTRACT

Growth is one of the most important characteristics of cultured species. The objective of this study was to determine the fitness of linear, log linear, polynomial, exponential and Logistic functions to the growth curves of *Macrobrachium rosenbergii* obtained by using weekly records of live weight, total length, head length, claw length, and last segment length from 20 to 192 days of age. The models were evaluated according to the coefficient of determination (R^2), and error sum off square (ESS) and helps in formulating breeders in selective breeding programs. Twenty full-sib families consisting 400 PLs each were stocked in 20 different hapas and reared till 8 weeks after which a total of 1200 animals were transferred to earthen ponds and reared up to 192 days. The R^2 values of the models ranged from 56 – 96 in case of overall body weight with logistic model being the highest. The R^2 value for total length ranged from 62 to 90 with logistic model being the highest. In case of head length, the R^2 value ranged between 55 and 95 with logistic model being the highest. The R^2 value for claw length ranged from 44 to 94 with logistic model being the highest. For last segment length, R^2 value ranged from 55 – 80 with polynomial model being the highest. However, the log linear model registered low ESS value followed by linear model for overall body weight while exponential model showed low ESS value followed by log linear model in case of head length. For total length the low ESS value was given by log linear model followed by logistic model and for claw length exponential model showed low ESS value followed by log linear model. In case of last segment length, linear model showed lowest ESS value followed by log linear model. Since, the model that shows highest R^2 value with low ESS value is generally considered as the best fit model. Among the five models tested, logistic model, log linear model and linear models were found to be the best models for overall body weight, total length and head length respectively. For claw length and last segment length, log linear model was found to be the best model. These models can be used to predict growth rates in *M. rosenbergii*. However, further studies need to be conducted with more growth traits taken into consideration.

KEYWORDS: linear, log linear, polynomial, exponential, Logistic models, *Macrobrachium rosenbergii.*

INTRODUCTION

Freshwater prawns are of large and growing importance in India and are of the major contributors to aquaculture production. The pace of development faced an a unprecedented set back because of diseases and water quality issues in Giant fresh water prawn farming, which once thought to have been relatively free from diseases and other production issues. The peak production of giant freshwater prawns in India *(since 1999 as per MPEDA records)* took place in 2005-2006 which was 42780 tonnes from 43,395 ha of area (NFDB). However, in 2006-07 the prawn production and farming drastically decreased by 30% to 30,115 tonnes and 30,042 ha of area respectively. The Giant fresh water prawn, *Macrobrachium rosenbergii* contributed 4.3% by quantity (5.8% by value) of the total frozen shrimp export from the country during 2005 to 2006, but its contribution declines in 2007, despite the global production showing a steady progress over the past few years, thanks to surging production from China. The initial failures were earlier than anticipated, but there are many lessons to learn from the rise and fall of *M. rosenbergii* farming in India, if it needs to be sustainable (NFDB). Growths being a parameter of obvious importance, numerous studies have been conducted on various aspects of growth, but yet to be understood completely no previous studies have been conducted on the growth curve parameters of *M. rosenbergii.* Therefore, the present study was designed with the following objective to develop growth models and to estimate the factors affecting the growth curves.

MATERIALS AND METHODS

The animals were procured from the river Narmada, India. Twenty full-sib families of *M. rosenbergii* consisting 400 PLs each were stocked in 20 different hapas and reared till 8 weeks after which a total of 1200 animals were randomly selected and transferred to earthen ponds and reared for another 16 weeks. Feeding was done with Tiger I commercial pelleted feed (CP Company) at the rate of 5-8% of the body weight thrice a day. The experiment was conducted at freshwater fish farm of CIFE, Powarkheda centre, India. Sampling was performed and data recorded for overall body weight, total length, head length, claw length and last segment length at 8 days interval from hapa phase up to 192 days. The data obtained was analysed using the SAS Version 9.2. In the present study, a total of five models comprising three linear models (linear model, log linear model, polynomial model) and two non-linear models (exponential model and logistic model) were evaluated for their goodness of fit in determining the growth curves of *M. rosenbergii*. All the models were evaluated according to determination coefficient (R^2), error sum of square (ESS).

Models used for fitting the growth data

a. Linear model

$Y= a+bx+e$

Y= growth (body weight, total length, head length, claw length and last segment length), a= intercept, b= slope, x=age, e= random error assumed to have mean zero and variance (σ^2).

b. Log linear model

$\ln Y= a+bx+e$

ln Y= Natural log of growth (weight, total length, head length, claw length and last segment length), a= intercept, b= slope, x= age, e= random error assumed to have mean zero and variance (σ^2).

c. Polynomial model

$Y= a+bx+cx^2+dx^3+fx^4 +e$

Y= growth (weight, total length, head length, claw length and last segment length) at age x, a= intercept, b= growth rate at age x, c, d and f= parameters for multiples of 2nd, 3rd and 4th degree of age x, e= random error assumed to have mean zero and variance (σ^2).

Polynomial was limited to 2nd order as there was no further improvement in R^2 by increasing the order of fit.

d. Exponential model

$Y=a*e^{bx} +e$

Y= Growth (weight, total length, head length, claw length and last segment length) at age x, a=Estimated initial value for growth traits (body weight/ total length/head length/claw length/last segment length), b=Growth rate at estimated exponential rate, x= age, e= random error assumed to have mean zero and variance (σ^2), body traits measurement at x+1 age is e^b times higher than the same at age x.

e. Logistic model

$Y=a/(1+((a-b)/b)e^{-rx}) + e$

Y= Growth (weight, total length, head length, claw length and last segment length) at age x, a= height of the horizontal asymptote (the expected value of Y when age approaches infinity), b= expected initial value of Y, r= measure of growth rate, e= random error assumed to have mean zero and variance (σ^2), In this model r should be a small positive number.

RESULTS

Analysis of growth pattern

Overall mean body weight of 20 families during the hapa phase from stocking until 64th day rearing period ranged from 0.05 to 5.0 g. Among all the 20 families 3rd family attained the highest growth of 5g followed by 13th and 18th families with a weight of 4.9g (Table 1). Mean total length during grow-out phase from stocking till harvest phase ranged between 2.97 and 18.45 cm while the mean body weight was 14.54g. The head length, claw length and last segment lengths were ranged from 1.24 to 9.12 cm, 1.24 to 10.24 cm and 0.32 to 3.9 cm respectively. Significant difference was observed in all the traits tested among all age groups (Table 2).

Goodness of fit

Coefficients of determination for different growth traits computed using linear, log linear, polynomial, exponential and logistic models for overall as well as for different sex of *M. rosenbergii* were used to evaluate the models for goodness of fit. For overall data on body weight, the coefficient of determination R^2 (%) was 78, 64, 93 for linear, log linear and 2^{nd} degree polynomial models respectively, while it was 56% and 98% for no intercept models like exponential and logistic models respectively. The ESS (Error sum of squares) was recorded minimum for log linear model followed by linear model, while the highest ESS was obtained by exponential model (Table 3). The lowest R^2 values of 19% and 10% for males and females respectively were obtained in case of exponential model while the same for logistic model were for both male and female are 89% and 86% respectively. Among the models tested exponential model had lowest ESS for both the sexes (Table 6, 7 .8, 9, 10). The R^2 (%) values of different models for total length, head length, claw length and last segment length were ranged from 62-90%, 54-90%, 44-94% and 62-80% respectively. The lowest ESS was recorded by log linear model followed by exponential model for total length, log linear model followed by exponential model for head length, log linear and exponential model for claw length and linear and exponential model for last segment length (Table 3, 4 and 5).

Table 1. Average body weight (g) of different families during hapa phase rearing at different time intervals

Family	8 day	16 day	24 day	32 day	40 day	48 day	56 day	64 day
01	0.1± 0.01	0.2±0.021	0.2±0.01	0.8±0.07	1.0±0.08	1.8±0.11	3.4±0.1	4.2±0.1
02	0.3±0.03	0.6±0.06	0.7±0.06	1.3±0.09	2.0±0.05	2.2±0.12	3.3±0.14	4.7±0.1
03	0.05±0.005	0.1±0.01	0.2±0.01	0.7±0.07	1.±0.03	1.2±0.10	3.2± 0.1	5.0± 0.1
04	0.06±0.004	0.1±0.01	0.2±0.01	0.7±0.06	0.9±0.06	1.1±0.1	3.4±0.1	4.2±0.1
05	0.06±0.005	0.1±0.01	0.2±0.01	0.7±0.07	1.1±0.07	1.4±0.1	3.2±0.13	4.4±0.1
06	0.07±0.005	0.1±0.01	0.1±0.01	0.9±0.08	1.0±0.09	1.2±0.1	3.3±0.15	4.2±0.1
07	0.06±0.004	0.1±0.01	0.2±0.01	0.9±0.09	1.2±0.06	1.6±0.1	3.4±0.1	4.2±0.1
08	0.07±0.005	0.1±0.01	0.2±0.01	0.7±0.07	1.0±0.07	1.4±0.1	3.3±0.1	4.2±0.1
09	0.06±0.005	0.1±0.01	0.2±0.01	0.7±0.07	1.0±0.05	2.1±0.08	3.2±0.1	4.01±0.1
10	0.07±0.004	0.1±0.01	0.2±0.01	0.5±0.04	0.8±0.05	1.9±0.05	3.3±0.1	4.3±0.2
11	0.06±0.004	0.1±0.006	0.1±0.01	0.7±0.06	0.9±0.06	1.6±0.09	3.4±0.1	4.0±0.13
12	0.07±0.005	0.1±0.01	0.2±0.01	0.9±0.06	1.1±0.05	2.0±0.07	3.4±0.1	4.8±0.1
13	0.07±0.005	0.1±0.01	0.2±0.01	1.0±0.07	1.4±0.06	2.0±0.1	3.2±0.1	4.9± 0.1
14	0.07±0.005	0.1±0.008	0.2±0.01	0.4±0.03	1.0±0.09	2.1±0.1	3.4±0.1	4.3±0.1
15	0.08±0.005	0.1±0.01	0.2±0.01	0.8±0.09	1.6±0.04	1.8±0.1	3.4±0.1	4.3±0.1
16	0.08±0.004	0.1±0.01	0.2±0.01	0.4±0.02	0.6±0.04	2.0±0.1	3.1±0.1	4.3±0.2
17	0.1±0.01	0.2±0.02	0.2±0.01	0.6±0.06	0.8±0.07	2.2±0.09	3.4±0.1	4.0±0.1
18	0.1±0.02	0.2±0.04	0.2±0.01	0.6±0.13	1.4±0.08	2.1±0.1	3.4±0.1	4.9±0.1
19	0.2±0.02	0.3±0.03	0.3±0.01	0.5±0.05	0.8±0.08	2.1±0.1	3.2±0.1	4.0±0.1
20	0.2±0.02	0.2±0.04	0.3±0.01	0.6±0.06	1.1±0.1	2.5±0.1	3.4±0.1	4.5±0.1

Table 2. Overall mean of total length, body weight, head length, claw length and last segment length at different time intervals

Age in days	Total length (cm)	Body Weight (gm)	Head Length (cm)	Claw Length (cm)	Last segment Length (cm)
8	2.97	0.20	-	-	-
16	3.02	0.26	-	-	-
24	3.27	0.76	-	-	-
32	3.59	1.01	-	-	-
40	4.65	1.73	-	-	-
48	5.26	2.37	-	-	-
56	5.79	3.02	1.24	1.24	0.32
64	6.24	4.36	2.46	2.45	0.39
72	7.16	4.99	2.99	3.33	0.75
80	7.69	5.56	3.11	3.60	0.49
88	7.81	6.35	3.75	3.80	0.64
96	8.19	7.08	3.99	4.08	0.70
104	8.69	7.54	4.25	4.34	0.75
112	9.31	8.17	4.52	4.67	0.78
120	10.05	8.81	4.91	5.04	0.81
128	10.71	9.68	5.29	5.56	0.84
136	11.261	10.26	5.56	5.87	0.92
144	11.794	10.64	5.81	6.15	1.07
152	12.386	10.99	6.10	6.49	1.17
160	12.847	11.59	6.34	6.72	1.39
168	13.882	11.97	6.85	7.32	2.92
176	14.67	12.67	7.42	8.14	3.3
184	16.79	13.56	8.30	9.43	3.7
192	18.456	14.54	9.12	10.32	3.9

Sex wise comparisons of models

The R^2 (%) values for overall body weight of males and females was between 19% and 89%, 10% and 86% respectively. ESS values were low for exponential model followed by log linear model for both sexes (Table 7). The R^2 (%) values for total length, head length, claw length and last segment length were ranged from 16% to 93%, 61% to 95%, 37% to 95% and 64% to 95% respectively for both sexes. ESS values were low for the exponential model followed by the log linear model for all the traits in both sexes (Table 6, 8, 9, 10).

Table 3. Estimated parameters and standard errors of different models for body weight and total length

Models	Equations for overall data	a ± SE	b ± SE	c ± SE	ESS	R^2%
Body weight						
Linear	Bw=4.4+0.15pond age	4.4 ± 0.09	0.15 ± 0.001		2525	78
Log linear	Bw=3.6+.153pond age	3.6±0.006	0.15±0.001		677	64
Polynomial	Bw=0.16+.004pond age+.0004 pond age^2	0.16±0.04	0.004±0.001	0.0004 ±0.000006	3326	93
Exponential	Bw=0.10*e $^{(3.9 \text{ *pond age})}$	0.10±-30.5	3.9±77.5		69229	56
Logistic	Bw=16/(1+((16-1.5)/1.5)*e(-0.0202*pond age))	16.0±0.003	1.5±0.001	0.020±0.0023	2563	98
Total length						
Linear	Tl=1.06+.08pondage	1.0 ± 0.05	0.08± 0.0007		31654	66
Log linear	Tl=0.8+.012/pond age	0.8± 0.008	0.01± 0.0001		859	63
Polynomial	Tl=.06+.09pond age+.00006pondage^2	0.6±0.09	0.09± 0.002	0.00006±0.000014	31553	66
Exponential	Tl=0.7*e $^{(29 \text{ *pond age})}$	0.7±0.006	29±0.005		3124	62
Logistic	Tl=20/(1+((20-2)/2)*e(-0.017*pond age))	20.6± 0.5	2.4±0.04	0.01± 0.0004	34167	90

Table 4. Estimated parameters and standard errors of different models for head length and claw length

Models	Equations for overall data	a ± SE	b ± SE	c ± SE	ESS	R^2%
Head length						
Linear	Hl=0.14+0.44pond age	0.14 ± 0.04	0.04 ± 0.0004		1325	73
Log linear	Hl=0.282+.0105pond age	0.2±0.01	0.01±0.0001		202	69
Polynomial	Hl=1.57+.0063pond age+0.00017pond age^2	1.5± 0.1	0.006± 0.002	0.0001± 0.00001	2726	75
Exponential	Hl = 0.02*e $^{(23.4 \text{ *pond age})}$	0.02±0.005	23.4±0.3		29	55
Logistic	Hl=161/(1+((1.4-.01)/1.4)*e(-0.0102*pond age))	161.5±213.9	1.4±0.0356	0.01±.0004	2705	95
Claw length						
Linear	Cl=0.32+.04pond age	0.3± 0.05	0.04±0.0005		3468	72
Log linear	Cl=3.8+0.15pond age	3.8±0.008	0.15±0.001		237	66
Polynomial	Cl=1.43+.008pond age+0.00018pond age^2	1.4± 0.1	0.008± 0.002	0.0001± 0.00001	3234	74
Exponential	Cl=0.009*e $^{(24 \text{ *pond age})}$	0.009±0.006	24.1±0.4		49	44
Logistic	Cl=54/(1+((1.38-0.011)/1.38)*e(-0.011*pond age))	54.3±9.9	1.3±0.03	0.01±0.0004	3222	94

Table 5. Estimated parameters and standard errors using of different models for last segment length

Models	Equations for overall data	a ± SE	b ± SE	c ± SE	ESS	R^2%
Linear	Lsl=0.38+0.01pond age	0.38 ± 0.01	0.01 ± 0.0001		108	67
Log linear	Lsl=1.8+.013pond age	1.8±0.01	0.01±0.0001		193	75
Polynomial	Lsl=0.82+.014pond age+0.00012pond age^2	0.8 ± 0.02	0.01± 0.0006	0.0001± 0.000002	3047	80
Exponential	Lsl=0.3*e $^{(183*pond\ age)}$	0.3±0.03	183.3 ±2.2		995	69
Logistic	Lsl=3.45/(1+((2.45-0.002)/0.002)*e(-0.001*pond age))	3.45±0.002	0.002±0.001	0.0001±0.000004	3562	62

Table 6. Estimated parameters and standard errors of different models for total length for different sexes

Model	Sex wise equations	a ± SE	b ± SE	c ± SE	ESS	R^2%
Male						
Linear	Tl=3.6+0.06pond age	3.6±0.23	0.06±0.002		9295	39
Log linear	Log Tl=1.6+.005pond age	1.6± 0.02	0.005±0.0002		95	33
Polynomial	Tl=14.7+0.16pond age-.0010pon^{2}nd age^2	14.7±0.58	0.16± 0.01	0.001± 0.00005	6898	55
Exponential	Tl=0.05*e $^{(4.8\ *pond\ age)}$	0.05±0.003	4.8±0.27		1	29
Logistic	Tl=24/(1+((24-5.)/5)*e(-0.006*pond age))	24±0.0024	5.0± 0.11	0.006±0.00018	8309	93
Female						
Linear	Tl=3.16+.05pond age	3.1 ± 0.1	0.05 ± 0.001		12744	41
Log linear	LogTl=1.4+.006pond age	1.4± 0.01	0.006±0.0002		219	31
Polynomial	Tl=11.3+.11pond age+.0008pon^{2}d age	11.3± 0.4	0.11 ± 0.008	0.0008 ±0.00003	10550	51
Exponential	Tl=0.06*e $^{(5.9\ *pond\ age)}$	0.06± 0.003	5.9± 0.2		5	16
Logistic	Tl=20/(1+((20-5.)/5)*e(-0.004*pond	20±0.002	5.0±0.005	0.004±0.0003	573	74

Table 7. Estimated parameters and standard errors of different models for body weight for different sexes

Models	Sex wise equations	a ± SE	b ± SE	c ± SE	ESS	R^2%
Male						
Linear	Bw=2.3+.08pond age	2.2± 0.2	0.08 ± 0.002		7959	54
Log linear	LogBw=0.27+0.013pond age	0.2± 0.05	0.01± 0.0005		456	36
Polynomial	Bw=8.5+0.12pond age+.0009pond age²	8.5± 0.5	0.1 ± 0.01	0.0009 ± 0.00004	5918	66
Exponential	Bw=0.1*e $^{(36 \text{ *pond age})}$	0.1±0.02	36.8±2.1		95	19
Logistic	Bw=14.6/(1+((14.6-1.7)/1.7)*e(-0.012*pond age))	14.6± 031	1.7 ±0.05	0.01 ± 0.0002	6313	89
Female						
Linear	Bw=2.0+0.07pond age	2.0± 0.13	0.07 ± 0.001		10792	56
Log linear	Log Bw=1.3+0.04 pond age	1.3±0.18	0.04±0.02		3124	61
Polynomial	Bw=6.0+.09pond age+.00078pondn Nd age²	6.0± 0.3	0.09± 0.007	0.0007± 0.00003	8676	65
Exponential	Bw=0.2*e $^{(62.5 \text{ *pond age})}$	0.2±0.05	62.5±3.9		1052	10
Logistic	Bw=13.7/(1+((13.7-1.2)/1.2)*e(-0..0136*pond age))	13.7±2.1	1.2±0.06	0.01 ± 0.0007	9097	86

Table 8. Estimated parameters and standard errors of different models for head length for different sexes

Models	Sex wise equations	a ± SE	b ± SE	c ± SE	ESS	R^2%
Male						
Linear	Hl=0.51+.04pond age	0.5 ± 0.1	0.04± 0.001		1219	66
Log linear	Log Hl=0.51+.009pond age	0.5±0.02	0.009±0.0002		40	66
Polynomial	Hl=3.46+.022pond age+.00 030pond age²	3.4± 0.3	0.02± 0.005	0.0003± 0.00002	1045	71
Exponential	Hl=0.01*e $^{(21.2 \text{ *pond age})}$	0.01±0.006	21.2±0.5		3	61
Logistic	Hl=8.8/(1+((8.8-1.7)/1.7)*e(-0.009*pond age))	8.8±0.06	1.7±0.0401	0.009±0.0001	2345	95
Female						
Linear	Hl=0.45+.04pond age	0.4 ± 0.06	0.04± 0.0006		1325	74
Log linear	LogHl=.21+.010pond age	0.2±0.01	0.01±0.0001		105	67
Polynomial	Hl=1.36+0.008pond age+.000 016pond age²	1.3± 0.2	0.008± 0.003	0.0001±0.00001	1252	75
Exponential	Hl=0.01*e $^{(20 \text{ *pond age})}$	0.01±0.006	20.0±0.5		2	62
Logistic	Hl=7.8/(1+((8.8-1.5)/1.5)*e(-0.009*pond age))	7.8±0.008	1.5±0.003	0.009±0.0003	4576	78

Table 9. Estimated parameters and standard errors of different models for claw length for different sexes

Models	Sex wise equations	a ± SE	b ± SE	c ± SE	ESS	R^2%
Male						
Linear	Cl=0.8+.05pond age	0.8±0.1	0.05± 0.001		1404	65
Log linear	Log Cl=3.9+0.11pond age	3.9±0.01	0.11±0.003		47	59
Polynomial	Cl=3.6+0.02pond age+.0003 Pond age^2	3.6± 0.3	0.02± 0.006	0.0003± 0.00002	1210	70
Exponential	Cl=0.01*e $^{(20 *pond\ age)}$	0.01±0.006	20.0±0.5		34	62
Logistic	Cl=10..4/(1+((10.4-1.8)/1.8)*e(-0.009*pond age))	10.4±0.003	1.8±0.04	0.009±0.0001	1202	95
Female						
Linear	Cl=0.74+.04 pond age	0.7± 0.07	0.04± 0.0007		1532	74
Log linear	LogCl=3.9+0.14pond age	3.9± 0.01	0.14±0.002		127	69
Polynomial	Cl=1.03+0.012pond age+0 .00015pond age^2	1.0 ±0.2	0.0 ± 0.004	0.0001±0.000012	1462	75
Exponential	Cl=0.04*e $^{(31.4*pond\ age)}$	0.042±0.01	31.4±1.03		34	37
Logistic	Cl=9.8/(1+((9.8-1.14)/1.14)*e(-0.013*pond age))	9.8±3.6	1.14±0.051	0.013± 0.0007	1466	95

Table 10. Estimated parameters and standard errors of different models for last segment length for different sexes

Models	Sex wise equations	a± SE	b±SE	c ± SE	ESS	R^2%
Male						
Linear	Lsl=0.62+0.015pond age	0.6±0.03	0.01±0.0003		126	65
Log linear	Loglsl=1.5+.013pond age	1.5±0.02	0.01±0.0002		50	78
Polynomial	Lsl=1.62+.028pond age+.00019pond age^2	1.6± 0.07	0.02± 0.001	0.00019± 0.000005	58	84
Exponential	Lsl=0.19*e $^{(150.5*pond\ age)}$	0.19±0.03	150.5±3.16		102	71
Logistic	Lsl=4.0/(1+((4-0.05)/0.05)*e(-0.0136*pond age	4.0±0.01	0.05±0.03	0.013±0.01	245	64
Female						
Linear	Lsl=0.44+.011pond age	0.44 ± 0.01	0.01 ± 0.0001		108	71
Log linear	Loglsl=1.8+.013pond age	1.8±0.01	0.01±0.0001		77	81
Polynomial	Lsl=1.02+.017pond age+0.00012pond age^2	1.0± 0.04	0.01± 0.0008	0.0001±0.000003	60	83
Exponential	Lsl=0.3*e $^{(194.9 *pond\ age)}$	0.3±0.04	194.9±3.4		393	66
Logistic	Lsl=3.3/(1+((4-0.03)/0.03)*e(-0.0136*pond age	3.3±0.05	0.03±0.09	0.013±0.05	2345	67

Comparison of model parameters

The best fitting model for overall body weight having highest R^2 value and lowest ESS was logistic model and the equation was BW=16/(1+((16-1.5)/1.5)*e (0.0202*pond age)), where the parameters include a horizontal asymptote (a) of 16, an initial value (b) of 1.5 and the growth rate per pond age (c=0.0202) (Table 3). But the initial value (b) was 1.7 and 1.2, horizontal asymptote (a) was 14.6 and 13.7 and the rate of growth was 0.01 and 0.01 respectively for males and females (Table 7). Other models fitted were having slope (rate of growth) value of 0.08-0.07. Similar slope value (linear rate of growth b) was estimated for both linear and 2nd degree polynomial models with values of 0.08 and 0.07 for males respectively and was higher than that obtained for females (linear, 0.08 and polynomial, 0.1) (Table 7). The estimated parameters for exponential models obtained values for initial body weight (a =0.1) and rate of growth was 36.8 (b=36.8) (Table 7).

For total length, the intercept (Initial value-a) of linear and polynomial model was higher for males (3.6 and 14.7 respectively) in comparison to females with intercepts 3.1 and 11.3 respectively. Estimated slope value obtained for linear and 2nd degree polynomial models were 0.06 and 0.16 for males and were higher than the slope obtained for females with values 0.05 and 0.11 respectively. The log linear model obtained intercept for males 1.6 and females (1.4) and the slope was 0.005 for males, which was slightly lower than that of females (0.006) (Table 6). The ESS was considerably reduced by fitting 2nd degree polynomial and linear models for males, but the R^2 value was very low (33 for females and 55 for males) for 2nd degree polynomial model. The R^2 value obtained for logistic model and exponential models was in the range of 98% and 29% for both the sexes indicating logistic model as best fit model (Table 6).

Estimated slope value for head length of male was 0.5 for linear model, while it was higher for males (0.5) in comparison to that of females (0.4). For log linear and polynomial models estimated slope values were 0.5 and 3.4 respectively for males, which are higher than females (0.2 and 1.3 respectively) (Table 8). Estimated initial value for head length (0.01) for exponential model was similar for both male and female. In males higher slope value was obtained (0.21) followed by females with growth rate 0.2. For logistic model the slope (growth rate parameter c) of males and females was similar (0.009) (Table 8).

For claw length the intercept value of log linear and polynomial model was higher for males (3.9 and 3.6) in comparison to intercept value of females (3.9 and 1.0) respectively. For the linear model the intercept value of male (0.8) was higher than female (0.7). In case of exponential and logistic models the initial value (a) was higher for male (0.01 and 10.4 respectively) compared to initial value (a) of female (0.042 and 9.8 respectively). ESS was minimum estimated in log linear model and exponential model compared to the other models in both the sexes (Table 9).

The estimated intercept values of linear and log linear models were higher in male (0.6 and 1.5) compared to females (0.44 and 1.8) respectively for last segment length. Polynomial model showed the highest intercept value for males (1.6) than the intercept value of females (1.0). The initial values of exponential and logistic models were high in males (0.04 and 0.05) compared to females (0.02 and 0.03) respectively. The ESS value was lowest for the log linear model and polynomial model for both the sexes (Table 10).

DISCUSSION

Five models viz., linear, log linear, polynomial, exponential and logistic models were tested for their goodness of fit to develop a best suitable growth model for *M. rosenbergii*. Based on analysis of R^2 values from linear, log linear, polynomial, exponential and logistic models were found to be explaining 78, 64, 93, 56 and 98% of variation in body weight of *M. rosenbergii* for overall values in response to pond age. Apart from R^2 value, ESS values were also considered to identify the model that is best fitting. The model that shows highest R^2 value with low ESS was regarded as the best fit model. Among the models tested logistic model showed lowest ESS with high R^2 value making it the best model for overall and sex-wise body weights of *M. rosenbergii*. In the experiment conducted by Katsanevakis (2006) revealed that the Gompertz model was found to be the best among all the candidate models for the yellowfin tuna. The logistic model was also supported to some extent by the data, while all the other models had considerably less support.

In case of total length linear, log linear, polynomial, exponential and logistic models showed R^2 values of 66, 63, 66, 62 and 90%. Among the models log linear model was considered as the best fit model as it had lowest ESS value even though the highest R^2 value was registered by the logistic model. For head length linear model with R^2 value of 73% with minimum ESS value was considered as best fit model. Claw length was explained by the logistic model with R^2 value of 94% with minimum ESS value while last segment length was explained by the log linear model with R^2 value of 75% and low ESS.

Sarmento *et al.* (2006) studied Brody, Von Bertalanffy, Logistic, Gompertz and Richards' models to identify a model that best explains the average growth curve of Santa Ines sheep. The results show that the growth curve was well fitted by all models but larger residual variation was obtained by the Brody and Logistic models. According to the absolute average residual error, the Gompertz model showed a better fit than the models Von Bertalanffy and Richards. Growth curves differed for males and females, born from single and twin lambing. Contemporary group, type of birth and sex significantly affected the estimation of parameters A and K.

Tsukahara *et al.* (2008) investigated growth patterns of goats utilizing data from a crossbreeding program involving the exotic German Fawn (GF) and the indigenous Kambing Katjang (KK) goats using four growth curve models (Brody, Bertalanffy, Gompertz and Logistic). By comparing the R^2 values among genotypes it was reported that the goodness of fit is highest in the Brody model in most cases. Sousa *et al.* (2010) suggested that polynomial functions are efficient tools for modeling growth curve and polynomials of at least fourth order should be used for modeling the average growth curve of goat in random regression models. Malhadoa *et al.* (2009) analyzed Brody, Von Bertalanffy, Richards, Logistic and Gompertz functions in order to describe the growth in crossbred sheep Dorper×Morada Nova (DMN), Dorper×Rabo Largo (DRL) and Dorper×Santa Inês (DSI) and reported that both Gompertz and Logistic functions presented the best adjustment, being the latter slightly superior. All these reports including the present findings suggest that growth models can have immense application in predicting the growth as a function of time.

In conclusion, among the five models tested, logistic model was found to be the best model for overall body weight with an R^2 value of 96% and low ESS value that can better describe the growth pattern in *M. rosenbergii* reared in the conditions used in the present study. Among the both sexes males showed high R^2 value of 89% while females showed 86%. For last segment length, the best model was found to be the log linear model with a R^2 value of 75 and low ESS value. These models can be used to predict growth rates in *M. rosenbergii*. However, further studies need to be conducted with even more growth traits taken into consideration to arrive at a better growth curve model that can potentially predict the growth patterns in *M. rosenbergii*.

CONCLUSION

The present study concludes the models that were found to be best fit for different growth traits could be used to predict growth patterns in *M. rosenbergii* when cultured in the same environmental conditions. However, several factors like age, sex and environmental factors greatly affect these growth models. Therefore care should be taken in employing such growth models for selective breeding programs. Further studies need to be conducted with even more growth traits and different age groups taken into consideration to arrive at a better growth curve model that can potentially predict the growth patterns in *M. rosenbergii*.

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