Indian J. Fish., 68(4): 142-145, 2021
DOI: 10.21077/ijf.2021.68.4.88965-16

Note

Modeling seasonal growth of *Tor tor* (Hamilton, 1822) in pond environment

N. OKENDRO SINGH[1], CH. BASUDHA[2], N. GOPIMOHAN SINGH[1] AND SURINDER KUMAR[3]
[1]*College of Agriculture, Central Agriculture University, Iroisemba, Imphal - 795 004, Manipur, India*
[2]*ICAR Research Complex for North-Eastern Hill Region, Manipur Centre, Imphal - 795 004, Manipur, India*
[3]*Department of Applied Statistics, Baba Saheb Bhimrao Ambedkar University, Lucknow - 226 025, Uttar Pradesh, India*
e-mail: nosingh2000@yahoo.com

ABSTRACT

The present investigation attempted to determine the seasonal growth of *Tor tor* (Hamilton, 1822) in different ponds in Manipur, North-east India, by fitting non-linear models and their modified forms. Gompertz model performed better than other models irrespective of different ponds, when they were fitted to the growth data of *T. tor*. Gompertz model with sine wave function was found to be the best fitted model to the growth of *T. tor*.

Keywords: Growth modeling, Sport fishing, Tor mahseer, von Bertalanffy growth model

The genus *Tor* includes *Tor tor* (Hamilton, 1822) and nine other species, popularly known as 'mahseer' in India (Desai, 2003). Among Indian mahseers, *T. tor* is an important food as well as game fish. An endangered upland fish species, the tor mahseer is an important source of food for the inhabitants of hilly areas and a source of recreation to innumerable local anglers as well as anglers from abroad. It is well known that the growth of fish does not proceed at the same rate throughout the year as a result of fluctuations in the aquatic environment mainly related to temperature and food (Fulton, 1901). Many authors (Sparre, 1990; Pauly *et al*., 1992) discussed the need to use a seasonal version of the growth models. The von-Bertalanffy growth (VBG) model was modified by addition of a sine wave function to adjust for seasonal variations by Pitcher and MacDonald (1973) and seasonally oscillating versions of the von-Bertalanffy growth model have also been developed by Somers (1988) and by Hoenig and Hanumara (1990). Moreover Singh *et al*. (2009a) observed that, von-Bertalanffy growth model is the best fitted model for growth of *Tor putitora* in different aquatic environments of Kumaun lakes and Gobindsagar Reservoir. However, Singh *et al*. (2009b) found that a modified logistic model with sine wave function was appropriate to explain the growth of *T. putitora* in the foothill of river Ganga and upstream tributary Nayar. The present study attempts to find a suitable growth model of *T. tor* that can incorporate the highly fluctuating conditions of pond environments in Manipur, North-east India, using a modified version of Gompertz growth model.

River Barak is the biggest river in the southern part of the North-eastern Hill region of India flowing through the Barak valley region of Assam. Barak originates from Japvo peak in Nagaland (N 25028' E 94017') (at approx 3353.65 m.s.l.) and flows through Karong Village along the Manipur-Nagaland border, drains almost the entire Manipur valley before entering Assam. To study the growth performance, 260 numbers of *T. tor* having average weight and length of 1.7 g and 2.9 cm respectively were randomly collected using ordinary net from the River Barak at Nungba, Tamenglong District of Manipur in the month of April 2016. Of these, 200 fishes were stocked in a pond at Rongdai Village of Nungba, Manipur and the remaining 62 fishes were stocked in a pond at ICAR Research Complex, Imphal, Manipur maintaining approximately the same conditions and density of fish. During the rearing period of nearly one year, fishes were fed with a mixture of rice bran and oilcake. Size of fish in terms of total length in cm and total weight in g were recorded by measuring 10 individual fishes randomly at an equal interval of 30 days during May, 2016 - April, 2017. The total length of the fish was measured from the tip of the snout to the tip of the longer lobe of the caudal fin, usually measured with the lobes compressed along the midline. The basic information of the observed growth data of *T. tor* is presented in Table 1. The data collected on fish from the two different pond environments were further used for growth study through statistical modeling.

The following are some of the most commonly used non-linear models in fisheries that have been used to fit the growth data sets of *T. tor*:

Von-Bertalanffy growth model:

$$L_t = L_\infty \left[1 - e^{-K(t - t_0)}\right] + e_t \quad \text{.......(1)}$$

Gompertz growth model:

$$L_t = L_\infty \exp\left[-\exp\left\{-K(t-t_0)\right\}\right] + e_t \quad \text{.......(2)}$$

Logistic growth model:

$$L_t = L_\infty \left[1 + e^{-K(t-t_0)}\right]^{-1} + e_t \quad \text{.......(3)}$$

where, L_t = Fish length at age t; L_∞ = Asymptotic length; K = Growth coefficient; t = Age; t_0 = Theoretical age when fish was of length zero; e_t = The error term associated with time t

The von Bertalanffy growth model with the sine wave function introduced by Pitcher and MacDonald (1973) is as follows:

$$L_t = L_\infty \left(1 - e^{-\left[C \sin\left(\frac{2\pi(t-S)}{52}\right) + K(t-t_0)\right]}\right) + e_t \quad \text{.......(4)}$$

where C describes the magnitude of the growth oscillations around a non-seasonal or non-fluctuating growth curve, S is the starting point (relates to phase) and 52 indicates a time scale in weeks. Using P, rather than a fixed 52 weeks of equation (4), extends the scope of the model:

$$L_t = L_\infty \left(1 - e^{-\left[C \sin\left(\frac{2\pi(t-S)}{P}\right) + K(t-t_0)\right]}\right) + e_t \quad \text{.......(5)}$$

where P is the period of the cycle.

In the similar fashion, when a sine wave function is added to the Gompertz model of equation (2), it becomes:

$$L_t = L_\infty \exp\left[-\exp\left\{-\left(C \sin\left(\frac{2\pi(t-S)}{P}\right) + K(t-t_0)\right)\right\}\right] + e_t \quad \text{....(6)}$$

Ratkowsky (1990) explained about non-linear models in detail and gave different forms of R^2 for them. The most commonly used "Levenberg-Marquardt Method" is applied to estimate the parameters *viz*, L_∞, K and t_0. in the present study. For selecting the best-fit model, MSE (mean square error) and MAE (mean absolute error) are used:

$$MSE = \frac{1}{(n-p)} \sum_{t=1}^{n} (L_t - L_t)^2 \quad \text{.......(7)}$$

$$MAE = \frac{1}{n} \sum_{t=1}^{n} \left|L_t - L_t\right| \quad \text{.......(8)}$$

where, L_t = Predicted length (in cm) of the fish at time t; n = No. of observations and p = No. of parameters involved in the model; t - 1, 2,......,n.

The best model will have the least values of MSE and MAE. It is, further, recommended that residual analysis for independence or randomness be carried out to check the assumptions of the growth model. This was done using the run test procedure (Ratkowsky, 1990). Although the normality assumption is not so stringent for selecting non-linear models because their residuals may not follow normal distribution, testing the normality assumption of residuals was performed by Shapiro-Wilk test in the present study.

The fish growth data was fitted to different non-linear models given by equations (1) to (3) using SAS 9.3 and IBM SPSS 22.0 versions available at College of Agriculture, CAU, Imphal, Manipur (India). Different sets of initial parameter values were attempted so that a global convergence criterion was met for fitting the non-linear models. The global convergence criterion was met only for two models, the logistic and Gompertz, out of the three models considered. The estimates of parameters, MSE, MAE, run test statistic (|*Z*|) value and Shapiro-Wilk test p-value for the above two models under different pond environments are presented in Table 2. Gompertz model showed better performance than the other model when the criteria of MSE and MAE were used to identify the best-fit model irrespective of the different pond environments. The asymptotic fish length was higher in the pond environment of ICAR Research Complex, Imphal, however, the growth rate of fish was higher in the village pond at Rongdai, Manipur. Furthermore, the assumption of independence of residuals was also satisfied since the run test |*Z*| values (Table 2) were below the critical value of 1.96 at 5% level of significance. The significance values of Shapiro-Wilk test for residuals clearly indicate ($p>0.05$) that residuals were normally distributed. From visual inspection of Fig. 1a and 1b, it is evident that when residuals were plotted against the respective expected lengths, the residuals followed a definite pattern. Hence we added a sine wave function to the model as a possible solution. The von-Bertalanffy growth model with a sine wave function of equation (4) failed to give optimal solution for the present dataset considered. The modified version of the Gompertz model was again fitted to the above dataset and the parameter estimates are given in Table 2. The values of MSE and MAE were significantly improved, as compared to the simple Gompertz and logistic models and the corresponding run test (|*Z*|) values were also less than the critical value of 1.96, which indicated that the assumption of randomness was satisfied. The modified version of the Gompertz model described the *T. tor* data of the pond environments in Manipur better than other popular growth models. Thus, Gompertz model with sine wave function was adjudged to be the best fit, which is depicted in Fig. 2a and 2b for ponds at ICAR, Lamphelpat, Imphal and Rongdai Village, Nungba, Manipur respectively. The asymptotic sizes of *T. tor* estimated by the Gompertz with sine wave function are approximately 29.44 and 26.38 cm under different pond conditions at ICAR Research Complex, Imphal and Rongdai Village, Manipur respectively.

Table 1. Basic information of the observed growth data of *T. tor*

	Pond at ICAR Research Complex, Lamphelpat	Pond at Rongdai Village, Manipur
No. of observations (months)	12	12
Average fish length (cm)	13.42	10.58
Standard deviation	5.52	4.13
Maximum length of fish (cm)	21.80	16.35
Minimum length of fish (cm)	2.92	2.92

Table 2. Summary statistics for fitting various growth models on growth data of *T. tor*

	Pond at ICAR Research Complex, Imphal			Pond at Rongdai Village, Manipur		
	Logistic	Gompertz	Gompertz with Sine wave	Logistic	Gompertz	Gompertz with Sine wave
Parameter estimates						
L_∞	22.07 (2.54)	23.42 (3.13)	29.44 (4.86)	15.01 (0.71)	15.76 (0.89)	26.38 (11.85)
K	0.32 (0.08)	0.22 (0.06)	0.26 (0.18)	0.46 (0.08)	0.31 (0.05)	0.14 (0.05)
t_0	4.71(0.93)	3.27 (0.71)	5.57 (1.48)	3.60 (0.35)	2.55 (0.28)	5.74 (3.86)
C	-	-	0.49 (0.72)	-	-	0.18 (0.03)
S	-	-	14.60 (5.21)	-	-	13.08 (1.61)
P	-	-	15.45 (10.19)	-	-	10.47 (2.62)
Model adequacy						
MSE	2.22	1.76	0.19	0.80	0.62	0.13
MAE	1.13	1.00	0.26	0.62	0.53	0.16
Residual analysis						
Run test (|Z|)	1.54	1.54	0.42	1.46	1.46	1.51
Shapiro-Wilk test p value	0.68	0.40	0.80	0.73	0.65	0.40

Figures in parentheses are the corresponding asymptotic standard errors.

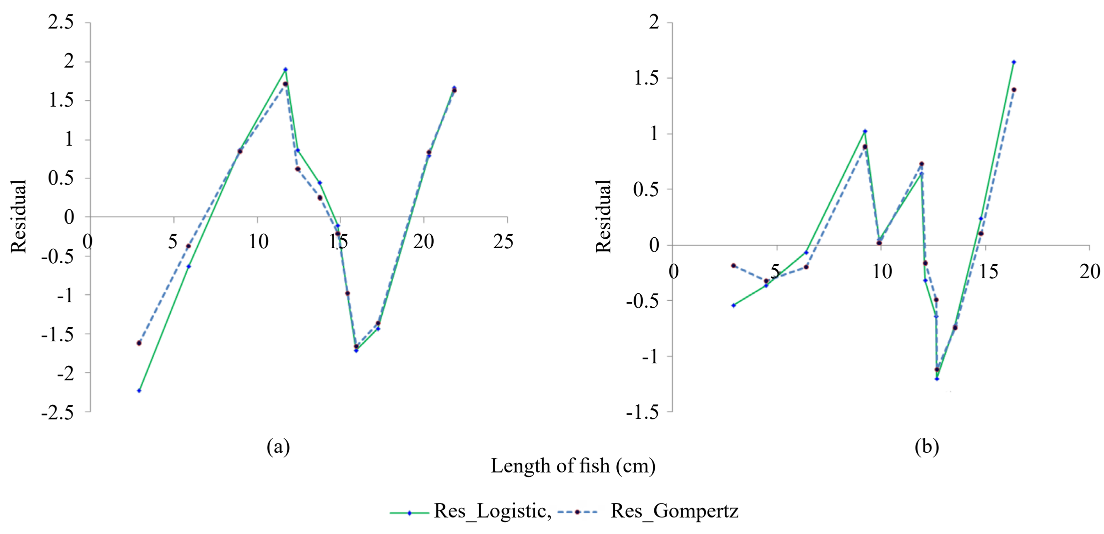

Fig. 1. The residuals remaining after fitting of Gompertz and logistic models to the growth data of *T. tor* under pond condition at (a) ICAR Research Complex, Lamphelpat, Imphal; (b) Rongdai Village, Nungba, Tamenglong District of Manipur

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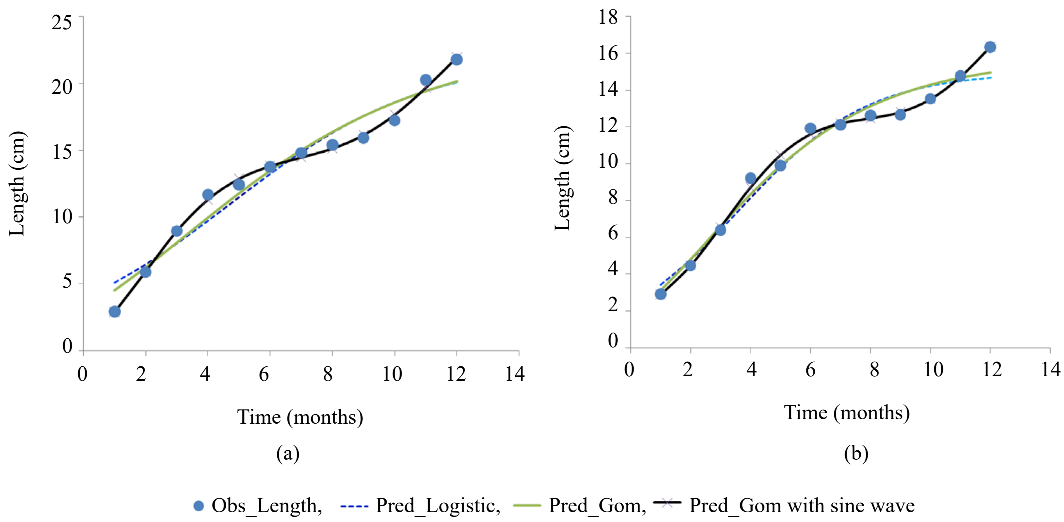

Fig. 2. Graphical display of observed and predicted growth of *T. tor* under pond condition at (a) ICAR Research Complex, Lamphelpat, Imphal (Gompertz model with sine wave is adjudged to be the best fit); (b) Rongdai Village, Nungba, Tamenglong District of Manipur (Gompertz model with sine wave is adjudged to be the best fit)

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Date of Receipt : 16.04.2019
Date of Acceptance : 06.12.2021