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Research Note

Statistical Models for Estimating Trend and Growth Rate of Shrimp Culture and Production in India

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Abstract

Linear and non-linear parametric regression models were fitted to the secondary data on area under culture and production of different species cultured crustaceans viz: Tiger shrimp (*Penaeus monodon*), White leg shrimp (*Litopenaeus vannamei*) and Scampi (*Macrobracium rosenbergii*) to estimate the trend growth rate. Linear regression models like simple and polynomial models and non-linear models like Monomolecular, Logistic and Gompertz models were fitted to the data on total area under culture (AUC) and total production (P) as well as selected species wise shrimp culture and production using ordinary least square (OLS) method. Logistic model was found to be the best fitted model for total AUC and shrimp production. The estimated growth rate of total AUC was 0.138 ha/ year and total production was 0.379 tonnes/year. Gompertz model was the best fitted model for both AUC and production data of white leg shrimp, and cubic model was the best fitted model for AUC and production of Tiger shrimp and Scampi. In general, it was observed that the total area under culture and shrimp production in India is increasing. The introduction of White leg shrimp contributed significantly to the increase in total AUC and production of Shrimp in India. Based on the estimated carrying capacity of AUC and production of total shrimp and White leg shrimp indicated that there is further potential to increase the AUC and production of shrimp in India.

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Introduction

Commercial shrimp farming in India started its roots only during the mid-eighties and later shrimp farming sector grew rapidly with the introduction of new species and technologies. Shrimp is the most important commodity in India's fish export basket, accounting for about two-third of the total fish export value. With such explosive growth, the country has established itself as the second-largest farmed-shrimp producer in the world. Shrimp farming also supports the rural livelihood of the people, which provides social and economic stability to the rural population. The major species of cultured crustaceans in India include white leg shrimp (*Litopenaeus Vannamei*), Tiger shrimp (*Penaeus Monodon*) and scampi (*Macrobracium Rosenbergii*). The growth of total area under culture (AUC) and production of shrimp has increased exponentially. Growth rate of a commodity is considered as an important economic factor for policy formulation and implementation (Panse, 1964; Dey, 1975; Reddy, 1978). The growth rate of AUC and production can be estimated using linear and nonlinear statistical growth models (Lorenzen, 1990; Prajneshu, 2005). The present study used linear and nonlinear growth models to estimate the trend and growth rate of AUC and production of shrimp in India.

The study used all India secondary data on area under culture (AUC) and production of three major species of cultured crustaceans viz: Tiger shrimp (*Penaeus monodon*), White leg shrimp (*Litopenaeus vannamei*), scampi (*Macrobracium rosenbergii*) collected from Marine Products Exports Development

Authority (MPEDA) for the period 2000-2020. These three species were only considered because these three species together accounts nearly 90 % of the total AUC and production. The Linear models used in the study were linear, quadratic and cubic models, whose mathematical expression is given in Equation (1). The parameters of the linear models were estimated by ordinary least square method (OLS) as given by Montgomery et al. (2008). The nonlinear models used were Monomolecular, Logistic and Gompertz models, whose mathematical expressions are given in Equations (2), (3) and (4), respectively. The detail description about the nonlinear models is given by Gallant (1987). The parameters of nonlinear models were estimated by OLS method employing Levenberg–Marquardt algorithm as given by Seber & Wild (2003) using SAS 9.3 (SAS Institute Inc., 2011). The goodness of fit of linear and nonlinear models were assessed using coefficient of determination (R^2) and root mean square error (RMSE) criteria (Kvalseth, 1985). The model with the highest R^2 value and the lowest RMSE value was selected as the best fitted model to estimate and describe the growth rate.

$$Y_t = b_0 + \Sigma_{i=1}^{3} b_i t^i + \epsilon_t \quad (1)$$

$$Y_t = C - (C - Y_0)\exp(-rt) + \epsilon_t \quad (2)$$

$$Y_t = \frac{C}{[1 + (CY_0 - 1)\exp(-rt)]} + \epsilon_t \quad (3)$$

$$Y_t = C\exp[\log(Y_0 C)\exp(-rt)] + \epsilon_t \quad (4)$$

where b_0 is the intercept and b_i is the growth rate of linear regression models, Y_0 is the value of Y at t = 0, C is the carrying capacity, r is the intrinsic growth rate of nonlinear models and ϵ_t is the error term associated with the Y_t assumed to have zero mean and constant variance.

It was observed from the Fig. 1 that the total AUC and production of shrimp has increased during the period 2010 – 2020. Logistic model was found to be best fitted model for total AUC and production of shrimp with the highest R^2 and the lowest RMSE values. The parameters estimated along with the standard error are given in Table 1. The estimated growth rate for total AUC was 0.14 ha/year and production was 0.38 tonnes/year; the estimated carrying capacity was 172716.8 ha for total AUC and 870527.6 tonnes for total shrimp production.

The white leg shrimp was introduced India by 2010. Since then, the AUC and production of white leg shrimp increased exponentially (Fig. 2). Gomeprtz model was found to be the best fitted model for AUC and production of white leg shrimp (Table 1). The estimated growth rates were 0.46 ha/year and 0.32 tonnes/year respectively for AUC and production of white leg shrimp respectively; the estimated carrying capacity for AUC was 97875.41 ha and for production was 843862.81 tonnes. The observed and predicted values of AUC and production of white leg shrimp is given in Fig. 2.

The AUC and production of Tiger shrimp was found to be declining (Fig. 3) during the period 2002 - 2020. Cubic model was found to be the best fitted model for Tiger shrimp. The estimated parameters and statistics are given in Table 1. The AUC of Tiger shrimp was declining at a rate of 908.04 ha/year and the production was declining at a rate of 890.72

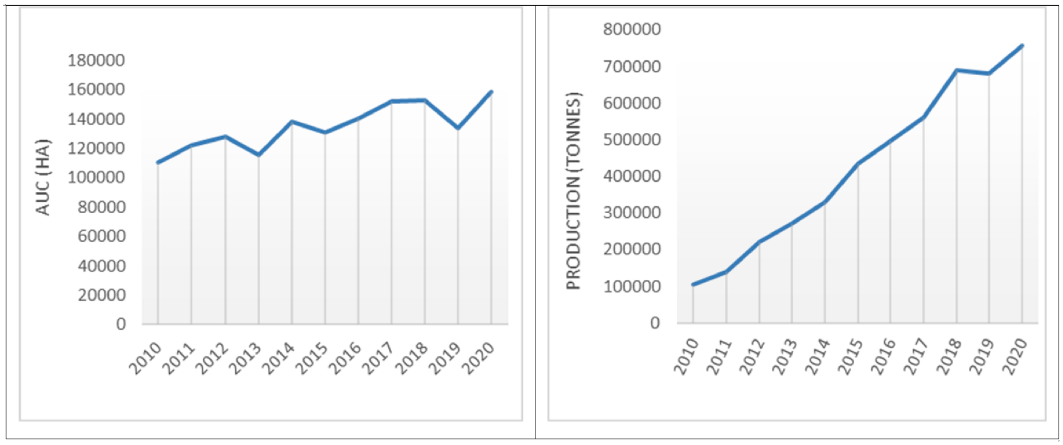

Fig. 1. Total AUC and production of shrimp

tonnes per year. The observed and predicted values of AUC and production of Tiger shrimp is given in Fig. 3.

The AUC and production Scampi had a mixed trend; initially it showed an increasing trend till 2004, then both the AUC and production declined up to 2015 and gradually increased there after (Fig. 4). The estimated parameters are given in Table 1.

The best fitted models were then used to predict the future value of total and species wise AUC and production of shrimp, which is given in Table 2. One step ahead prediction error (OSAPE) for total and each species wise AUC and production was compared and it was less than 10 % for the future values. The total AUC and production of shrimp in India is predicted to increase in the future with substantial contribution from White leg shrimp, whereas the AUC and production of Tiger shrimp is predicted to have ups and down in the future. Similarly, the structural changes in the Scampi production in India was observed by Rajani & Balasubramanian (2020). The introduction of White leg shrimp in India for culture practices is the major reason for increase in shrimp production in India and increase in the export of frozen shrimp as indicated by MPEDA

Table 1. Estimated parameters of the best fitted models with goodness of fit statistics

Species	Models	Yt	Parameters	Estimate	Standard error	R^2	RMSE
Total	Logistic	P	C	870527.63	49266.75		
			Y_0	10.229	1.08	0.994	20613.98
			r	0.379	0.032		
		AUC	C	172716.8	55275.13		
			Y_0	0.607	0.414	0.723	9826.249
			r	0.138	0.165		
White leg	Gompertz	P	C	843862.81	60379.65		
			Y_0	6.09	0.869	0.994	21809.89
			r	0.315	0.637		
		AUC	C	97875.414	11855.33		
			Y_0	8.483	5.385	0.941	10095.79
			r	0.462	0.153		
Tiger	Cubic	P	b3	100409.730	21699.39		
			b2	8493.273	9155.79	0.708	17011.29
			b1	-890.717	1049.60		
			b0	14.294	34.55		
		AUC	b3	155215.272	9989.13		
			b2	909.167	4214.79	0.952	7831
			b1	-908.004	483.17		
			b0	30.845	15.90		
Scampi	Cubic	P	b3	27256.247	8073.00		
			b2	4533.865	3417.12	0.776	6111.18
			b1	-964.673	394.89		
			b0	36.508	13.08		
		AUC	b3	26636.113	11488.68		
			b2	9717.738	5773.60	0.768	6695.48
			b1	-1858.238	789.78		
			b0	74.981	30.82		

P - Production (tonnes); AUC - area under culture (ha)

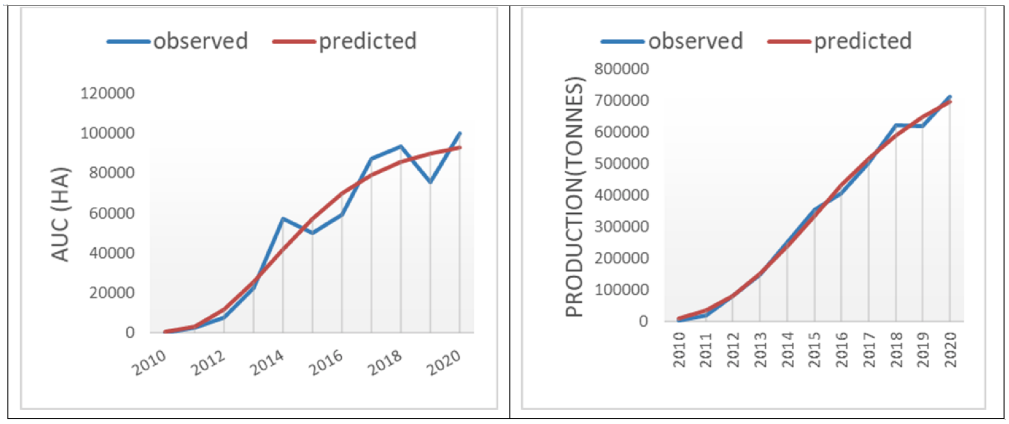

Fig. 2. The observed and predicted values of AUC and production of white leg shrimp

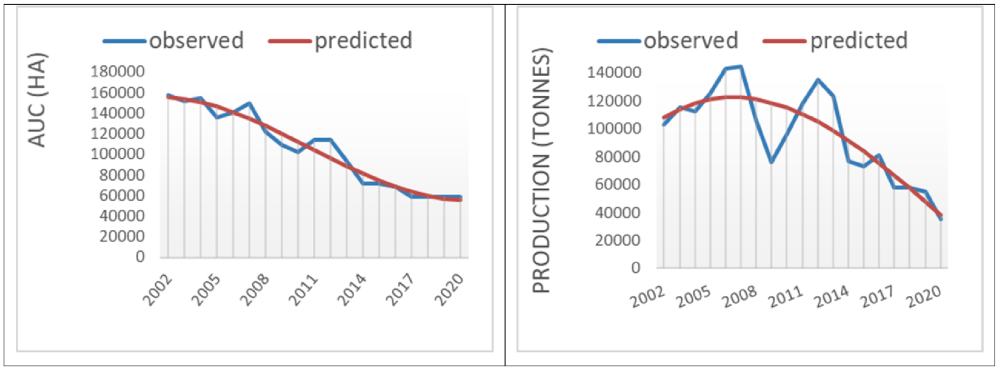

Fig. 3. The observed and predicted values of AUC and production of Tiger shrimp

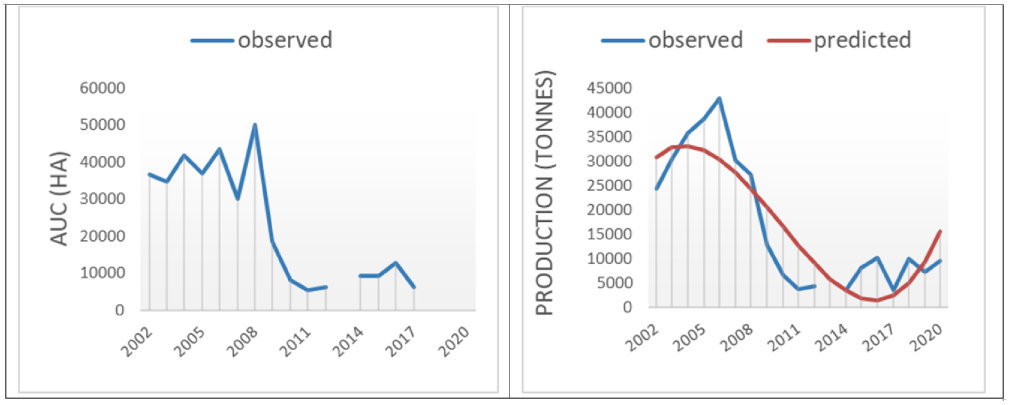

Fig. 4. The observed and predicted values of AUC and production of Scampi

(2022b). Kumaran et al. (2017) found in a comprehensive study that mean technical efficiency of white leg shrimp farms in the country was 0.9013, indicating that the farms achieved 90 % of the maximum possible output from a given set of inputs. White leg shrimp culture industry has seen a rapid expansion in the last few years mainly due to faster growth, which gained popularity among the Indian farmers. The state of Andhra Pradesh has been leading in white leg shrimp farming contributing nearly 80 % of total production in India. Due to the higher net returns, the production of white leg shrimp stands ahead of other species in India as reported by Nisar et al. (2021).

Table 2. Forecasted values of AUC and production (P)

Year	Total		White leg shrimp		Tiger shrimp	
	AUC (ha)	P (Tonnes)	AUC (ha)	P (Tonnes)	AUC (ha)	P (Tonnes)
2021	154219	785000	94678	733790	56953	28339
2022	155693	810080	95848	761994	59529	18338
2023	156678	828201	96593	783269	64175	8356

The increase in AUC and production of shrimp is mainly due to the demand in the export market as shrimp-based products contributes nearly 55 % of the total marine export quantity and 75 % of the total marine export value from India in 2022. In this, white leg shrimp-based product constituted the highest, followed by Tiger shrimp. This could have led to the increase in the AUC and production of White leg shrimp MPEDA (2022a). The Scampi data had missing observations as shown in Fig. 4. The AUC and production of Scampi also showed a decreasing trend up to 2018, but showed mixed (up and down) trend in the future with respect to AUC and production.

The study observed positive growth for total AUC and production of shrimp. Further improvement is possible by expanding the culture practices and introduction of better and sustainable technologies, as evidenced by the estimated carrying capacity of AUC and production of shrimp.

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