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Understanding the Sustainability and Growth Dynamics of Shrimp Aquaculture in Odisha, India: A Decomposition Approach

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In this paper, we examine the growth and decomposition trends of the area, production, and yield of the shrimp aquaculture sector in Odisha. We use annual time series data for the period 2010–11 to 2022–23, and with the help of exponential function, we evaluate growth rate and trend. CV and CDVI were used to analyze production instability. Minha's decomposition model was used to evaluate the contributions of area and yield to change in farm production. Our findings show a commendably high compound growth rate of 11.55 per cent for area, 26.12 per cent for production, and 13.06 per cent for yield. The instability index, CV and CDVI of the area are low. The influence of the area, yield, and interaction effects accounted for 26.35 per cent, 22.18 per cent, and 51.47 per cent, respectively, of shrimp production. The analysis of decomposition and area effect stresses

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the need to understand shrimp production dynamics in Odisha. Monitoring land use patterns and markets and promoting research and innovation is not only securing sustainability, nutritional security, and employment but also the economic development of the state.

Keywords: Decomposition analysis; growth trends; production instability; shrimp aquaculture; sustainability.

1. INTRODUCTION

Shrimp aquaculture has emerged as a pertinent subsector in aquaculture. It supports the production of seafood and drives economic growth in coastal areas worldwide [1,2]. This industry has notably promoted job creation and improved the food security of coastal areas over the years [3]. Furthermore, the industry has gained immense popularity globally attributable to the increased demand for shrimp in the world market [4,5].

The FAO reported substantial growth in shrimp production where, based on the estimation, the annual production of shrimp was approximately 953,310 tons in 2001, valued at nearly 5.4 million dollars, and thereafter it increased to 5.5 million tons in 2017, valued at about 32 million dollars [6]. The major market player in the global seafood market in Southeast Asia is India, but 70% of the total value comes from Shrimp aquaculture, despite having 1.2 million hectares of potential brackish water distributed in its nine marine states [7,8]. The United States, South Asia, Japan, and the European Union, along with the Middle East, China, and other nations, are the largest importers of Indian shrimp [9,10]. The acquisition of selective breeding methods and Specific Pathogen-Free seeds of P. vannamei from the international market has increased farming areas [11,12]. Other efforts to boost shrimp yield include technological advancements, scientific semi-intensive farming practices, and biofloc technology, among others [13]. Despite these, approximately 70% of the Shrimp aquaculture area is still under the traditional and extensive aquaculture farming system [14].

However, brackish water aquaculture has expanded rapidly compared to traditional coastal occupations, including traditional agriculture where it is more profitable and has played a significant role in the socio-economic improvement of people’s livelihoods [15]. The state of Odisha, which is located in the Indian East coastal region, has recently become a significant Shrimp aquaculture hub due to its extensive coastal resources. The state has 6.83 lakh hectares of freshwater resources and 4.18 lakh hectares of brackish water resources, with the coastline covering 480 km [16,17]. Brackish water occupies six coastal districts with a great aquaculture-growing potential of 32,587 hectares out of a possible 38,575 hectares. Currently, 15,123 hectares have been developed, and out of the 9,175 hectares have been used to culture shrimp, which yielded 29,409 metric tonnes in 2016-17 at 1300 kg per hectare per year [18,19].

Nevertheless, there has been a surge in the trajectory of shrimp aquaculture growth in Odisha due to various factors, including irregular outbreaks of diseases, natural calamities, the COVID-19 pandemic, and the late supply of inputs. The objective of the present study was to investigate the growth patterns, variability, and spatial dissimilarities in the shrimp farming sector of Odisha through area, production, and productivity dimensions. Furthermore, to decompose the sources of growth of shrimp production and provide policy implications to policymakers, researchers, and stakeholders for sustainable shrimp production in Odisha.

2. MATERIALS AND METHODS

2.1 Data Collection Source

Information on the production of shrimp in the state of Odisha was collected for a period of thirteen years, from 2010-11 to 2022-23. The given data was acquired from the state’s Statistical Division, Directorates of Fisheries, Government of Odisha. The data includes information on all six coastal districts involved in Shrimp aquaculture. The analysis was carried out based on the shrimp cultivation area in hectares, production in metric tonnes, and yield in kilograms per hectare per year. The chosen parameters measure the growth dynamics, instability values, and variability of Shrimp aquaculture. For analyzing these aspects, various statistical techniques were implemented as the progression of research.

2.2 Analysis of Compound Annual Growth Rate (CAGR)

Compound annual growth is the average growth experienced over recorded periods of more than one year, unlike simple growth which is not characterized by the compounding of rates from base values [20]. It is used to calculate growth rates of area, production and yield over defined periods. The compound growth model was estimated on the basis of the exponential growth equation expressed as in equation (1) [20,21]:

$$Y_t = a * b^t * e_i \quad (1)$$

Where,

Y_t = the variable for which the growth rate is being estimated,
t = time variable (in years)
a = intercept in the equation,
b = the regression coefficient of 'Y_t' on 't',
e_i = the error term

To linearize the model, the equation is transformed into a logarithmic form, as shown in Equation (2):

$$\log(Y_t) = \log(a) + t * \log(b) \quad (2)$$

The compound annual growth rates (*r*) are derived using the relationship:

$$r = [Antilog(b) - 1] * 100 \quad (3)$$

Where, *b* = the instantaneous growth rate or rate of change.

Subsequently, growth rates are computed for all the studied districts pertaining to the area under cultivation, production, and yield within the state of Odisha.

2.3 Analysis of Growth Instability

Different indices were used to measure variability in terms of area, production, and yield of shrimp, which indicates variability. The coefficient of variance and the Cuddy Valle instability index were employed to investigate instability in time series data for this study.

The coefficient of variance (CV) is a standard measure of variability [22]. The coefficient of variance (CV) can be expressed as:

$$\text{Coefficient of Varience(CV)} = \left(\frac{\sigma}{\bar{X}}\right) * 100 \quad (4)$$

$$\text{Standard deviation } (\boldsymbol{\sigma}) = \sqrt{\frac{\sum(\mathbf{X_i} - \bar{\mathbf{X}})^2}{\mathbf{n}}} \quad (5)$$

Where,

X_i = observed value of the time series data
$\bar{X}$ = time series data arithmetic mean
n = total number of time series observations

However, because the coefficient of variance contains the trend part, it overestimates instability in time series data with long-term trends [23]. Higher stability indices were employed in the analysis to reduce the impact of the trend part in the current study.

Cuddy and Della [24] developed and applied the Cuddy Valle instability index in their study to calculate instability augmentation in time series data. This instability index was employed in preference to the coefficient as it serves as a superior indicator and equally adjusts for trends that are commonly found in times series data. The expression of the index is given below:

$$\text{CVDI} = \text{CV} * \sqrt{1 - \text{adj. R}^2} \quad (6)$$

Where,

CVDI = the CV around the trend line
CV = the simple coefficient of variance
adj. R^2 = the adjusted coefficient of the determinant

2.4 Analysis of Growth Trend

The trends in area, yield, and production of shrimp for the most recent 13 years from 2010–11 to 2022–23 was calculated using the exponential trend function. The exponential function is expressed as:

$$Y_t = a * exp^{(b*t)} + e_i \quad (7)$$

Where,

Y_t = observed value of the variable at time 't'
t = time variable (in years)
a = intercept
b = the regression coefficient of 'Y_t' on 't'
e_i = error term

2.5 Outputs Decomposition Analysis

The relative contributions of area and yield on the total production of shrimp were examined using the decomposition analysis model [25,26]. The variables Ao, Po and Yo represent the area, production, and yield repeated from the base year, whereas the variables An, Pn and Yn repeated to another set present the variables in the nth year.

$$P_o = A_o \cdot Y_0 \text{ and } P_n = A_n \cdot Y_n \tag{8}$$

The following functions are used to determine the changes in area, production, and yield:

$$P_n - P_0 = \Delta P,$$
$$A_n - A_0 = \Delta A \quad \text{and}$$
$$Y_n - Y_0 = \Delta Y \tag{9}$$

For equations (10) and (11) we can write;

$$P_o + \Delta P = (A_o + \Delta A).(Y_o + \Delta Y) \tag{10}$$

Hence,

$$P = \frac{A_o.\Delta Y}{\Delta P} \times 100 + \frac{Y_0.\Delta A}{\Delta P} \times 100 + \frac{\Delta Y.\Delta A}{\Delta P} \times 100 \tag{11}$$

Production = area effect + yield effect + interaction effect

Thus, the overall change in output was decomposed into three components: the area effect, the yield effect, and the interaction effect resulting from the change effect in yield and area.

3. RESULTS AND DISCUSSION

Fig. 1 illustrates the production trends in production, area, and yield of shrimp culture in the state from 2010-11 to 2022-23. Based on the above data, the shrimp culture area maintained an increasing growth rate during the entire year. Shrimp culture in Odisha emerged as an alternative income generation opportunity for coastal farmers. An almost similar shrimp culture area reduction was recorded in both years in 2010-11 and 2021-22, while the shrimp culture area increased drastically only in one year that is in 2022-23, subsequently that year 2020-21 and 2019-20 had nearly similar growth in shrimp culture area. In terms of production, the maximum growth was recorded only in 2022-23 but it was not much compared with 2021-22 and then 2020-21. Similarly, production drastically reduced in 2013-14, which may be due to the cyclonic storm ‘Phalin,’ non-availability of seeds, and disease outbreaks [27].

Since 2011, after Tiger shrimp culture was shifted to Pacific White shrimp culture, farmers had no technology information on the cultivation practice of the new species leading to a low level of production. However, with the standardization of culture technology and the increased awareness of farmers on advanced culture technology in grow-out systems in later years, the production and yield in the state of Odisha and all over India gradually increased [28]. Shrimp yield in 2021-2022 has registered high, followed by 2022-2023 and 2019-2020. This has resulted from probable causes such as semi-intensive Vannamei shrimp culture in low salinity water, input availability seasonally in time, more institutional training, and less prevalence of disease [26]. Normally, yield is associated with technology and species. It is noted that yield drastically reduced only in 2020-21 though area and production were stable. It might be due to the lack of transportation facilities, delayed availability of inputs, restricted labour movements, and lockdown due to COVID-19 [10,29,30]. From the years 2010-11 to 2013-14 there was a sluggish growth in area, production, and yield. It was due to disease spread, seed non-availability, price fluctuation, low international market demand, high production cost, less credit availability, and various sociological and economic problems.

3.1 Trend and Growth Rates of Shrimp Aquaculture in Odisha

Table 1 summarizes the trend coefficients and compound growth rates of area, production, and yield of Shrimp aquaculture in different districts from 2012 to 2022. As indicated in the results of the F-values, there was statistical significance in the exponential model of area, production, and yield of shrimp aquaculture across all the coastal districts (viz., Balasore, Bhadrak, Kendrapada, Jagatsinghpur, and Puri), except Ganjam. Notably area and yield were statistically non-significant while production was significant when the empirical model was applied. However, F-values for sorghum area, production, and yield of Shrimp aquaculture were significant. Similarly, the trend coefficients of area, production, and yield of Shrimp aquaculture presented positive values across districts and the state. The t-statistic values of the trend coefficients of area, production, and yield were significant at a 1 per cent level across all the coastal districts, Balasore, Bhadrak, Kendrapada, Jagatsinghpur, and Puri, except Ganjam. In Ganjam, the t-statistic values of area and yield were statistically non-significant and only production was significant at the 1 per cent level. Nonetheless, the overall t-statistic values of the trend coefficients of area, production, and yield were significant at a 1 per cent level. The positive trend can be attributed to farmer awareness, training in advanced shrimp aquaculture techniques, higher profit margins, linking with feed & processing companies, and supportive policy by the government [28].

The data presented in Table 1 show a positive compound annual growth rate in the shrimp culture area during the assessment period. Puri is witnessing the highest growth rate of 19.09%, followed by Balasore (14.34%), Bhadrak (10.81%), Kendrapada (7.67%), Jagatsinghpur (7.50%), and Ganjam (3.73%) are the least growing districts. As in total Odisha, a positive compound annual growth rate of 11.55 per cent was observed in the shrimp culture area. This growth rate is mainly associated with farmer knowledge, institutional support, conversion of agricultural land for shrimp culture, relaxation in land lease policy, and a profitable business in the coastal districts [31,32].

Similarly, a positive compound annual growth rate in shrimp production was observed. Bhadrak is witnessing the highest growth rate of 30.50 per cent in shrimp production, followed by Balasore (30.12%), Puri (28.15%), Kendrapada (21.14%), Jagatsinghpur (18.85%), and Ganjam (11.38%) are the least growers. In Odisha, a positive compound annual growth rate of 26.12 per cent was witnessed in shrimp production. This growth rate is mainly linked to the shift from extensive farming to semi-intensive farming, new culture methods, credit availability, institutional support, and the government's pro-business policy [32].

In the same way, there is a positive compound annual growth rate in shrimp culture yield was noticed. Bhadrak district is witnessing the highest growth rate of 17.77 per cent, followed by Balasore (13.80%), Kendrapada (13.51%), Jagatsinghpur (10.56%), Puri (7.61%), and Ganjam (7.38%) respectively (Rao et al.,2021). In Odisha, a positive compound growth rate of 13.06 per cent was witnessed in shrimp culture yield. This growth is mainly due to the use of new farming technologies like biofloc technology, species dilution, technical efficiency, exposure to best management practices (BMPs), and concurrent growth of culture areas in the state [31,33].

3.2 Variability in Odisha's Shrimp Area, Production and Yield

Tables 2 show the district-level assessment of the coefficient of variation and Cuddy Della Valle Instability Index in the case of area, production, and yield in the Shrimp aquaculture sector in Odisha. It was consistently observed that the mean CVs for production were constantly higher than those of area and yield in all districts and the state on average. Similarly, the production presented higher values of CDVI than area and yield within most districts, except Puri and Ganjam, where the area was consistently higher than average.

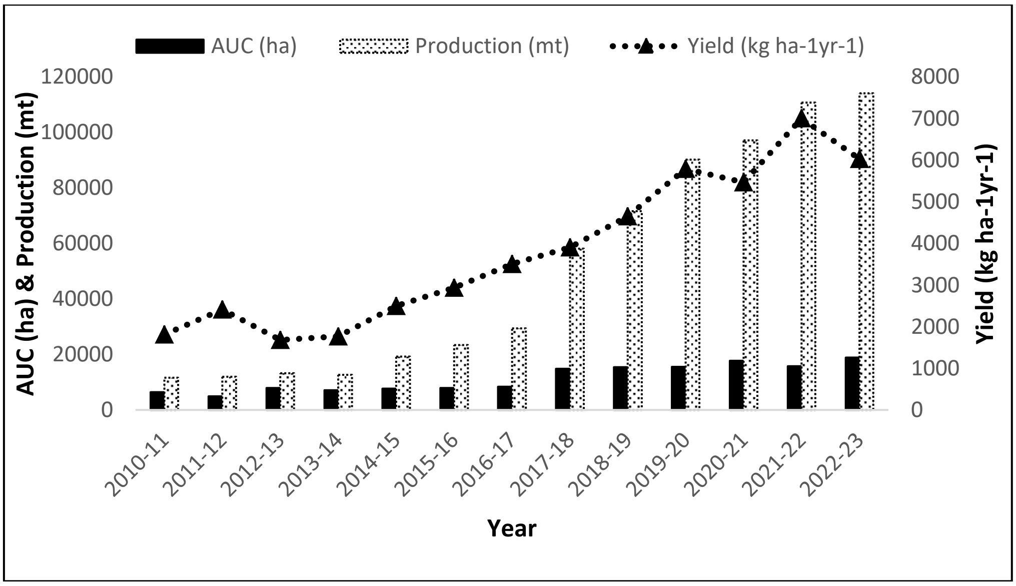

Fig. 1. Area under culture, production and yield of shrimp farming in Odisha

Table 1. Growth rates and trends analysis of area, production, and productivity across the districts

Districts	Components	F-statistics	Trend coefficient	t-statistic	CAGR (%)	R^2
Balasore						
	AUC	85.72**	0.134	9.26**	14.34	0.8863
	Production	176.09**	0.263	13.27**	30.12	0.9412
	Yield	86.80**	0.129	9.32**	13.80	0.8875
Bhadrak						
	AUC	79.23**	0.103	8.90**	10.81	0.8781
	Production	170.77**	0.266	13.07**	30.50	0.9395
	Yield	112.99**	0.164	10.63**	17.77	0.9113
Kendrapada						
	AUC	57.75**	0.074	7.60**	7.67	0.8400
	Production	67.35**	0.192	8.21**	21.14	0.8596
	Yield	40.46**	0.118	6.36**	12.51	0.7863
Jagatsinghpur						
	AUC	71.18**	0.072	8.44**	7.50	0.8661
	Production	322.04**	0.173	17.95**	18.85	0.9670
	Yield	56.37**	0.100	7.51**	10.56	0.8367
Puri						
	AUC	47.71**	0.175	6.91**	19.09	0.8126
	Production	106.45**	0.248	10.32**	18.15	0.9063
	Yield	18.43**	0.073	4.29**	7.61	0.6262
Ganjam						
	AUC	1.11^{NS}	0.037	1.05^{NS}	3.73	0.0915
	Production	26.08**	0.108	5.11**	11.38	0.7033
	Yield	3.12^{NS}	0.071	1.77^{NS}	7.38	0.2210
Overall						
	AUC	79.89**	0.109	8.94**	11.55	0.8790
	Production	203.36**	0.232	14.26**	26.12	0.9487
	Yield	104.46**	0.123	10.22**	13.06	0.9047

*Significant levels: **1 per cent, *5 per cent, NS- Non-Significant*
(AUC: Area Under Culture, CAGR: Compound Annual Growth Rate)

Table 2. Percentage of variability in the area under culture, production and yield across the districts

Districts	CV			CDVI		
	AUC	Production	Yield	AUC	Production	Yield
Balasore	53.39	89.23	53.97	21.56	30.98	23.56
Bhadrak	41.28	91.63	62.59	14.43	33.78	21.50
Kendrapada	28.89	68.36	48.65	11.75	33.56	25.89
Jagatsinghpur	30.14	65.32	43.67	12.97	20.74	20.25
Puri	67.87	80.34	33.33	34.75	26.42	20.30
Ganjam	48.55	49.43	42.19	50.20	28.66	39.79
Overall	43.21	79.79	47.82	15.83	24.86	15.68

Table 3. The effect of area, yield and their interaction on Odisha's shrimp production

Components (1)	Balasore (2)	Bhadrak (3)	Kendrapada (4)	Jagatsinghpur (5)	Puri (6)	Ganjam (7)	Overall (8)
Area Effect	17.38	32.16	39.45	41.9	12.41	54.69	26.35
Yield Effect	25.89	13.41	25.03	18.33	39.06	16.5	22.18
Interaction Effect	56.73	54.42	35.52	39.77	48.54	28.81	51.47

That is an indicator of low instability as per the values in Table 2. Meanwhile, yield and production also presented low instability values within the production and yield in Balasore, Bhadrak, Kendrapada and Jagatsinghpur moderated levels. Notable, lower instability was noted in the area for the two latter districts which is due to consistent but limited extension of the culture area observed during the study period. Moderate instability in yield and production could be attributed to various environmental factors such as cyclonic storms, salinity and temperature fluctuation as well as discrepancies in ecological and economic sustainability and related diseases such as white faeces, early mortality and empty gut syndrome cited in few other studies [34-37]. However, low instability was observed in yield and production for Puri and Ganjam largely because the majority of farmers use extensive Shrimp aquaculture systems that tend to have higher operational costs, a large element of uncertainty in profiteering, and limited market opportunities only at the domestic level and to nearby processing facilities [28].

3.3 Decomposition Analysis of Odisha's Shrimp Production

Table 3 evidences the percentage contribution of area effect, yield effect and interaction effect from decomposition analysis. The area effect had a significant share by contributing 26.35% to shrimp production expansion. For the shrimp culture department in Odisha, the positive area effect was seen in each district along the coastal Odisha. The highest positive area effect was recorded in Ganjam with 54.69 per cent followed by Jagatsinghpur with 41.90 per cent, Kendrapada (39.45%), Bhadrak (32.16%), Balasore 13.80% and Puri (7.61%) have the least positive area effect. The positive area effect might be due to the initiation of shrimp farms and conversion of agriculture to shrimp culture from learning higher profit if compared to traditional agriculture practices during this research period [31,38].

The yield effect was positive in all districts throughout the period from 2010-11 to 2022-23, and the maximum was observed in Puri with 39.06%, followed by Balasore (25.89%), Kendrapada (25.03%), Jagatsinghpur (18.33%), 16.50% in Ganjam and the lowest in Bhadrak (13.41%). The yield effect over the years from 2010-11 to 2022-23 was 22.18% in the entire Odisha. Ghoshal et al. [38] argued that the semi-intensive vannamei Shrimp aquaculture was more profitable and productive and had less incidence of pathogens than the tiger shrimp therefore the production increased in the research period and planting allowed for technical need training for the majority of farmers. However, the positive yield effect might be due to the conducive climate for farming, recent technology, technical knowledge generation to the farming community, and encouraging farmers to adopt best management practices and frequent disease surveillance [39,40]. Thus, the yield effect was positive due to several production factors influencing the environment conducive to this research period.

Shrimp production in the state was driven by the combined effect of area and yield, the interaction effect. The total interaction effect significantly increased shrimp culture by 51.47 per cent during the period 2010-11 to 2022-23. The positive interaction effect was observed in Puri (39.06%), then Balasore (25.89%), Kendrapada (25.03%), Jagatsinghpur (18.33%), Ganjam (16.50%) and with a minimum positive interaction in Bhadrak with (13.41%). However, this indicates that area and yield effects influenced Shrimp aquaculture in the coastal districts of Odisha state. In recent years the increase in culture areas was because of an increase in the market share of farmed shrimp, high export demands, timely availability of seed and feed, adherence to BMPs guidelines, and supportive land use and leasing policies by the government, which issued semi-intensive Shrimp aquaculture method in Odisha enhanced the yield of Shrimp aquaculture [31,41,42].

4. CONCLUSION

In conclusion, the analysis of growth trends, variability and regional disparities in area, production, and productivity of shrimp farming in Odisha from 2010-11 to 2022-23 have been analyzed in the present study. The industry dynamics reveal a continuous upward trend in terms of area, production and productivity with fluctuations. It indicated the rise of shrimp farming as an alternative income generation opportunity for coastal farmers by acting as an economic growth driver. Shrimp farming emerging as an economic growth driver could be assessed due to knowledge-oriented training to the farmers, better adaptive capacity to environmental events, shifts in farming from traditional to semi-intensive systems and upgradation in technologies. The district-wise positive CAGR reflects the balanced share of policy, institutional and technological aspects. Production and productivity are highly varying factors, as they are always under pressure from natural as well as economic uncertainty. Thus, the findings from the study need to be supported by further research, policy support and effective market creation. Finally, the analysis will be helpful to the stakeholders not limited to Odisha, but across the top shrimp farming regions. The findings will support them to analyze growth trends, understand factors causing variability and look for sustainable profitability measures. Furthermore, the interaction of the area growth, better technologies and relevant external factors could be assessed for diversification of programmes and projects which aim towards the expansion of shrimp farming in the regions. Thus this study lays a foundation for the decision-making and to proceed with collaborative efforts for shrimp farming in future for employment generation, food security, economic growth, resource sustainability and resilience in areas beyond Odisha.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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