Effect of Price Volatility on the Profitability of Asian Seabass Farming in Pond Production System: Evidence from Andhra Pradesh, India

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Abstract

This study evaluates the economic performance of pond-based Asian seabass (*Lates calcarifer*) culture in India through profitability and sensitivity analyses, focusing on Andhra Pradesh as a case study. The pond culture of Asian seabass in Andhra Pradesh has seen significant growth in recent years. A survey was conducted using a structured interview schedule with 60 seabass farmers from two districts, namely Krishna and Eluru. The analysis revealed that farm and management characteristics, including average pond size, crop duration, stocking density, feed usage, and chemical inputs, were significantly higher ($p < 0.05$) in Krishna compared to Eluru district. The average feed conversion ratio (FCR) was estimated at 7.43 across both districts. Variable costs dominated the total production cost, accounting for 93.05%, with feed costs alone constituting 64.65% of the total cost. Fixed costs contributed a minor share of 6.95%. Feed price and seabass market price emerged as the key factors influencing profitability. Cost and return analysis showed that seabass farming was unprofitable under adverse market price conditions, particularly due to disruptions in the Kolkata export market. However, an overall assessment based on sensitivity analysis demonstrated that seabass farming was profitable under normal market conditions. Based on the findings, this study recommends that farmers focus on the rational use of feed and consider early harvesting during unfavourable market conditions. Additionally, government support through price stabilization measures during adverse market scenarios is crucial for ensuring the profitability and sustainability of Asian seabass farming in Andhra Pradesh.

Keywords: *Lates calcarifer*, pond culture, price volatility, cost and return, sensitivity analysis

Introduction

Asian seabass, commonly referred to as giant seaperch, barramundi, or bhetki (Mathew, 2009; Biswas, Thirunavukkarasu, Sundaray, & Kailasam, 2011), is a highly valued food fish species belonging to the family Latidae (Siddik, Islam, Hanif, Chaklader, & Kleindienst, 2016). It is a carnivorous predator that thrives in diverse aquatic habitats, including streams, lakes, billabongs, estuaries, and coastal waters (Kungvankij, Tiro, Pudadera, & Potestas, 1986). This species is native to the tropical and subtropical regions of the western Pacific and Indian Ocean countries (Boonyaratpalin & Williams, 2002). Asian seabass is renowned for its delicately flavoured white meat, which is highly nutritious and in high demand in both domestic and international markets, making it a premium-priced fish (Barlow, Williams, & Rimmer, 1996; Boonyaratpalin, Suraneiranat, & Tunpibal, 1998). The global market for seabass, valued at USD 3.5 billion in 2020, is projected to reach USD 7.9 billion by 2030, growing at a robust compound annual growth rate (CAGR) of 6.8% during 2021–2030 (Mojjada et al., 2024). In addition

to its market value, Asian seabass possesses several favourable traits for aquaculture, including a fast growth rate, tolerance to varying salinity and turbidity levels (Boonyaratpalin et al., 1998), and adaptability to high stocking densities (Cheong, 1989; Mathew, 2009). It is widely cultivated in brackish water ponds (Cheong, 1989), freshwater ponds (Venkatachalam, Kandasamy, Krishnamoorthy, & Narayanasamy, 2018; Ghosh, 2019), and cages in coastal waters (Imelda et al., 2010; Philipose et al., 2013; Liyanage & Pushpalatha, 2018; Aswathy & Imelda, 2018, 2019; Wijayanto, Bambang, Nugroho, Kurohman, & Nursanto, 2020).

India ranks as the third largest global fish producer, contributing 8% to the world's total production and achieving an export value of USD 8.09 billion in 2022–2023 (Divu et al., 2024). In tandem with the significant growth in fisheries sector, the culture of Asian seabass has also seen rapid growth in India, bolstered by government recognition of its potential as a promising species for mariculture development (Mojjada et al., 2024). In India, Asian seabass is found in natural waters and has been traditionally farmed on a small scale in several coastal states (Thirunavukkarasu, Abraham, & Kailasam, 2004).

This study focuses on Andhra Pradesh as a case state due to the remarkable growth in pond-based Asian seabass farming in recent years. Following the third wave of the COVID-19 pandemic in India, shrimp farming in Andhra Pradesh became highly risky due to high input production costs and low output market prices, leading to reduced profits (Bhargavi et al., 2024). Similarly, mud crab aquaculture, a vital livelihood source for small-scale farmers, was devastated by the Mud Crab Reovirus (MCRV) outbreak during the same period (Naidu, 2022; Sravani et al., 2024). These challenges created an opportunity for seabass farming, which had already been practiced by a few farmers, to gain traction as an alternative. By 2022, most farmers had transitioned to seabass farming with the expectation of stable returns. In 2023, seabass fetched a lucrative market price of ₹570 per kg as depicted in Fig. 1 resulting in significant profits to farmers. Encouraged by these returns, farmers began a new culture cycle immediately. However, their harvests in 2024 yielded losses as market prices for seabass plummeted to nearly ₹350 per kg by June 2024 (Fig. 1). This decline in prices was linked to disruptions in the Kolkata export market caused by events like India's general elections and riots in Bangladesh and

West Bengal. Apart from this, fluctuations in the feed price added another layer of economic risk for seabass farmers (Field Survey, 2024).
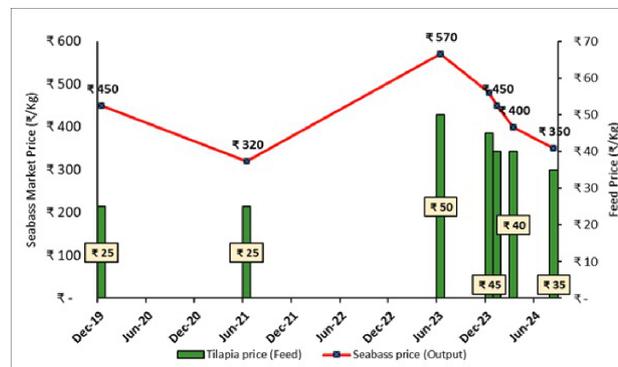

Fig. 1. Price trend of seabass and feed (Tilapia) during 2019-2024

Source: Field Survey (2024)

The preceding discussion raises several important questions: What is the cost and return structure of Asian seabass farming within the pond production system of Andhra Pradesh? How do fluctuations in feed and output market prices affect the profitability of seabass farmers in the region? Notably, while several studies (Imelda et al., 2010; Mojjada, Dash, Pattnaik, Anbarasu, & Imelda, 2013; Ail & Bhatta, 2016; Aswathy & Imelda, 2018, 2019; Kumaran et al., 2021; Kumaran et al., 2022; Divu et al., 2024; Mojjada et al., 2024) in India have explored the cage farming of Asian seabass, Singh (2000) remains the sole study addressing its growth and productivity in ponds. To the best of the knowledge of the authors, no research has yet examined the productivity and profitability of Asian seabass farming in ponds using actual farm data. Against this backdrop, the present study aims to assess the cost and return structure of Asian seabass farming and evaluate profit sensitivity under varying feed and fish prices. The empirical findings offer valuable insights into the economic resilience of Asian seabass farming to price fluctuations, which could guide policymakers in designing strategies to promote and expand pond-based Asian seabass farming in Andhra Pradesh.

Materials and Methods

This study was conducted in Andhra Pradesh, a coastal state in southeast India, renowned for its leadership in aquaculture production, contributing 40% to India's total cultured fish export value

(Subramanyam & Prasad, 2017). A three-stage purposive sampling technique was employed to select districts, villages, and sample farms. Two districts namely Krishna, and Eluru were purposively selected in the first stage due to the presence of high concentration of seabass culture area. In the second stage, Chorampudi and Garisepudi villages from Krishna district, along with Kondangi and Mattagunta villages from Eluru district were chosen (Fig. 2). However, there were no extensive official registers available for seabass farms separately in these four villages. Due to this, at the third stage of sampling, initially with the help of Village fishery officers (VFO), first few farmers were identified and selected purposively. Later a snowball sampling approach was adopted, wherein the first few identified farmers helped in identifying other seabass farmers in their respective villages. Apine, Ramappa, Bhatta, Turner, and Rodwell (2023) also used snowball sampling technique for selecting mud crab farmers in Andhra Pradesh, where no registers were available depicting the number of mud crab farms. In total, 15 seabass farmers were selected from each of these four villages, making the total sample size 60 for this study. Data collection was carried out during June-August 2024 through focus group discussions (FGDs) and one-on-one interviews using a structured interview schedule. The schedule comprised sections for gathering data on demographics, farm and management characteristics, costs, historical fluctuations in tilapia and seabass prices (Fig. 1), and profitability.

An enterprise budget-based economic analysis, as outlined by Engle (2010), was conducted to evaluate the economic performance of seabass farms on a per-hectare basis. The key variables used were variable

Fig. 2. Map showing selected villages from Andhra Pradesh

cost, fixed cost, total cost, total revenue, and profitability indicators. Variable costs included expenses on fingerlings, feed, chemicals, labour (family), harvesting, electricity, fuel, repair and maintenance, miscellaneous costs like daily transport, and interest on operating expenses calculated at an annual rate of 7%. Fixed costs comprised depreciation, land lease, and other expenses such as registration fees and interest on initial investments. The total cost is derived by summing variable and fixed costs, while depreciation is calculated using the straight-line method. Total revenue is determined by multiplying the total production by the average farmgate sale price. Profitability metrics included net farm income (NFI), calculated as the difference between total revenue and total cost, and income above variable cost, derived by subtracting variable costs from total revenue. The benefit-cost ratio (BCR) evaluates the efficiency of the investment by dividing total revenue by total cost. Additionally, the rate of farm income (RFI) measures profitability as a percentage, dividing NFI by total revenue and multiplying by 100%. Breakeven-price (BEP), a key break-even analysis indicator was obtained by dividing the total cost by the total production.

Sensitivity analysis was conducted to assess the economic outcomes of seabass farming under varying feed (live tilapia) and seabass market prices. Similar approaches have been employed in previous studies to evaluate profitability of aquaculture enterprises under different price scenarios (Hossain, Khan, Dey, & Alam, 2022; Saha et al., 2022). Fig. 1 depicts the fluctuations in feed (live tilapia) and seabass market prices that were used as input variables in the sensitivity analysis. Due to the unavailability of documented secondary data on price trends, primary data obtained from key informants and farmers during the field survey were used to construct seven distinct scenarios (Table 1). The farmgate price of seabass showed considerable fluctuation, ranging from ₹450 per kg in 2019 (pre-COVID period) to a post-pandemic low of ₹320 per kg in 2021, followed by a peak of ₹570 per kg in 2023, and subsequently declining to ₹350 per kg in 2024. Similarly, the feed (live tilapia) price varied between ₹25 and ₹50 per kg during the same period (Fig. 1). These irregular price movements were mainly attributed to post-pandemic disruptions in export logistics and inter-species market dynamics where seabass prices tend to rise when shrimp prices fall due to trade substitution in coastal
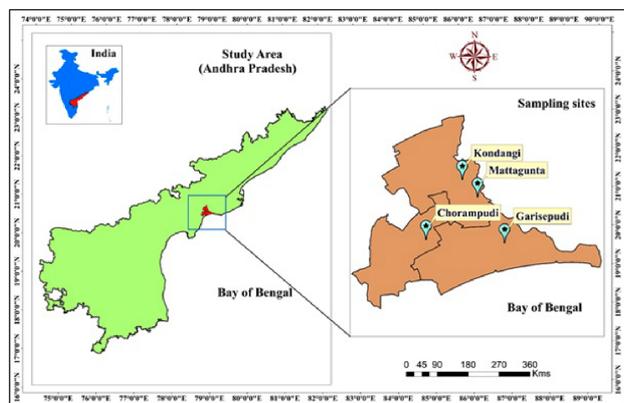
markets. The sharp decline in 2024 was further linked to disturbances in the Kolkata export market, compounded by political instability and regional riots in Bangladesh and West Bengal, which temporarily constrained exports. Likewise, the feed (live tilapia) price followed a pattern similar to seabass market prices, rising during favourable market conditions due to increased farmer demand and declining when demand weakened. The sensitivity analysis began by defining a baseline scenario that represented the economic variables under present conditions (2024), including the BCR, RFI, BEP, and NFI, which were later compared across all other scenarios.

The Mann-Whitney U test was employed to evaluate differences in demographic characteristics between farmers in the two districts. Conversely, an independent t-test was used to assess differences in key farm and management characteristics, production costs, and profitability indicators between the two districts.

Results and Discussion

The demographic information of seabass farmers by farm location is presented in Table 2. All the 60 seabass farmers interviewed were male, with Telugu as their native language. The mean age of farmers was 41 years, ranging from 28 to 48 years, with a majority (73.33%) being in their middle adulthood (35–44 years). None of the farmers were illiterate, with 5% having completed primary education, 40% completing secondary education, 41.67% attaining higher secondary education, and 13.33% holding a bachelor's degree or higher. This trend aligns with findings by Mugaonkar, Kumar, and Biradar (2019) regarding literacy levels among aquaculture farmers in Andhra Pradesh. In Krishna district, all farmers belonged to the other backward class (OBC) social group. In Eluru district, 60% of farmers were from the other caste (OC) category, followed by OBC (23.33%) and scheduled caste (SC) (16.67%). Most farmers in both districts had a family size of 4–5 members, with 21.67% having a family size of ≤ 3 members and only 10% with ≥ 6 members. These findings are consistent with reports by Dhande, Sharma, Ananthan, and Vinay (2023) and Dhande, Sharma, Kumar, and Prasad (2024), who noted similar family sizes among aquaculture farmers in Andhra Pradesh. In Eluru district, all farmers were exclusively engaged in aquaculture. In contrast, in Krishna district, a majority (76.67%) of farmers practiced both agriculture and aquaculture, while 16.67% engaged only in aquaculture, and 6.67% balanced aquaculture with roles in allied sectors. Farmers in Krishna and Eluru districts had similar aquaculture experience levels (14 ± 6 years and 15 ± 5 years, respectively). Similar levels of aquaculture experience by the farmers in Andhra Pradesh were reported by Abraham, Sil, and Vineetha (2010). However, seabass-specific experience showed a significant difference ($p < 0.01$), with Eluru farmers averaging 7 ± 3 years compared to 6 ± 2 years in Krishna district. This difference is largely attributed to the fact that Eluru district has strong historical roots in seabass farming, which has enhanced

Table 1. Scenarios for sensitivity analysis with possible change in feed price and seabass market price.

Scenario	Value of Input variables
Scenario 1	If feed[a] price reaches its highest of ₹50 per Kg
Scenario 2	If feed price reaches ₹35 per Kg
Scenario 3	If feed price reaches its lowest of ₹25 per Kg
Scenario 4	If seabass market price reaches its highest of ₹570 per Kg
Scenario 5 (Best-case)	If feed price reaches its lowest of ₹25 per Kg + If seabass market price reaches its highest of ₹570 per Kg
Scenario 6 (Most-probable case) [b]	If feed price reaches ₹35 per Kg + If seabass market price reaches its highest of ₹570 per Kg
Scenario 7 (Worst case)	If feed price reaches its highest of ₹50 per Kg + If seabass market price reaches its lowest of ₹320 per Kg

Note: [a]Feed implies only live tilapia, excluding shrimp.

[b]The values of input variables in scenario 6 were based on the previous production cycle, which earned good profits for farmers, considering it the most probable case that could occur.

Table 2. Demographic information of seabass farmers by farm location.

Variable	Krishna (n=30)		Eluru (n=30)		Overall (n=60)	
	Freq	%	Freq	%	Freq	%
Gender						
Male	30	100.00	30	100.00	60	100.00
Female	-	-	-	-	-	-
Age (years)						
Early adulthood (25-34 years)	0		9	30.00	9	15.00
Middle adulthood (35-44 years)	21	70.00	14	46.67	35	58.33
Senior-age group (45-54)	9	30.00	7	23.33	16	26.67
Education						
Primary Education	3	10.00	0		3	5.00
Secondary Education	19	63.33	5	16.67	24	40.00
Higher Secondary Education	6	20.00	19	63.33	25	41.67
Graduate and above	2	6.67	6	20.00	8	13.33
Caste[a]						
OC	0		18	60.00	18	30.00
OBC	30	100.00	7	23.33	37	61.67
SC	0		5	16.67	5	8.33
Family size						
≤ 3	6	20.00	7	23.33	13	21.67
4-5	20	66.67	21	70.00	41	68.33
≥ 6	4	13.33	2	6.67	6	10.00
Occupation						
Aquaculture only	5	16.67	30	100.00	35	58.33
Aquaculture + Agriculture	23	76.67	0	0.00	23	38.33
Aquaculture + Others	2	6.67	0	0.00	2	3.33
Experience in aquaculture (years)						
1-5	0	0.00	0	0.00	0	0.00
6-10	15	50.00	12	40.00	27	45.00
11-15	6	20.00	3	10.00	9	15.00
≥ 16	9	30.00	15	50.00	24	40.00
Experience in Seabass aquaculture (years)						
1-5	15	50.00	5	16.67	20	33.33
6-10	14	46.67	21	70.00	35	58.33
11-15	1	3.33	4	13.33	5	8.33

Note: [a]OC: Other caste; OBC: Other backward caste; SC: Scheduled caste.

farmers' skills and knowledge in this aquaculture practice.

The details of characteristics and management by farm location are given in Table 3. All farmers from both districts operated a single pond for seabass culture, with an average pond size of 0.76 ± 0.33 ha, ranging from 0.4 to 1.2 ha. The mean pond size in Eluru district was significantly larger ($p < 0.01$) compared to Krishna district. The average pond water depth across both districts was 2.15 ± 0.45 metres, showing no significant variation ($p > 0.05$). Most seabass ponds were rectangular, while a few larger ponds were square-shaped. Similarly, studies from Cambodia (Sorphea et al., 2018) and Bangladesh (Islam et al., 2023) reported pond depths for seabass

farming ranging from 1.0 to 1.5 m, typically rectangular in shape, aligning with the characteristics observed in this study. Farmers in the study area exclusively stocked seabass juveniles in grow-out ponds, with a mean size of 6–8 inches in length and weighing 100–200 grams. Similarly, Kumaran et al. (2021) reported that seabass juveniles of 100–120 g size were stocked in grow-out cages in Tamil Nadu, India. The mean stocking density was significantly higher ($p < 0.01$) in Krishna district (4347.22 ± 952.18 per ha) compared to Eluru district (3427.78 ± 1214.48 per ha) (Table 3). The average grow-out culture duration for seabass in the study area was 16 ± 2 months. Farmers in Krishna district reported a significantly longer culture period (17 ± 2 months; $p < 0.001$) compared to those in Eluru district (15 ± 1 months) (Table 3). This extended duration in Krishna district was primarily due to its farmers delaying harvests than Eluru farmers in anticipation of better farmgate prices. The observed culture duration in this study is considerably longer than those reported in other studies (Biswas et al., 2011; Philipose et al., 2013; Gammanpila & Singappuli, 2014; Ghosh et al., 2016; Aswathy & Imelda, 2018;

Sorphea et al., 2018; Kumaran et al., 2021; Nhan, Tu, & Van Tu, 2022), which range between 5 and 11 months. The mean yield of marketable-size seabass in the study area was 12.95 ± 4.46 t ha^{-1}, with Krishna district recording significantly higher yields (14.72 ± 4.31 t ha^{-1}; $p < 0.01$) than Eluru district (11.18 ± 3.94 t ha^{-1}) (Table 3). This can be attributed to the higher stocking densities and more intensive feeding practices in Krishna district. These findings align with an experimental study by Nhan et al. (2022), which demonstrated that higher stocking densities of Asian seabass in earthen ponds result in greater fish biomass at harvest. In the study area, the average harvested seabass size ranged between 2.5–4.5 kg in both districts. This corresponds with findings by Ail and Bhatta (2016), who reported that farmers often extend the culture period to 18–20 months to achieve a size of 3–4 kg. Asian seabass farming in the study area heavily relied on live feed, such as tilapia (*Oreochromis* sp.) and small shrimp (*Acetes* sp.), which aligns with Islam et al. (2023), who reported that seabass prefer live prey like shrimp and tilapia fry. Tilapia (*Oreochromis* sp.) of 1–3 inches in length, and small shrimp (*Acetes* sp.)

Table 3. Characteristics and management by farm location.

Characteristics	Farm location (mean ± SD)		
	Krishna (n=30)	Eluru (n=30)	Overall (n=60)
Sample pond size (ha)	0.64 ± 0.25	0.88 ± 0.35	0.76 ± 0.33
Sample pond depth (m)	2.13 ± 0.31	2.16 ± 0.57	2.15 ± 0.45
Culture duration (months)	16.70 ± 1.82	14.93 ± 0.87	15.82 ± 1.67
Stocking density (no.'s per ha)	4347.22 ± 952.18	3427.78 ± 1214.48	3887.50 ± 1177.09
Feed (t per ha)			
Live tilapia fish	103.83 ± 26.76	77.93 ± 25.58	90.88 ± 29.05
Small shrimp	4.55 ± 2.17	2.67 ± 0.63	3.61 ± 1.85
Chemicals			
Zeolite (kg per ha)	498.42 ± 132.31	420.28 ± 94.02	459.35 ± 120.43
Gasonex (kg per ha)	16.40 ± 4.23	14.14 ± 1.77	15.27 ± 3.41
Agri-lime (kg per ha)	807.50 ± 106.30	641.11 ± 99.52	724.31 ± 132.14
Oxygen powder (kg per ha)	29.94 ± 6.58	19.27 ± 13.20	24.61 ± 11.66
Iodine 20% (lit per ha)	3.78 ± 1.24	3.02 ± 1.44	3.40 ± 1.39
Iodine 2% (lit per ha)	30.87 ± 18.13	17.30 ± 4.90	24.08 ± 14.84
Potash (kg per ha)	671.33 ± 66.10	562.00 ± 32.89	616.67 ± 75.62
Salt (kg per ha)	2230.00 ± 718.79	666.67 ± 113.14	1448.33 ± 938.94
Total Production (t per ha)	14.72 ± 4.31	11.18 ± 3.94	12.95 ± 4.46
FCR	7.50 ± 1.02	7.37 ± 1.00	7.43 ± 1.00

were used as feed during the initial 2–3 months of culture. From the 7th month onward, only tilapia (*Oreochromis* sp.) of 3–4 inches were used for feeding. Feeding was done once daily, typically before 2 p.m. The average quantity of tilapia (*Oreochromis* sp.) used was 90.88 ± 29.05 t ha^{-1} (range: 35–137.5 t ha^{-1}), while small shrimp (*Acetes* sp.) usage averaged 3.61 ± 1.85 t ha^{-1} (range: 1–10 t ha^{-1}) (Table 3). Feed usage was significantly higher ($p <$ 0.001) in Krishna district due to longer culture durations and higher stocking densities. The FCR averaged 7.50 ± 1.02 in Krishna district and 7.37 ± 1.00 in Eluru district, ranging from 5.9 to 9.6 across farms respectively (Table 3). These values were much higher than those reported in studies using pelleted feeds, which range from 1.49 to 2.5 (Hajirezaee, Ajdari, Matinfar, Aghuzbeni, & Rafiee, 2015; Kumaran et al., 2021; Nhan et al., 2022), and consistent with findings by Schipp, Bosmans, and Humphrey (2007), who reported FCRs of 6–10 for baited trash fish as feed usage.

In the study area, seabass farmers used various chemicals and fertilizers for pond management and fish health. Table 3 shows the various chemicals used in seabass farming by farm location. Zeolite and gasonex were applied in combination once every month or two months. These were primarily used to control pH, absorb toxic substances such as NH_3 and H_2S, and improve pond hygiene (Hossain, Haq, Chawkraborty, Hasan, & Mazumder, 2014). The average quantities used were 459.35 ± 120.43 kg ha^{-1} crop^{-1} for zeolite and 15.27 ± 3.41 kg ha^{-1} crop^{-1} for gasonex. Agri-lime and dissolved oxygen (DO) powder were applied together after being mixed with sand, once every month. The average quantities used were 724.31 ± 132.14 kg ha^{-1} crop^{-1} for agri-lime and 24.61 ± 11.66 kg ha^{-1} crop^{-1} for DO powder. Iodine compounds were applied during the culture period as disinfectants (Zawada, Polechoñski, & Bronowska, 2014). Iodine 20% was used during the first three months of culture, while from the fourth month onward, Iodine 2% was applied. The average

Table 4. Average production costs (₹ lakh ha^{-1} crop^{-1}) for seabass farming by farm location.

Cost items	Krishna (n=30)		Eluru (n=30)		Overall (n=60)	
	₹	%	₹	%	₹	%
Variable cost (VC)						
Seabass juveniles	5.96	8.04	4.10	7.76	5.03	7.93
Feed	49.46	66.69	32.66	61.79	41.06	64.65
Chemicals	1.46	1.96	1.23	2.32	1.34	2.11
Labour (family [a])	2.51	3.37	2.24	4.24	2.37	3.74
Harvesting	0.36	0.48	0.35	0.65	0.35	0.55
Electricity	2.60	3.51	2.59	4.91	2.60	4.09
Fuel	0.45	0.61	0.41	0.78	0.43	0.68
Repair and Maintenance	0.31	0.41	0.34	0.65	0.32	0.51
Miscellaneous	0.75	1.01	0.67	1.27	0.71	1.12
Interest on operating expenses	6.01	8.11	3.75	7.09	4.88	7.68
Total Variable cost (TVC)	69.86	94.20	48.34	91.45	59.10	93.05
Fixed cost (FC)						
Depreciation	1.25	1.69	0.92	1.74	1.09	1.71
Land lease	2.52	3.40	3.11	5.89	2.82	4.43
Others (Registration fee, interest on investment)	0.53	0.71	0.49	0.92	0.51	0.80
Total Fixed cost (TFC)	4.30	5.80	4.52	8.55	4.41	6.95
Total cost (TVC+TFC)	74.16	100.00	52.86	100.00	63.51	100.00

Note: [a]Cost of family labour was considered the opportunity cost forgone by the farmers. The imputed value was approximately ₹15,000 per month, based on the minimum wages demanded by hired labour in the study area.

quantities used were 3.40 ± 1.39 litres ha^{-1} crop^{-1} for Iodine 20% and 24.08 ± 14.84 litres ha^{-1} crop^{-1} for Iodine 2%. Potash and salt were also commonly used, with average quantities of 616.67 ± 75.62 kg ha^{-1} crop^{-1} and 1448.33 ± 938.94 kg ha^{-1} crop^{-1} for each respectively. These were primarily used to treat parasitic flukes such as dactylogyrosis and gyrodactylosis (Chowdhury, Saha, Hossain, Shamsuddin, & Minar, 2012), a problem reported by seabass farmers in the study area. All these chemicals and fertilizers were used in significantly higher quantities ($p < 0.05$) in Krishna district compared to Eluru district. This can be attributed to the higher stocking densities and feeding levels in Krishna district.

The details of the average production costs for seabass farming by farm location are given in Table 4. The mean total production cost of seabass farming in the study area was ₹63.51 lakh ha^{-1} crop^{-1}, with significantly higher costs ($p < 0.01$) observed in Krishna district (₹74.16 lakh ha^{-1} crop^{-1}) compared to the Eluru district (₹52.86 lakh ha^{-1} crop^{-1}). The total variable cost contributed the majority of the expenses, averaging ₹69.86 lakh ha^{-1} crop^{-1} in Krishna district and ₹48.34 lakh ha^{-1} crop^{-1} in Eluru district, representing 93.05% of the total costs across the districts. These findings align with previous studies (Ravisankar & Thirunavukkarasu, 2010; Nhan et al., 2022) that reported variable costs accounting for 91–98% of total costs in seabass farming. Feed costs emerged as the largest variable expense, comprising 66.69% and 61.79% of the total production costs in Krishna and Eluru districts, respectively, with a significant difference ($p < 0.001$)

between the two districts. The higher feed costs in Krishna district were primarily due to the higher stocking densities and feed requirements, as reflected in the district's slightly higher FCR. Consequently, feed costs were the primary driver behind the higher total production costs in Krishna district. Similar studies reported comparable findings, with feed costs contributing 66.2% (Gammanpila & Singappuli, 2014) and 64.04% (Ravisankar & Thirunavukkarasu, 2010) to the total costs of seabass farming. Compared to other aquaculture production systems in Andhra Pradesh, the feed cost contribution from this study was similar to that observed in pangasius monoculture (Mugaonkar et al., 2019) but higher than shrimp farming and polyculture production systems (Dhande et al., 2023; Dhande et al., 2024). The contribution of other components of the variable expenses across both the districts include cost of seabass juveniles (7.93%), interest on operating expenses (7.68%), electricity charges (4.09%), imputed family labour cost (3.74%), chemicals (2.11%), miscellaneous expenses (1.12%), fuel (0.68%), harvesting charges (0.55%), and repair and maintenance cost (0.51%). The average fixed cost was ₹4.41 lakh ha^{-1} crop^{-1}, with a slight variation between districts: ₹4.30 lakh ha^{-1} crop^{-1} in Krishna and ₹4.52 lakh ha^{-1} crop^{-1} in Eluru. Fixed costs accounted for 5.80% of the total cost in Krishna district and 8.55% in Eluru district. Among fixed cost components, land rent contributed the largest share (4.43%), followed by depreciation on capital assets (1.71%) and other fixed expenses (0.80%).

The details of returns and profitability indicators of seabass farming by farm location are given in Table

Table 5. Returns and profitability indicators of seabass farming by farm location.

Variables	Krishna (n=30)		Eluru (n=30)		Overall (n=60)	
	Mean	SD	Mean	SD	Mean	SD
Production (tons ha^{-1})	14.72	4.31	11.18	3.94	12.95	4.46
Market price (₹ / kg)	375.00	5.09	370.67	13.37	372.83	10.27
Total Revenue (₹ lakh ha^{-1})	55.21	16.18	41.45	14.47	48.33	16.73
Net Farm Income (₹ lakh ha^{-1})	-18.95	6.43	-11.41	7.30	-15.18	7.81
Income above variable cost (₹ lakh ha^{-1})	-14.65	5.94	-6.89	6.70	-10.77	7.40
Benefit-cost ratio	0.73	0.09	0.77	0.13	0.75	0.11
Rate of farm income (%)	-38.36	18.37	-33.86	25.35	-36.11	22.06
Break-even price	518.55	67.05	494.76	84.79	506.65	76.73

5. The farmgate price of marketable-size seabass during the study period ranged between ₹350–390 per kg. The average total revenue was ₹48.33 lakh ha^{-1} crop^{-1} across both the districts. Krishna district reported significantly higher revenues ($p \leq 0.001$) at ₹55.21 lakh ha^{-1} crop^{-1} compared to ₹41.45 lakh ha^{-1} crop^{-1} in Eluru district, primarily due to higher yields attributed to increased stocking densities and feeding rates. Despite good yields, the net farm income was negative across all farms, primarily due to low market price of seabass. The average net farm income was -₹15.18 lakh ha^{-1} crop^{-1}, ranging from -₹3.09 lakh to -₹27.69 lakh ha^{-1} crop^{-1}. Farms in Krishna district notably experienced higher losses (-₹18.95 lakh ha^{-1} crop^{-1}) compared to Eluru district (-₹11.41 lakh ha^{-1} crop^{-1}), primarily due to higher production cost. The average income above variable costs was -₹10.77 lakh ha^{-1} crop^{-1}, indicating that farmers faced losses even after covering only their variable costs. The mean benefit-cost ratio (BCR) was 0.75, with no significant differences ($p \geq 0.05$) between districts. Accordingly, a higher negative rate of farm income (RFI) was observed in Krishna district (-38.36%) compared to Eluru district (-33.86%). The break-even prices were estimated at ₹518.55 ± 67.05 and ₹494.76 ± 84.79 per kg for Krishna and Eluru districts, respectively. The average market prices were substantially below the break-even prices by 38.28% in Krishna district and 33.48% in Eluru district, emphasizing that low market prices were the primary cause of financial losses in the year 2024.

From the empirical analysis and also as reported by farmers during the survey, it was evident that the cost of feed and the output price of harvested seabass were the key factors that affected farmers' profitability. Table 6 shows the different economic outcomes for seven scenarios obtained through sensitivity analysis. Keeping all other criteria constant, if the price of feed alone were to increase to ₹50 per kg (Scenario 1), the losses in seabass farming are projected to deepen significantly, resulting in net farm incomes of approximately -₹24.63 lakh ha^{-1} crop^{-1} in Krishna district and -₹19.82 lakh ha^{-1} crop^{-1} in Eluru district. Under this scenario 1, the BCR would decline further to 0.69 and 0.68 from the current baseline values of 0.73 and 0.77 in Krishna and Eluru districts, respectively. Conversely, if the feed price reduces to ₹35 per kg (Scenario 2), losses would still persist, with projected net farm incomes of -₹7.54 lakh ha^{-1} crop^{-1} in Krishna, and -₹7.11 lakh ha^{-1} crop^{-1} in Eluru districts. However, compared to scenario 1, the BCR under scenario 2 would improve to 0.88 and 0.85 in Krishna and Eluru districts, respectively. Further potential reduction in feed prices to ₹25 per kg (Scenario 3) could make seabass farming economically viable, with projected net farm incomes of ₹3.85 lakh ha^{-1} crop^{-1} in Krishna district and ₹1.36 lakh ha^{-1} crop^{-1} in Eluru district, and the BCR would marginally exceed one. Similarly, all variables being constant, if the seabass market price alone increases to ₹570 per kg (Scenario 4), it could lead to significant improvements in profitability, with net farm incomes reaching ₹9.76 lakh ha^{-1} crop^{-1} in Krishna and ₹10.95 lakh ha^{-1} crop^{-1} in Eluru districts, respectively. This implies that future adjustments in output prices could have a greater positive impact on profitability

Table 6. Sensitivity analysis of price changes and their effects on profitability of seabass farms.

	Krishna				Eluru			
	BCR	RFI	BEP	NFI	BCR	RFI	BEP	NFI
Business as usual	0.73	-38.36	518.55	-18.95	0.77	-33.86	494.76	-11.41
Scenario 1	0.69	-44.64	542.39	-24.63	0.68	-47.81	547.89	-19.82
Scenario 2	0.88	-13.67	426.25	-7.54	0.85	-17.15	434.25	-7.11
Scenario 3	1.08	6.98	348.82	3.85	1.03	3.28	358.49	1.36
Scenario 4	1.13	11.64	518.55	9.76	1.21	17.17	494.76	10.95
Scenario 5	1.63	38.80	348.82	32.55	1.59	37.11	358.49	23.65
Scenario 6	1.34	25.22	426.25	21.16	1.31	23.82	434.25	15.18
Scenario 7	0.59	-69.50	542.39	-32.73	0.58	-71.21	547.89	-25.49

Note: BCR: Benefit-Cost Ratio; RFI: Rate of Farm Income (%); BEP: Break-even Price (₹ / kg); NFI: Net Farm Income (₹ lakh ha^{-1}).

compared to reductions in feed cost. Simulating the profitability on best-case scenario (Scenario 5) seabass farming would become highly profitable, with projected net farm incomes of ₹32.55 lakh ha^{-1} crop^{-1} in Krishna district and ₹23.65 lakh ha^{-1} crop^{-1} in Eluru district, alongside the highest BCRs of 1.63 and 1.59. Conversely, a worst-case scenario (Scenario 7) could lead to devastating losses of -₹32.73 lakh ha^{-1} crop^{-1} in Krishna district and -₹25.49 lakh ha^{-1} crop^{-1} in Eluru district, coupled with the lowest BCRs of 0.59 and 0.58. Under the most-probable scenario (Scenario 6), the prices of feed (live tilapia) and seabass considered was the actual data provided by the farmers of their previous harvest crop. Results of this most-probable scenario indicated that seabass farmers earned good profits during their harvest in 2023 with average net farm incomes of ₹21.16 lakh ha^{-1} crop^{-1} in Krishna district and ₹15.18 lakh ha^{-1} crop^{-1} in Eluru district (Table 6). Similarly, the RFI would be highest under the best-case scenario (Scenario 5), and lowest under the worst-case scenario (Scenario 7). With yield held constant, the break-even price is influenced by the total production cost. Since feed cost constitutes the largest share of total production cost in seabass farming, reductions in feed cost led to changes in the break-even price across all scenarios, except scenario 4.

In conclusion, this study suggests that farmers harvest their ponds once the culture period reaches maturity (12 months) to maximize profits when market prices are high or minimize losses when prices are unfavourable. There is huge demand for value-added products of seabass in international markets. For this, seabass with a weight above 2 kg is the best suited for filleting and producing value-added products. Andhra Pradesh's well-established processing infrastructure has significant potential to capitalize on this opportunity, as farmers in the region produce seabass weighing 2.5–4.5 kg. Additionally, targeted measures are needed to boost domestic demand for seabass, including promotional campaigns and awareness programs. Currently, seabass farming's reliance on live feed, often juveniles, impacts wild fish populations. This study highlights the need for further research to assess the effects of alternative feed types, such as pelleted feeds, on the productivity and profitability of pond-based Asian seabass culture.

Acknowledgements

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