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Performance evaluation of mullets with carp-prawn polyculture in low saline (<5ppt) earthen ponds: A sustainable and profitable approach for coastal farmers

Asish Mondal[1*], Joy Kumar Mandal[2]
[1] Department of Oceanography, Techno India University, Salt Lake campus, Kolkata, India
[2] Department of Agriculture Chemistry and Soil Science, Bidhan Chandra Krishi Vishwavidyalaya, Kalyani, Nadia, West Bengal, India

Abstract

This study assessed the production performance, water productivity, and economic viability of a scampi–carp–mullet polyculture system under low-saline pond conditions (<5 ppt) as a sustainable alternative to intensive shrimp farming in coastal India. The experiment was conducted in earthen ponds using freshwater prawn (*Macrobrachium rosenbergii*), Indian major carps (*Labeo rohita*, *Catla catla*, *Cirrhinus mrigala*) and mullets (*Mugil cephalus*, *Liza tade*, *Liza parsia*). Two treatments with similar management practices, including organic fertilization and periodic liming, were evaluated. Water quality parameters remained within optimal ranges due to low stocking density and regular organic inputs. Scampi exhibited satisfactory growth, while carps and parsia, tade mullet achieved higher average body weights, more compatible with scampi. Indigenous mullets, particularly *L. tade* and *L. parsia*, adapted well to low-saline conditions. The relative condition factor confirmed species health and compatibility. The polyculture system enhanced water productivity and provided favourable economic returns with reduced production risks compared to shrimp monoculture. These findings suggest that scampi–carp–mullet polyculture in low-saline ponds offers an environmentally and economically viable approach for sustainable aquaculture and coastal livelihoods in India.

Keywords: Scampi-carp-mullet polyculture, low-saline water, growth and profitability

Introduction

The global demand for fish is increasing rapidly as the world population is expected to reach nearly 9 billion by 2050. This trend poses a serious challenge to global food and nutritional security. Capture fisheries have stagnated or declined due to overexploitation and environmental stress. As a result, inland aquaculture has become a key option for increasing fish production [1]. India has large inland water resources, including about 2.36 million ha of ponds and tanks, 3.54 million ha of reservoirs and 1.24 million ha of brackishwater areas. However, only around 40% of these resources are currently used for aquaculture, showing considerable potential for expansion and livelihood improvement (HFS, 2022).

In recent years, coastal aquaculture in India has shifted towards intensive and super-intensive shrimp farming to meet export demand. These systems often produce high yields in the short term. However, they also face frequent disease outbreaks such as WSSV, BGD, MC and WFD. Problems such as poor growth, declining pond carrying capacity and degradation of water and soil quality are common. As a result, shrimp farming areas have reduced in states like Andhra Pradesh, Odisha and West Bengal. Intensive shrimp farming has also caused environmental pollution. Small and marginal farmers are increasingly excluded by large corporate farming systems, often referred to as "*Mathsonya*". In addition, the conversion of mangroves and agricultural land into shrimp ponds threatens coastal ecosystems and food security.

Most of coastal region of India has low-salinity water (1-5 ppt), especially during the monsoon when freshwater mixes with coastal water. This creates a unique transitional environment locally known as *Do-Asla Jol/Pani*. These conditions are suitable for culturing freshwater prawn (*Macrobrachium rosenbergii*), Indian major carps, mullets and tilapia. Many small and marginal farmers in these areas are adopting low-input and diversified aquaculture practices to improve their livelihoods while reducing environmental risks [3, 4].

Polyculture systems allow different species to be cultured together by using different ecological niches within the pond. This improves resource use efficiency and stabilizes the pond ecosystem. Scampi-based polyculture with Indian major carps and mullets has been shown to improve growth, survival, water productivity, and economic returns compared to monoculture systems [5, 6, 7]. Grey mullet (*Mugil cephalus*) is commonly used in such systems. However, indigenous mullets such as tade (*Liza tade*) and parsia (*Liza parsia*) are locally preferred and may perform better under low-saline conditions.

Therefore, the present study evaluates scampi–carp–mullet polyculture systems in low-saline ponds (<5 ppt). The study focuses on species compatibility, production performance, water productivity, and profitability. The aim is to identify sustainable and farmer-friendly aquaculture models for coastal India.

Methodology

Culture site, design, and species combinations

Mithun Das, a vannamei shrimp farmer from Gadagarishpur village (20.084694°N, 86.428214°E) in Ersama block, Jagatsinghpur district, Odisha had to pause his farming due to the COVID-19 pandemic. As an aqua input supplier, he agreed to start a trial in his leased pond. The trial was conducted along the coastal zone of the Sankha River for 270 days from March 2019 to December 2019. Six earthen ponds (1500- 2000 m^2) were selected, following locally improved scampi-carp polyculture practices.

Ponds were stocked with two different species combinations. In the first treatment (T_1), mullets (*Liza tade*, *Liza parsia*) with freshwater giant prawn or scampi (*Macrobrachium rosenbergii*) and carps (Rohu, *Labeo* *rohita*; Catla, *Catla catla*; Mrigal, *Cirrhinus mrigala*); in the second treatment (T_2), grey mullet (*Mugil cephalus*) was stocked with scampi and carps. Two different species combinations were taken as treatments with three replications each (Table 1). Farming ponds of uniform size for this kind of field study were not available, thus the experiment was restricted to three replicates.

Table 1: Treatment-wise species combinations in low saline homestead prawn-carp-mullet polyculture system

Species combinations	Treatment
Scampi- Carps (rohu, catla and mrigal), Tade mullet and Parsia	T_1
Scampi- Carps (rohu, catla and mrigal) and Grey mullet	T_2

Pond preparation and stocking of species

The ponds were dewatered, dried in sunlight and necessary earthwork was done to retain water depth in the range of 120-150 cm which is suitable for polyculture [8]. Lime (CaO) was applied to each pond bottom at the rate of 300 kg ha^{-1} (day 1). After three days of lime application, ponds were filled with filtered low saline water (<5 ppt salinity) up to a depth of 120 cm. Low saline water from any retained rainwater reserve ponds was used for this purpose. On the day of 4th, dolomite was applied at the rate of 100 kg ha^{-1} and on the day of 5th, organic juice was applied at the rate 200 kg ha^{-1} to boost planktons (Table 2). The same schedule of dolomite and organic juice application was reapplied on the respective 9th and 10th. Stocking was carried out on 15th day after achieving the desired plankton bloom.

Table 2: Organic juice preparation and expenses (dose of application- 200 liters ha^{-1})

Sl. No.	Items	Units	Quantity	Rate (INR)	Amount (INR)
1	Mustard oil cake	kg	20	35	700
2	Paddy dust	kg	10	18	180
3	Flour	kg	10	40	400
4	Molasses	kg	10	20	200
5	Yeast cake or dust	kg	0.5	500	250
6	Water	liters	150	-	-
			Total		1730

[1]Misture: place all ingredients in a plastic drum or aluminum hundi. [2]Sealing: cover the open portion with black polythene paper to make it airtight. [3]Fermentation: Let it sit for 48 hours to allow fermentation. [4]Juice has unique flavors and is applied to the pond between 9:30 AM 10:00 AM in full sunlight

Ponds were stocked with scampi and carps, which were collected from a nearby hatchery that produced fingerlings in the Ersama block of Jagatsinghpur district, Odisha. Mullets were sourced from the Chilka Lake site in Odisha and acclimatized to the culture pond water [9].

Table 3: Stocking density and initial mean body weight (MBW) of each species used in low saline homestead scampi-carp-mullet polyculture system

Species	Stocking density (nos ha^{-1})	Initial MBW (g)
Scampi	5000	3.15±1.21
Rohu	2500	26.14±7.63
Catla	2500	24.00±8.32
Mrigal	2500	19.50±1.20
Tade mullet	5000	3.55±1.72
Parsia	5000	2.30±0.89
Grey mullet	7500	7.21±1.41

After stocking, the fish were fed with commercially available floating pellet feed at the rate of 5–2% of fish biomass (5% in the 1st month to 2% in the 9th month), divided into two equal meals (09:00 and 16:00). The major composition of the fish feed was included protein (24%), fat (4%), fiber (4%), and moisture (10%). Lime was applied at the rate of 250 kg ha^{-1} at fortnightly intervals to maintain optimum water quality. Water was not exchanged during the culture period.

Determination of water and soil quality parameters

Major water quality parameters such as water temperature, pH, salinity, dissolved oxygen (DO), total alkalinity, turbidity, and total ammonia-nitrogen (NH_3-N) were measured in situ (between 09:00 and 10:00 h at 15 days intervals) following standard methods [10]. Salinity was recorded using a refractometer (ATAGO S-10, Japan). Fortnightly collection of plankton samples by filtering 100 L of pond water through bolting silk plankton net (mesh size 64 µm), its preservation in 4% buffered formalin and one ml of aliquot and estimation using Sedgewick- Rafter counting cell and analyzed [11]. Surface sediment samples up to a depth of 3 cm from the pond bottom using a spatula were collected twice (pre-stocking and post-harvesting) and analysed for soil pH.

Growth monitoring and zootechnical parameters

Fortnightly samplings were carried out prior to feeding to assess scampi and fish growth performances. This ensures total evacuation of gut. The total length (TL, cm) of mud crab and fishes was recorded with a slide caliper, while body weight (MBW, g) was measured using a digital electronic balance.

Daily weight gain (DWG) is a function of weight and time and was estimated using the following conventional equation: $\mathrm{DWG} = \frac{W_f - W_i}{t}$

Where, W_f and W_i are the average final and initial weight in time *t*.

Specific growth rate (SGR) was calculated using the following equation given by Brown, 1957 [12]:

$$\mathrm{SGR} = \frac{\ln w_f - \ln w_i}{t} \times 100$$

Where, W_f and W_i are the average final and initial weight in time *t*.

Fulton's condition equation [13] was used to find out the condition factor: $K = \frac{\bar{W}}{(\overline{TL})^3} \times 10^2$

Where, K is the condition factor, $\overline{W}$ is the average weight (g) and $\overline{TL}$ is the average total length (cm).

The mathematical relationship between length and weight was calculated using the conventional formula (14):

$W = a\,TL^b$

Where, W is fish weight (g), TL is total length (cm), 'a' is the proportionality constant and 'b' is the isometric exponent. The parameters 'a' and 'b' were estimated by non-linear regression analysis.

After harvest at 270 days by drag netting and dewatering the pond, production parameters like survival (SR: %), and productivity (kg ha^{-1}) of individual species were estimated as follows.

$$SR(\%) = \frac{\text{Number of fish harvested}}{\text{Number of fish stocked}} \times 100$$

Economic efficiency and water productivity

$$\text{Apparent feed conversion ratio (AFCR)} = \frac{\text{Cumulative total feed in kg}}{\text{Total biomass or yield in kg}}$$

Net total water productivity (NTWP, INR m^{-3}) and water use efficiency (WUE, g m^{-3}) was calculated as described by Mohanty *et al.* 2017 and Mohanty *et al.* (2018b) [4, 15].

This measures the economic return per cubic meter of water used. The formula is:

$$\text{Net Total Water Productivity (NTWP, INR per cubic meter)} = \frac{\text{Total Economic Value (INR)} - \text{Producton cost (INR)}}{\text{Total Water Use (TWU, g per cubic meter)}}$$

This measures how much biomass (fish & scampi) is produced per cubic meter of water used.

$$\text{Water Use Efficiency (WUE, g per cubic meter)} = \frac{\text{Total Biomass production (g per ha)}}{\text{Total Water Use (TWU, g per cubic meter)}}$$

Where, TWU (probable inflows to ponds) = initial water filling (W_f) + management additions or regulated inflows (I) + precipitation (P) + runoff (R).

The economic performance of four treatments and their comparison were analysed with estimation of the total income, net income and benefit-cost ratio (BCR) as per the methods described previously (Mondal *et al.*, 2020) [8]. Simple economic analysis was carried out to assess economic efficiency of each treatment and benefit cost ratios (BCR) were determined using the following formula.

$$BCR = \frac{\text{Total gross return}}{\text{Total culture cost}}$$

The operational cost mostly includes the cost of. scampi, fish fingerlings, organic manure. lime, fish feed, and labour (man-days) as presented in Table 7.

Statistical analysis

Differences in performance parameters were determined by analysis of variance using SPSS for Windows v.17.0 programme (SPSS Inc., Chicago, IL, USA). Duncan's Multiple Range Test by Duncan, 1955 [16] was used to assess the differences among the treatment means at the 5% significance level (i.e., $p<0.05$). All data are expressed as mean ± standard error (SE).

Results

Water and soil quality assessment

Water and soil quality parameters of the experimental ponds are presented in Table 4. All the measured water quality parameters differed significantly ($p<0.05$) between two except water temperature. Temperature varied between 24.50ºC and 32.00ºC and salinity ranged between 0.00 and 4.50 ppt throughout the study period. Maximum temperature values were recorded higher in the month Jun, while the lower values were observed in February. Significantly higher ($p<0.05$) pH was observed in T_2 (7.99±0.25) compared to T_1 which had lowest value (7.84±0.22). Significantly ($p<0.05$) higher DO value was recorded in T_1 (5.90±0.41 ppm), while lower value was observed in T_2 (5.82± 0.53ppm). Total alkalinity varied significantly among treatments, with highest value in T_2 (127.67±1.34 mg L^{-1}) and the lowest in T_1 (124.67±1.33 mg L^{-1}). Higher total ammonia nitrogen levels were recorded in T2 (0.28±0.012 mg L^{-1}), while significantly lower ammonia levels were observed in T1 (0.22±0.012 mg L^{-1}).

Phytoplankton density (units L^{-1} × 10^4) varied between 9.00±0.86 and 17.50±1.48 (Table 4). A significantly higher density of phytoplankton ($p < 0.05$) was observed in T1 (15.30±1.45) compared to T2. Zooplankton density (units L^{-1}×10^3) ranged between 6.00±0.18 and 7.00±0.21 (Table 4). A significantly higher density of zooplankton ($p < 0.05$) was observed in T2 (5.95±1.99) compared to T1. The phytoplankton population was dominated mainly by green algae and diatoms, while the zooplankton was dominated by copepods and rotifers.

The higher soil pH value ($p<0.05$) was recorded in T1 (7.96±0.32), while a lower value was observed in T2 (7.11±0.29).

Table 4: Treatment-wise major water and soil quality parameters in low saline polyculture system

Parameters	**T_1**	**T_2**
Water		
Temperature (°C)	27.95± 1.56 (24.50-32.00)	28.00± 1.36 (24.50-32.00)
pH	7.84±0.22^b (7.32-8.11)	7.99±0.25^a (7.75-8.25)
Salinity (ppt)	3.45 ±0.13^a (0.0-4.25)	3.20±0.09^b (0.0-4.50)
DO (ppm)	5.90 ± 0.41^a (4.50–7.00)	5.82± 0.53^b (4.25–7.00)
Total alkalinity (mg $CaCO_3$ L^{-1})	124.67±1.33^b (105-150.25)	127.67±1.34^a (105-155.22)
TAN (mg L^{-1})	0.22±0.012^b (0.11- 0.28)	0.28±0.012^a (0.14-0.31)
Phytoplankton (units l^{-1}× 10^4)	15.30 ± 1.45^a (13.25-17.50)	13.43± 1.22^b (12.12-15.50)
Zooplankton (units l^{-1}× 10^3)	4.12 ± 1.20^b (3.50-6.90)	5.95 ± 1.99^a (4.00-7.10)
Soil		
pH	7.96± 0.32^a (6.57-8.12)	7.11± 0.29^b (6.56-7.77)

Values are mean ± SE; Means with different superscripts in a row differ significantly ($P < 0.05$); Values in brackets indicate ranges

Growth and production performance

A comparative account of scampi and fish size at harvest is presented in Figure 1. Other growth parameters like daily weight gain (DWG), specific growth rate (SGR), condition factor (K) and length-weight relationship (b) of scampi and fishes in each treatment are depicted in Table 5 and Figure 2. Significantly (($p < .05$) higher growth of scampi (159.7 ± 14.80g) was observed in T_2 and lower (145.5± 13.70 g) in T_1. Among fishes, higher MBW (1010.5±21.80 g) and DWG (3.64±0.73) were recorded in case of catla in T_1.

Production performances of scampi and fishes in treatments like survival and biomass productivity are presented in Table 6. Significantly higher survival of scampi (55± 5%) was recorded in T_1 and lower (45±4%) in T_2. Scampi biomass was significantly higher (400±18.2 kgha^{-1}) in T_1, while highest fish biomass (5799kgha^{-1}) was recorded in T_2. Significantly higher total biomass was achieved in T_2 (6159± 386.8kg ha^{-1}) followed by T_1 (5967± 324.5kg ha^{-1}). Apparent feed conversion ratio (AFCR) was 1.84 and 1.89 in T_1 and T_2 respectively.

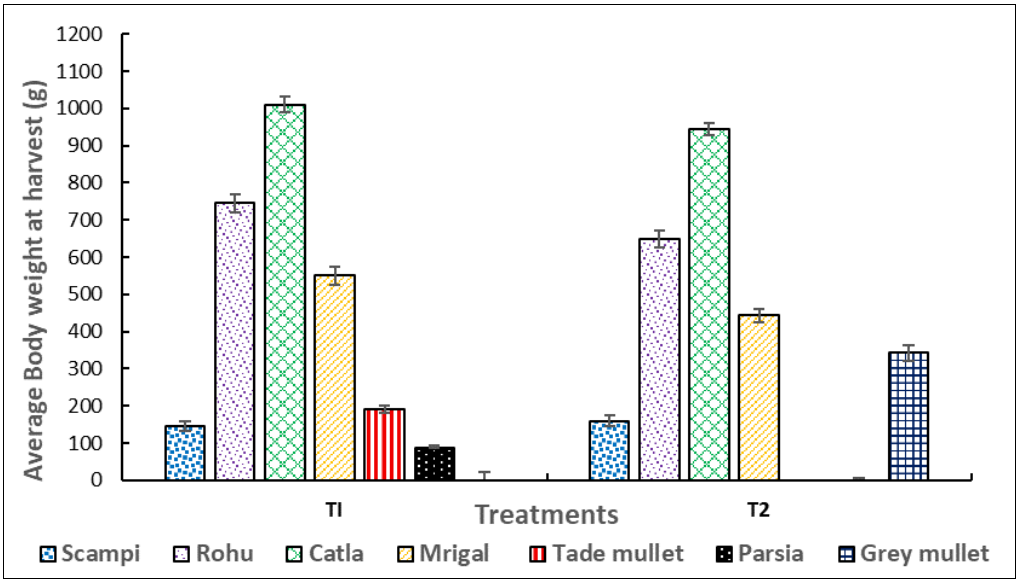

Fig 1: Mean body weight at harvest of scampi and different fish species under low saline polyculture system

Table 5: Growth performances of scampi and different fish species under low saline polyculture system

Parameters	Species Stocked	T_1	T_2
DWG (g day^{-1})	Scampi	1.08±0.13^{a}	0.72±0.15a
	Rohu	2.67±0.39^{a}	2.31±0.41^{b}
	Catla	3.64±0.73^{a}	3.45±0.91^{b}
	Mrigal	1.96±0.44^{a}	1.57±0.37^{b}
	Tade mullet	0.69±0.14	-
	Parsia	0.32±0.03	-
	Grey mullet	-	1.24±0.22
SGR (% day^{-1})	Scampi	1.80±0.65^{a}	1.53±0.16^{b}
	Rohu	1.24± 0.25^{a}	1.23±0.23^{a}
	Catla	1.39±0.29^{a}	1.36±0.34^{b}
	Mrigal	1.22±0.23^{b}	1.25±0.14^{a}
	Tade mullet	1.48±0.37	-
	Parsia	1.51±0.32	-
	Grey mullet	-	1.43±0.40
Condition factor (K)	Scampi	0.77±0.04^{a}	0.75±0.03^{a}
	Rohu	1.03±0.08^{a}	0.98±0.05^{b}
	Catla	1.20±0.16^{a}	1.09±0.09^{b}
	Mrigal	1.17±0.03^{a}	1.12±0.04^{b}
	Tade mullet	1.32±0.10	-
	Parsia	1.54±0.17	-
	Grey mullet	-	1.36±0.16
Length-weight relationship (LWR, b)	Scampi	3.03^{a}	2.98^{b}
	Rohu	3.00^{a}	2.99^{a}
	Catla	3.02^{a}	2.97^{b}
	Mrigal	3.00^{a}	2.97^{b}

Means bearing different superscripts indicate statistically significant differences in a row ($p < .05$); values are expressed as mean ± SE of three replicate ponds

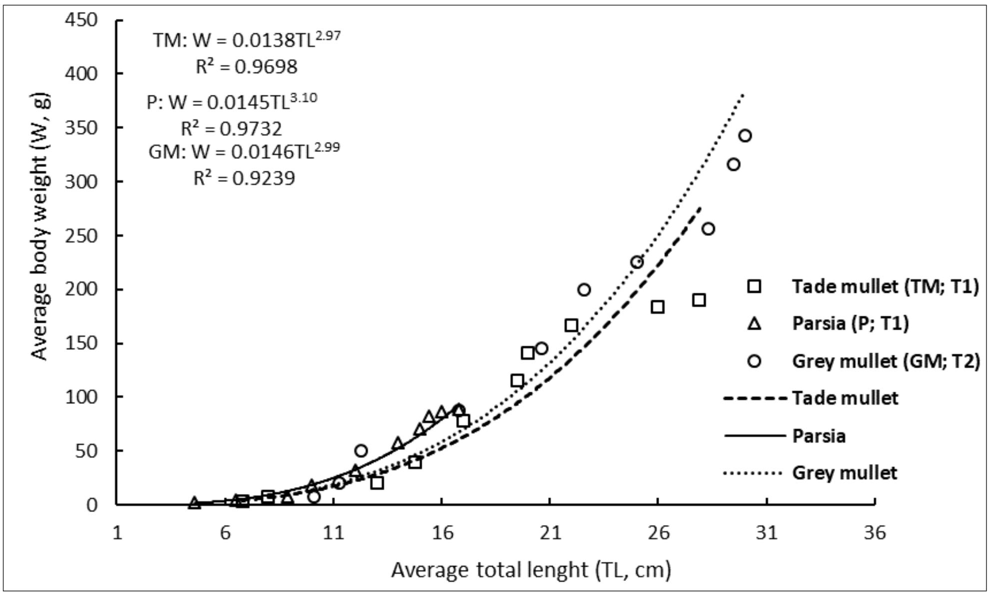

Fig 2: Length-weight relationships of mullets in different treatments of under low saline polyculture system

Table 6: Production performances of scampi and different fish species under low saline polyculture system

Parameters	Species used	T_1	T_2
Survival (%)	Scampi	55±5^a	45±4^b
	Rohu	84±4^b	86±4^a
	Catla	84±5^a	83±4^b
	Mrigal	74±4^a	70±6^b
	Tade mullet	67±3	-
	Parsia	58±3	-
	Grey mullet	-	65±3
Species-wise production (kg ha^{-1})	Scampi	400±18.2^a	359±16.4^b
	Rohu	1529±72.3^a	1389±56.7^b
	Catla	2122±100.2^a	1965±100.0^b
	Mrigal	1018±44.6^a	776±32.8^b
	Tade mullet	638±24.8	-
	Parsia	260±12.3	-
	Grey mullet	-	1669±77.3
	Total (kg ha^{-1})	5967± 324.5^b	6159± 386.8^a

Means bearing different superscripts indicate statistically significant differences in a row ($p<0.05$); values are expressed as mean ± SE of three replicate ponds

1. Economic efficiency and water Productivity

Economic and water productivity analysis revealed clear differences between the two polyculture treatments. Total operational cost was higher in T2 (INR 6.56 lakh ha^{-1}) compared to T1 (INR 5.98 lakh ha^{-1}, mainly due to higher seed and feed costs associated with grey mullet. Although T2 achieved significantly higher total biomass production (6159 ± 386.8 kg ha^{-1}), gross return (INR 10.81 lakh ha^{-1}) and net return (INR 4.25 lakh ha^{-1}) were lower than T1. The scampi–carp–tade mullet–parsia system (T1) recorded the highest gross return (INR 11.33 lakh ha^{-1}), net return (INR 5.35 lakh ha^{-1}), and benefit–cost ratio (1.90), indicating superior economic efficiency.

Net total water productivity (NTWP) was also higher in T1 (107.11 INR m^{-3}) compared to T2 (84.95 INR m^{-3}), reflecting better financial return per unit of water used. In contrast, water use efficiency (WUE) was marginally higher in T2 (1231.81 g m^{-3}) than in T1 (1193.12 g m^{-3}), due to higher biomass output. Overall, results indicate that inclusion of high-value indigenous mullets enhanced profitability and water-use economics, despite slightly lower biomass production.

Table 7: Expenditure, economic return (INR ha^{-1}) and benefit-cost ratio of two treatments of low saline homestead prawn-carp-mullet polyculture system

Different items	Quantity ha^{-1}	Rate (INR)*	Expenditure and economic return	
			T_1	T_2
Operational cost (OC, INR ha^{-1})				
Scampi fingerlings	5000 nos.	7 fry^{-1}	35000	35000
Carp fingerlings ((Rohu, Catla & Mrigal)	7500 nos.	5 fry^{-1}	37500	37500
Tade mullet fingerlings	5000 nos.	5 fry^{-1}	25000	-
Parsia fingerlings	5000 nos.	1fry^{-1}	5000	-
Grey mullet fingerlings	7500 nos	8 fry-1	-	60000
Organic juice	200 Liter	25Lit^{-1}	5000	5000

Lime	2500 kg	10 kg^{-1}	25000	25000
Feed	10980 kg	35 kg^{-1}	384302	-
	11641 kg	35 kg^{-1}	-	407434
Manpower	100 man-days	320	32000	32000
Sub total			548803	601935
Interest on OC	9 months	12% yr^{-1}	49392	54174
Total OC (INR)			598195	656109
Economic return from scampi and fish sale (INR ha^{-1})				
Scampi (INR 440 & 480 kg^{-1} for T_1 & T_2)			176055	172476
Rohu (INR 150 & 140 kg^{-1} for T_1 & T_2)			229343	194545
Catla (INR 175 & 165 kg^{-1} for T_1 & T_2)			371000	324225
Mrigal (INR 125 & 115 kg^{-1} for T_1 & T_2)			143360	76050
Tade mullet (INR 250 kg^{-1} for T_1)			157175	0
Parsia (INR 280 kg^{-1} for T_1)			72977	0
Grey mullet (INR 180 kg^{-1} for T_2)			0	300456
Total gross return (INR)			1133675	1080896
Net return (INR)			535480	424787
Benefit cost ratio (BCR)			1.90^{a}	1.65^{b}

*During the experiment, means bearing different superscripts indicate statistically significant differences in a row ($p < .05$); values are expressed as mean ± SE of three replications

Discussion

Hydrobiological parameters such as temperature, salinity, pH, dissolved oxygen (DO), alkalinity, and ammonia play a critical role in determining aquaculture productivity. In the present study, all key water quality parameters remained within optimal ranges in both treatments and showed no abrupt fluctuations (Table 4), indicating a stable culture environment. This stability can be attributed to uniform management practices, including periodic liming and the application of organic mixtures across treatments. Fortnightly liming and organic inputs likely helped maintain favourable water chemistry suitable for low-saline scampi-based polyculture [17-21]. Salinity during the culture period remained below 5 ppt, which falls well within the tolerance range reported for *Macrobrachium rosenbergii* under monoculture and polyculture conditions [22, 23]. Dissolved oxygen is a key determinant of growth and survival in aquaculture systems [24]. Throughout the study, morning DO levels ranged from 4.00 to 5.90 ppm and did not fall below critical thresholds, likely due to low stocking density and enhanced microbial activity that reduced biochemical oxygen demand. Higher DO levels observed in T1 may be associated with species-specific oxygen consumption patterns of tade mullet and parsia compared to grey mullet, as reported by Mitra *et al*. 2005 [7]. In contrast, earlier studies have documented DO depletion under high stocking densities and elevated suspended solids [25, 26]. Water pH (7.32–8.25) and total alkalinity (105.00–155.22 ppm) were consistently maintained within productive ranges, supporting optimal growth and ecosystem functioning [27, 28]. Although aquaculture systems often accumulate nitrogenous wastes from feed inputs [29, 30], total ammonia nitrogen levels in this study remained within acceptable limits and were effectively managed through adequate aeration and water quality control [31]. Phytoplankton and zooplankton densities showed moderate fluctuations, reflecting balanced nutrient availability and overall ecosystem stability. Adequate alkalinity ensured sufficient CO_2 availability for phytoplankton growth, while soil pH values indicated a moderately productive pond bottom conducive to nutrient mineralization and sustained fish and shrimp production [8].

Macrobrachium rosenbergii exhibited excellent growth performance during the culture period (Table 5; Figure 1), exceeding growth reported earlier for scampi–carp polyculture in Indian earthen ponds at 73–92 g in 292 days [32]. The enhanced growth observed in the present study can be largely attributed to low stocking density, which reduced competition for space and food and promoted better individual performance. However, overall survival of scampi was comparatively lower, possibly due to reduced water temperatures during the winter months and increased interspecific competition with bottom-feeding species, particularly *Cirrhinus mrigala* and *Mugil cephalus*, which may have intensified competition for benthic food resources [33]. As scampi largely depended on natural food availability in the polyculture system, such interactions likely influenced survival. Notably, scampi survival was significantly higher in T1, where *M. cephalus* was absent, indicating improved species compatibility. The average final weights of carps *Catla catla* (977.5 ± 18.34 g), *Labeo rohita* (697.66 ± 23.42 g), and *C. mrigala* (496.6 ± 21.05 g) were significantly higher than those reported in earlier scampi–carp polyculture trials, where average weights ranged between 718 and 820 g over a similar culture duration [33]. This improved performance is likely due to lower stocking densities and effective species combinations that minimized resource overlap. Grey mullet growth in the present study also surpassed earlier reports. Mondal *et al*. 2015 [21] documented growth from 3.36 ± 0.15 g to 307.20 ± 16.55 g over 300 days, while other studies reported comparatively lower growth in shrimp–mullet polyculture systems [34, 30, 21]. Indigenous mullets, particularly tade mullet, demonstrated better growth and adaptability under low-saline conditions, efficiently utilizing natural productivity. The relative condition factor (K) recorded for all cultured species indicates good health, robustness, and compatibility within the polyculture system (Table 5). Condition factor is influenced by both environmental conditions and biological factors such as feeding rate, growth, and seasonality [35], further confirming the suitability of the system under the given management practices. Tade mullet (*Liza tade*) and parsia (*Liza parsia*) exhibited satisfactory growth, survival and condition factor under low-saline (<5 ppt) polyculture conditions, confirming their compatibility with scampi–carp systems. Their detritivorous and periphyton-grazing feeding habits enabled efficient utilization of natural pond productivity, thereby improving nutrient recycling and reducing organic load in the culture system [21, 30]. The condition factor (K>1) indicated good health and favourable environmental conditions, suggesting minimal interspecific competition and effective niche partitioning [35]. Although their biomass contribution was lower than that of grey mullet, the higher market value of tade mullet and parsia significantly enhanced net returns and net total water productivity in T1. Similar observations have been reported for mullet-based polyculture systems, where inclusion of high-value indigenous species improved economic efficiency without increasing feed or management costs [36, 21]. These findings support the inclusion of *L. tade* and *L. parsia* as economically and ecologically viable species for sustainable coastal aquaculture.

Conclusion

This study assessed the performance, economic viability and water productivity of low-saline (<5 ppt) scampi-carp-mullet polyculture systems in coastal Odisha. Two species combinations were evaluated over a 270-day culture period, scampi with Indian major carps and indigenous mullets (*Liza tade* and *Liza parsia*, T1) and scampi with carps and grey mullet (*Mugil cephalus*, T2). Water quality parameters, including temperature, salinity, pH, dissolved oxygen, alkalinity and ammonia, remained within optimal ranges throughout the study. It indicates that periodic liming, organic inputs and low stocking density supported a stable culture environment.

Scampi and carps showed better growth and survival compared to earlier polyculture reports, reflecting effective species compatibility and niche utilization. Survival of scampi was higher in T1, suggesting reduced competition in the absence of grey mullet. Indigenous mullets, tade and parsia, exhibited satisfactory growth and good condition factors, efficiently utilising natural pond productivity and contributing to nutrient recycling. Although T2 achieved higher total biomass but the higher market value of tade mullet and parsia resulted in superior net returns, benefit cost ratio, and net total water productivity in T1.

The findings indicate a trade-off between biomass maximisation and economic efficiency. Overall, scampi–carp polyculture integrated with indigenous mullets offers a sustainable, low-risk and profitable aquaculture model for small and marginal coastal farmers under low-saline conditions.

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