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Cage aquaculture of Indian pompano for livelihood diversification of artisanal fishers: Insights from Andhra Pradesh, India

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Abstract

Artisanal fishers fishing in nearshore coastal waters off Visakhapatnam using motorised crafts and in estuaries of Krishna using non-motorised crafts were selected for the study. Their annual net operating income varied between US$ 469.63 (₹39,040) and US$ 2698.42 (₹2,24,320), respectively. Inspired by the potential of cage farming from the frontline demonstrations in marine and estuarine waters and after acquiring appropriate skills, 15 individuals from the Traditional Fishermen's Co-operative Society, Visakhapatnam and 76 individuals from Yanadri Girijana Matsya Sakhara Sangam, Krishna embarked on cage aquaculture of Indian pompano in 15 and 70 cages, respectively. Marine cages were circular (6 m diameter) and estuarine cages were square (5 m X 5 m), and were stocked with hatchery-produced Indian pompano (*Trachinotus mookalee*) fingerlings of 22.6 g weight @ 2500 and 1500 numbers respectively, and were fed with floating pellets at 8-3% of biomass. Average body weight, survival and biomass production from marine and estuarine cages after eight months of culture were 843 and 666 g, 96.28 and 91.47% and 2029.0 and 913.85 kg respectively. Deducting all capital and operational expenses, annual net operating income per unit ranged from US$ 1247.44 (₹1,03,700) to US$ 2632.02 (₹2,18,800); which represented a substantial increase from that of capture fishery. Cluster-cage farming, as adopted, did not adversely impact the water and sediment quality. The current research offers novel insights into the bio-growth and economic factors pertinent to commercial cage farming of Indian pompano. Cage farming in marine and estuarine conditions holds a great promise as an alternative source of livelihood for artisanal fishers, thereby bolstering their economic sustainability.

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Introduction

With a lengthy coastline of about 8129 km, a continental shelf of 0.50 million sq. km and an Exclusive Economic Zone (EEZ) of over 2 million sq. km, India is blessed with abundant marine resources. Marine fishing has long been a vital occupation for the coastal communities of the country. India's marine fisheries remain enormously diversified, from the mechanised fleets that spend close to a fortnight in the sea to small-scale fisheries in plank-built crafts engaged in subsistence fishing. Fisheries development in the country has however, failed to capture this variety and the artisanal fishers have remained deeply embedded in village socio-politics. Traditional or artisanal fisheries, in India, are characterised by less capital, smaller boats, lower-tech gears, fishing nearer to shore, production for local consumption and traditional governance (Jadhav, 2018; Gopal, 2019). Though prior to 1980s, bulk of the landing was from small-scale fisheries (Pillai and Katiha, 2004); with the advent of mechanisation and the commencement of voyage fishing in the 1980s, mechanised crafts proliferated and dominated the landings. Fishers in the traditional sector, using either oars or sails or outboard motors for their propulsion, were ill-equipped and hence, unable to compete with this organised mechanised sector. Of the total

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1,66,333 crafts presently engaged in exploiting the marine resources of the country; 97,659 (58.7%) are motorised and 25,689 (15.4%) are non-motorised. Among the motorised crafts, 31,409 (32.2%) have inboard motors and 66,250 (67.8%) have outboard motors (Marine Fisheries Census, 2016). The annual marine landings during 2013-2020 varied from 2.73 to 3.83 million t, with an average of 3.50 million t [Personal communication, Fisheries Resource Assessment Division, ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), Kochi]. The motorised and the non-motorised sectors contributed 18.13 and 1.56%, respectively on an average with their proportions exhibiting a decreasing trend over the years (Fig. 1). The catch per trip and per hour for motorised and non-motorised sectors ranged from 122-144 kg trip^{-1} and 20-23 kg h^{-1} and 45-55 kg trip^{-1} and 18-20 kg h^{-1} respectively.

Bestowed with 974 km length of coastline and 33,227 sq. km of continental shelf area, 94.8% of the crafts in Andhra Pradesh are either motorised (12,078) or non-motorised (6,965). Among motorised; 3,146 (26%) possess inboard motors and 8,932 (74%) have outboard motors (Marine Fisheries Census, 2016). Crafts with outboard motors are mostly manufactured of fiber-reinforced plastic (FRP); whereas non-motorised crafts vary widely in their type (catamarans, plank-built canoes and thermocol boats) and are propelled by sails and paddles. The gears used for fishing are both hooks and lines or gillnets and seine nets. Total landings and catches from motorised and non-motorised sectors over the past half decade are presented in Fig. 2. The demographic profile, of this traditional sector, is presented in Table 1. Fishers, belonging to this sector are poor and marginalised and hence, socially and economically backward. The primary reasons being poor regulatory measures and marketing facilities and overcapacity and overexploitation (Immanuel and Rao, 2012). In fact, more than one-quarter of the total marine fishermen in the country residing below the poverty line are from this state (Marine Fisheries Census, 2016).

The inherent economic uncertainty associated with the small-scale sector owing to the higher degree of risks and lower economic profitability warrants immediate incentives and assistance (Gopal, 2019). Kurien (1996) articulated a series of interrelated measures for empowering and enhancing the opportunities of small-scale fishers and ensuring their holistic development; however, a lack of effective implementation at the policy level or poor governance meant little accrued benefit to the traditional fishermen. Currently, after imparting necessary professional skills, an attempt was made to examine finfish cage farming as an addition or an alternate to their livelihood in marine capture. Despite the vast pristine ocean space available in the coastal states ideal for mariculture, commercial fish farming in the country is still in its infancy (Jha *et al*., 2017). Cage farming is not subjected to the same degree of uncertainty and risk attributable to environment parameters and inherent stock dynamics influencing fish catch. Factors such as increasing consumption of fish and declining stocks of wild fishes have increased interest in fish production from cages. Suitable locations in India's long coastline and vast brackishwater areas available in coastal states can be better utilised by rationally adopting cage culture. In view of the high production attainable in the cage culture system, it can play a significant role in increasing the overall fish production and household income (Ignatious, 2016). Since, there is very little or no requirement of land area, cage farming is ideal for artisanal fisherfolks as an alternative or diversified livelihood option (Rao, 2013). This can be taken up as a household activity too since the labour involved is minimal and can be managed by a small family. Marine finfish farming in cages was initiated in India by ICAR-CMFRI in 2007 (Rao, 2009). Since then, several innovations were made on the design, fabrication and the mooring systems of the cages which in turn improved their utility in diverse habitats. The technology is presently being popularised in marine and estuarine waters through frontline demonstrations in different maritime states of the country. Apart from few studies (Ramachandran, 2009; Vipinkumar *et al*., 2021) involving a handful of cages, detailed information on economic indicators for large-scale cage farming are lacking. Economic performance is expected to vary between government demonstrations and commercial operations and with no knowledge on the impact of commercial cage farming on water quality; present study assumes paramount importance.

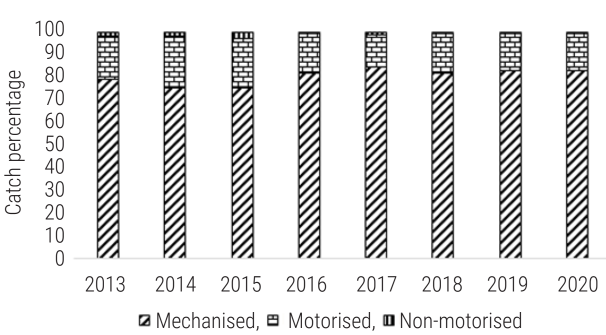

Fig. 1. Contribution by various sectors to the national marine fish landings (Source: ICAR-CMFRI, Kochi)

Table 1. Demographic profile of marine fishers in Andhra Pradesh (Values in parenthesis indicate percentage of total)

Total fisherfolk population	517435
Total number of fishermen families	155061
Traditional fishermen families	152062 (98%)
Traditional fishermen families below poverty line	150669 (97%)
Average size of a marine fishermen family	3
Sex ratio (females/1000 males)	945
Proportion of children among fishermen	35%
Proportion of fishermen with school enrolment	40%
Proportion of fishermen with membership in co-operative societies	40%

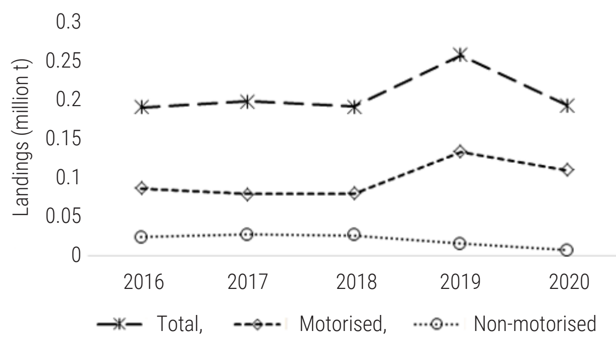

Fig. 2. Total marine landings, including catches from motorised and non-motorised sectors of Andhra Pradesh (Source: ICAR-CMFRI, Kochi)

Empowering small-scale fishers through finfish cage farming would ensure their contribution to enhance global food security, improve their socio-economic status and achieve sustainable and maximum utilisation of fishery resources. Adding culture to capture in livelihood would also restore and conserve their status as vital components in the fisheries sector.

Materials and methods

The Traditional Fishermen's Co-operative Society, Visakhapatnam with 110 fishermen members and the Yanadri Girijana Matsya Sakhara Sangam, Krishna with more than 600 fishermen families were selected for the study. The former, fish in the coastal waters of Visakhapatnam (Fig. 3) employing hooks and lines using fiberglass crafts (Overall length 6 - 9 m) with outboard motors (9 - 12 HP). Fishing operations are of short duration (a maximum of 20 km from shore) and catch mostly tunas, seerfishes, catfishes and carangids. An average of six crews is involved, with an actual fishing duration of 3 h. The latter, operate in the estuarine waters of Krishna (Fig. 3) from plank-built and thermocol boats (Overall length 6-8 m) and catch majorly clupeids, carangids and sciaenids using small-meshed gillnets. The crafts are propelled by paddles and fish at depths ranging from 10 to 30 m and are with an average of four crews.

Information on investment, operational expenses and returns were calculated from 20 units operated at the respective districts for two years from January 2017 to December 2018. From these selected units, using a pre-tested schedule, for 10 days in a month, data was collected with respect to capital costs (including investment in crafts and gears; charges for auctioning, berthing and other taxes; fuel (energy) expenses; expenses on craft and gear repairs and maintenance and other operational costs; labour costs and wages including food, stores and other provisions; and on the amount and value of various finfishes and shellfishes caught). Various economic performance indicators *viz.,* operating cost and gross income per trip, input-output and operating ratios (capital productivity), labour productivity, net cash flow, net profit and gross value added (GVA) were estimated following the methodologies of Sathiadas (1989), Narayanakumar *et al*. (2009) and Raju *et al*. (2022).

In 2019, a select group of fishermen from the above two associations, 15 and 76 from Visakhapatnam and Krishna respectively, were imparted hands-on training on marine and estuarine cage farming of Indian pompano (*Trachinotus mookalee*). Indian pompano, belonging to the family Carangidae is an ideal candidate species for marine and estuarine cage culture systems, owing to its optimum growth response, quick acceptance to artificial feed and better adoptability to the cage culture systems (Sekar *et al*., 2021a). Different aspects such as, cage fabrication and installation, fish seed stocking, fish feeding, cage net exchange and cage net cleaning, were demonstrated and the trainee fishermen were asked to perform the operations by themselves, which they successfully accomplished. The trained personnel were selected as beneficiaries for a demonstration project funded by National Fisheries Development Board (NFDB), Ministry of Fisheries, Animal Husbandry and Dairying (MoFAHD), Government of India and their active participation in all activities ensured expertise development. The accrued revenue from the harvest was shared among the beneficiaries, evoking great enthusiasm among them for adopting cage farming as an alternative or diversified means of livelihood. Consequently, on termination of the project by the end of 2020, in tune with the national guidelines, the cage structures with accessories were handed over to these selected beneficiaries for continuing the culture operations using their own finances.

Elated with the results obtained, in 2021, fifteen beneficiaries from the Traditional Fishermen's Co-operative Society commenced farming in 15 cages for Indian pompano in the marine waters of Ramakrishna Beach, Visakhapatnam. Simultaneously, in the estuarine waters of the river Krishna; at Nagayalanka, Edurumondi and Peddapalem, 76 beneficiaries from the Yanadri Girijana Matsya Sakhara Sangam, Krishna initiated farming for the same species in 70 estuarine cages. Present study, represents the maiden attempt to farm the species on a commercial scale. The above sites were selected using several criteria, including topographical, physical, chemical and biological (Benetti *et al*., 2010; Sekar *et al*., 2021b).

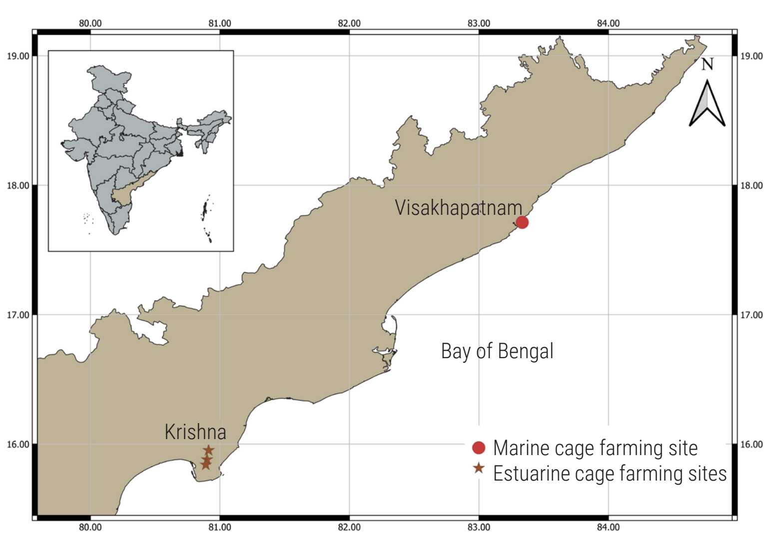

Fig. 3. Map showing the study locale

With no rules and regulations existent on leasing of open-waters, care was taken to ensure the approval and support of local fishers and fisherfolk organisation. Navigational routes were avoided and fishing voyage obstruction was minimised to avoid potential conflicts.

Marine cages were circular (6 m in diameter and 4 m in net-depth) and made up of high-density polyethylene (HDPE), whereas estuarine cages were square (5 m X 5 m and 3.5 m in net depth) and manufactured using galvanised iron (GI). Marine cages were moored using single point revolving mooring and in estuarine cages, batteries were anchored using fixed mooring. Mesh size for the outer HDPE net was 40 mm, whereas for the inner HDPE net, it increased from 10 mm to 25 mm with advancement in culture duration. Indian pompano seeds, produced in the hatchery at Visakhapatnam Regional Centre of ICAR-CMFRI, after nursery rearing in indoor cement tank systems, were stocked at an average body weight of 22.6 g in the marine and estuarine cages @ 2500 and 1500 numbers per cage during 2021 in the months of March and August, respectively. The stocked fishes were fed, thrice a day, at 8-3% of biomass with floating pellets possessing 40% crude protein and 10% crude fat. Pellet size increased from 1.2 to 6 mm with fish growth. Fouling on cage structure and nets, both outer and inner were cleaned periodically. Regular monitoring for health and growth was performed. Fishes were harvested after eight months of culture, in the month of November, 2021 for marine and April, 2022 for estuarine cages. During culture duration, at all sites, important water-quality (temperature, dissolved oxygen, salinity, pH, ammonia, nitrite, nitrate and phosphate) and sediment (pH and organic carbon) parameters were recorded at monthly intervals as per APHA (2017).

Innovative cluster cage farming approach was promoted during the demonstration project, and the same was well accepted. In tune to this approach, a set of 6 to 15 cages were installed at a particular place and were managed by individuals from the group or society on rotation basis, either on alternative days or on weekly basis at their convenience. Therefore, all members equally participated in routine cage culture activities and simultaneously managed their daily livelihood by performing other works. Economic performance was assessed from the fixed and variable costs and from the harvest and the price realised thereof. Although cages and accessories were provided to the beneficiaries at no cost; for estimating the economic parameters, their depreciation value and interest on the initial investment (fixed cost) were considered. Variable costs for each production cycle involved expenses towards fish seed and feed, labour wages, watch and ward and cage assembly maintenance. Indicators estimated were gross revenue, net income and net operating income, capital productivity (operating ratio), input-output ratio, rate of return and break-even production.

Results and discussion

In the traditional sector, termed as small-scale fisheries, wide variations in fishing methods and crafts and gears exist. Despite this diversity, all crafts and gears are relatively smaller and fishing methods are less capital intensive. Among all maritime states in the country, artisanal fisheries play a pivotal role in Andhra Pradesh. In the state, fishing in coastal waters using hooks and lines and small-meshed gillnets has traditionally been used for several decades by the artisanal fishermen. Catamarans (wooden *teppa* and fibre *teppa*) are the most common traditional crafts used for nearshore fishing. Various economic performance indicators *viz.,* operating cost and gross income per trip, input-output and operating ratios (capital productivity), labour productivity, net cash flow, net profit and GVA were estimated for the single-day motorised fishing operations using hooks and lines in Visakhapatnam District of Andhra Pradesh and non-motorised fishing operations using small-meshed gillnets in Krishna District and the results are presented in Tables 2 and 3. In the motorised crafts engaged in hook and line fishing off Visakhapatnam, the average cost per trip of this single-day fishing worked out to be ₹8,598 (US$ 114.64), with gross revenue of ₹9,600 (US$ 128.00); therefore, earning a net operating income of ₹1,402 (US$ 18.69). The capital productivity was worked out to 0.85 and the labour productivity was 13.33 kg per crew per trip. Fuel cost alone, accounted for 59% of the operating cost followed by crew wage, which accounted for about 32% (Table 2). For the non-motorised fishing in Krishna estuaries employing gillnets, the average cost per trip worked out to ₹308 (US$ 4.11), with gross revenue of ₹500 (US$ 6.67); thus, earning a net profit of ₹192 (US$ 2.56). The capital productivity was worked out to 0.51 and the labour productivity was 2 kg per crew per trip. Crew wages alone accounted for 95% of the operational expenses (Table 3). Earlier studies conducted from different locations along the Indian coasts had reported higher net operating profit and net profit per trip for motorised crafts than traditional crafts and for mechanised crafts than motorised crafts (Kurien, 1996; Narayanakumar *et al*., 2000; Immanuel and Rao, 2012; Salagrama, 2012; Raju *et al*., 2017; Infantina and Jayaraman, 2020). A comparison of the present economic indicators, to that reported earlier by these authors have indicated decreasing rate of returns over time. Similarly, techno-economic performance review of selected fishing fleets

Table 2. Economics of motorised fishing operations in Visakhapatnam District

Category	Components	Value ₹ (US$)
Fixed costs	Depreciation	252.00 (3.03)
	Interest on capital	148.00 (1.78)
	Sub-total fixed costs	400.00 (4.81)
Labour	Crew wages	2602.00 (31.30)
	Crew bata value	-
	Sub-total labour costs	2602.00 (31.30)
Inputs	Fuel cost	4860.00 (58.46)
	Auction charges	150.00 (1.80)
	Other charges	586.00 (7.05)
	Sub-total input costs	5596.00 (67.32)
	Total operating cost	8198.00 (98.62)
	Total cost of production	8598.00 (103.43)
Output	Catch (kg)	80.00
	Gross revenue (GR)	9600.00 (115.48)
	Crew size (No.)	6
Indicators	Net operating income	1402.00 (16.87)
	Net profit	1002.00 (12.05)
	Capital productivity	0.85
	Labour productivity	13.33
	Input-output ratio	0.58
	Gross value added (GVA)	4004.00 (48.17)
	% GVA to GR	41.71

Table 3. Economics of non-motorised fishing operations in Krishna District

Category	Components	Value in ₹ (US$)
Fixed costs	Depreciation	34.00 (0.41)
	Interest on capital	18.00 (0.22)
	Sub-total fixed costs	52.00 (0.63)
Labour	Crew wages	244.00 (2.94)
	Crew bata value	0.00
	Sub-total labour costs	244.00 (2.94)
Inputs		
	Auction charges	0.00
	Other charges	12.00 (0.14)
	Sub-total input costs	12.00 (0.14)
	Total operating cost	256.00 (3.08)
	Total cost of production	308.00 (3.71)
Output	Catch (kg)	2.00
	Gross revenue (GR)	500.00 (6.01)
	Crew size (No.)	1
Indicators	Net operating income	244.00 (2.94)
	Net profit	192.00 (2.31)
	Capital productivity	0.51
	Labour productivity	2.00
	Input-output ratio	0.024
	Gross value added (GVA)	488.00 (5.87)
	% GVA to GR	96.00

in developed countries in 2016 revealed that small scale coastal vessels (<12 m OAL) reported an average net profit margin (NPM) of around 22%, return on fixed tangible assets (ROFTA) of 39% and return on investment (ROI) as 31%; which were marginally lower than earlier estimates, indicating decreased profitability over time (Carvalho *et al*., 2020).

Since the 1990s, small-scale fishers in the country, particularly from the east coast have seen incomes from fishing fluctuate widely. Modernisation of the fisheries sector has made the small-scale fishers more vulnerable to emerging threats. Overcapacity and capital-intensive fishing practices, uncertain fish catches and decline of several commercial species that contributed to much of the fisher's incomes, competition and conflicts for fishing grounds and fishery resources at sea, rising levels of indebtedness with cost of credit accounting for a sizeable proportion of the earnings, and long and uncertain market supply chains consisting of several intermediaries who dictate the terms of market access for the produces are perceived as bottlenecks plaguing the status of small-scale fishers (Salagrama, 2012). With pitiable economic condition over the years due to decreasing returns, artisanal fishers were forced to borrow money from the middlemen for their essential needs, and while taking these loans, they were compelled to sell their catch to the middlemen at rates dictated by them. The loan accounts were often manipulated and by the end of the season, they delved deeper into debt and thus, always remained in the clutches of these money lenders. In extreme situations, their crafts and gears were seized by these middlemen (Rao, 1994; Kurien, 1996; Salagrama, 2012). Fully occupied with fishing activities and with limited access to land-based activities, their migration to other fields of work was extremely difficult resulting in no economic progress.

A perusal of the landings by motorised and non-motorised crafts in the country (Fig. 1) reveals a decreasing trend; from 0.71 to 0.84 million t and 0.07 to 0.10 million t during 2013-2015 to 0.56 to 0.62 million t and 0.04 to 0.05 million t during 2016-2018 and further to 0.44 to 0.56 and 0.03 million t during 2019-2020. Their contribution too, has come down from 23% and 2% to 15% and 1% respectively. In Andhra Pradesh, the landings by non-motorised crafts (Fig. 2) have decreased from 0.025 to 0.028 million t during 2016-2018 to 0.008 to 0.016 million t during 2019-2020, with their contribution decreasing over the years from 14 to 4% (personal communication, Fisheries Resource Assessment Division, ICAR-CMFRI). In view of the above reduction in catches by the traditional sector, their profits have waned with time in recent years. Their level of earnings is therefore, often not commensurate to the investments made and the costs incurred.

In situations where fishing is a full-time activity, getting fishermen out of fisheries and into other sources of livelihood in times of economic crisis is often suggested as the remedy (Panayotou, 1982). However, this strategy, for generating additional income on a sustainable basis should be driven by technological changes which would result in the creation of community level social assets, lower risk and uncertainty, sustainability of stock, assured income, self-reliant and sustainable development. Artisanal fisheries though contribute significantly to food and livelihood security; the stagnating fish landings and its price coupled with the ever-increasing input costs and operational expenses have made economic status of the fishers miserable. Considering the economic constraints, providing an additional or an alternate livelihood avenue in future is inevitable. Cage culture of marine finfishes is perceived as one such diversified avenue with promising outcomes. Identified artisanal fishers were encouraged to adopt cage aquaculture and the selected group from the Traditional Fishermen's Co-operative Society commenced farming in 15 cages for Indian pompano in the marine waters of Ramakrishna Beach, Visakhapatnam. Simultaneously, in the estuarine waters of the river Krishna; at Nagayalanka, Edurumondi and Peddapalem, 76 members of the Yanadri Girijana Matsya Sakhara Sangam, Krishna initiated farming for the same species in 70 estuarine cages. The economics worked out have been presented in Tables 4 and 5.

Economic performance was worked out by calculating the annual fixed cost, variable cost and return in terms of harvest from cage and revenue generated from these sales. Fixed costs are costs

Table 4. Economic indicators for marine cage farming of Indian pompano in ten HDPE circular cages

Details	Value ₹ (US$)
Annual fixed cost	5,41,776.00 (6517.21)
Variable cost	48,12,000.00 (57885.24)
Total cost of production	53,53,776.00 (64402.45)
Gross revenue	70,00,000.00 (84205.46)
Net Income (Profit)	16,46,224.00 (19803.01)
Net operating income	21,88,000.00 (26320.22)
Cost of production (₹ per kg)	263.86 (3.17)
Price realised (₹ per kg)	345.00 (4.15)
Capital productivity / Operating ratio	0.69
Annual rate of return to capital (%)	51.85
Break-even production (kg)	15,518.19

Table 5. Economic indicators for estuarine cage culture of Indian Pompano

Details	Value ₹ (US$)
Annual fixed cost	30,148.00 (362.66)
Variable cost	1,93,300.00 (2325.27)
Total cost of production	2,23,448.00 (2687.93)
Gross revenue	2,97,000.00 (3572.72)
Net Income (Profit)	73,552.00 (884.78)
Net operating income	1,03,700.00 (1247.44)
Cost of production (₹ per kg)	244.51 (2.94)
Price realised (₹ per kg)	325.00 (3.91)
Capital productivity / Operating ratio	0.65
Annual rate of return to capital (%)	53.92
Break-even production (kg)	687.53

that are independent on the level of production and have to be paid whether or not production occurs in a particular year. This includes cage frame, nets, chain, ballast, floats, buoys, mild steel anchors, wooden platform and fabrication and installation charges. Generally, fixed costs are spread out over the expected life of the production input involved. This allows the producer to consider the long-term view of profitability. The variable costs are costs that are dependent on the level of production and have to be paid for every cycle of culture such as the cost of fish seed, feed, labour wages, watch and ward and regular maintenance charges. Returns from cage culture is the revenue realised from the sale of harvest (total production in kg × price per kg). Using the cost and return figures, economic indicators were estimated to test the economic viability and financial feasibility of cage culture for Indian pompano in marine and estuarine waters (Tables 4 and 5). As all the cages in the marine waters were collectively operated and managed by the society, for ease of computation and understanding, their economics are presented as a set of 10 cages. The estuarine cages were also jointly operated by groups, but as the numbers of cages varied in each cluster from 6 to 8 and 10, and hence to avoid confusion, their economics are presented per cage.

The initial investment on ten HDPE marine cages of 6 m diameter was worked out to ₹31,75,000 (US$ 42333.33). The HDPE cage frame accounted for the maximum share of investment (35%) followed by the chain, D-shackles and revolving swivel (22%), nets (16%), cage installation charges (8%), floats (6%), boat and engine (6%), anchors (5%) and ballasts (4%). The annual fixed cost was calculated at ₹5,41,776 (US$ 7223.68). The operational costs for the culture period of eight months were worked out to ₹48,12,000 (US$ 64160.00). Feed cost alone accounted for 82% of the total operating cost. Thus, the total cost of production to the fishermen worked out to ₹53,53,776 (US$ 71383.68). The culture produced 20.29 t at harvest at the end of eight months, thus earning gross revenue of ₹70,00,000 (US$ 93333.33) to the fishermen. Average survival, body weight and feed conversion ratio were 96.28%, 843 g and 1.94, respectively. The culture, after eight months, earned a net operating income and a net profit of ₹21,88,000 (US$ 29173.33) and ₹16,46,224 (US$ 21949.65) respectively. The cost of production per kg worked out to ₹263.86 (US$ 3.52) against the price realisation of ₹345 per kg (US$ 4.60). The capital productivity measured through the operating ratio was 0.69. For a GI cage of 5 m x 5 m dimension, the initial investment was worked out to ₹1,36,400 (US$ 1818.66). The GI cage frame accounted for the maximum share of investment (31%), followed by nets (22%), ballasts (11%), cage fabrication and installation charges (10%), buoys (9%), chain (7%), anchors (5%) and others (5%). The annual fixed cost for the GI cage was calculated at ₹30,148 (US$ 401.97). The operational costs for the culture period of eight months were worked out to ₹1,93,300 (US$ 2577.33). Feed cost alone accounted for 71% of the total operating cost. Thus, the total cost of production for the fishermen worked out to ₹2,23,448 (US$ 2979.31). The culture of Indian pompano produced on an average 913.85 kg during the harvest at the end of eight months, thus earning gross revenue of ₹2,97,000 (US$ 3960.00) to the fishermen. Average body weight at harvest was 666 g, and average survival was 91.47%. Feed conversion ratio was estimated at 1.50. The culture of Indian pompano earned a net operating income of ₹1,03,700 (US$ 1382.66) after eight months and a net profit of ₹73,552 (US$ 980.69). The cost of production per kg was worked out to ₹244.51 (US$ 3.26) against the price realisation of ₹325 (US$ 4.33) per kg. The capital productivity measured through the operating ratio was 0.65. These economic parameters indicate that both, the marine HDPE cage culture and the GI estuarine cage culture for Indian pompano is economically viable. Knowledge on economic indicators is virgin information on culture for the species.

In an earlier study on the economic viability of open-sea cage culture for Asian seabass in HDPE cages, the annual rate of return for the investment was observed as 119% (Ramachandran, 2009). From Kerala backwaters, Asian seabass cage culture reported an average benefit-cost ratio of 2.5:1 during first year (Vipinkumar *et al*., 2021). Similarly, in Lakshmipuram Village of Krishna District, coastal cage farming of Asian seabass by a group of artisanal fishers resulted in a production of one ton, with a gross income of ₹3,00,000 (US$ 4000) at a selling price of ₹300 (US$ 4) per kg. Deducting the operational expenses, the net income realised was ₹1,00,000 (US$ 1333.33) and a comparison to their prior income from other occupations revealed a doubling of net income through cage farming (Jeeva *et al*., 2021). Cage farming for Indian pompano under the demonstration project at Nagayalanka in Krishna District had reported on an average body weight of 745 g at harvest, with a survival of 97.3% and feed conversions of 1.62 and biomass of 10.86 kg m^{-3} (Sekar *et al*., 2021b). Their harvest was sold to Maxwell Sea Foods, Kochi at the rate of ₹330 (US$ 4.40) per kg. In the same demonstration project at Peddapalem, after seven months of rearing, Indian pompano reached 675 g and 600 kg was harvested from individual cages and sold at ₹295 (US$ 3.93) per kg to wholesale fish traders in Chennai, Tamil Nadu (Sekar *et al*., 2021b). All bio-growth parameters reported in this study, are the first for the species from commercial-level operations and are comparable to that reported earlier from frontline demonstrations.

The comparative economic performance of artisanal fishing with estuarine and marine cage culture is presented in Table 6. With higher net operating income for estuarine cage culture and comparable net operating income for marine cage culture, both marine and estuarine cage culture offer viable alternatives to their counterparts; hook and line fishing from motorised crafts and gillnet fishing from non-motorised crafts. On a precautionary note, it is expected that once the practice expands with an increase in the number of cage units, the cost will automatically decline due to the economies of scale of operation. The present technological interventions on cage farming impacted positively the livelihood of traditional fishers under various dimensions *viz.,* technological, social and economic. Earlier, the daily earnings from various

Table 6. Comparative economic performance of artisanal fishing with cage culture (Values denote one operational unit)

Economic Indicators	Artisanal fishing with non-motorised crafts	Estuarine cage culture	Artisanal fishing with motorised crafts	Marine cage culture
Net Operating Income	₹39,040 (US$ 469.63) (for 8 months @ 20 trips per month)	₹1,03,700 (US$ 1247.44) (in a crop period of eight months)	₹2,24,320 (US$ 2698.42) (for 8 months @ 20 trips per month)	₹2,18,800 (US$ 2632.02) (in a crop period of eight months)

income-generating activities supported only their daily food. They hardly had any savings. The cash-in-hand generated in bulk from cage culture improved their savings, purchasing power, ability to repay their old debts, and ultimately improved their standard of living. Economic sustainability was also ensured when huge income was realised in a lump sum, and some portion was kept for investment towards the expenses for the next culture. It is therefore conclusive, that marine and estuarine cage farming offers additional or diversified alternatives to small-scale fishing. The marine and estuarine finfish cage culture model established in Visakhapatnam and Krishna is also perceived by the community as a role model for landless farmers, who do not have any reliable and sustainable source of income. This model is therefore, expected to be emulated by different groups of landless populations living in various coastal districts following the prescribed union guidelines for their livelihood improvement in the future.

Daily wave height for the marine site was derived from a secondary source (www.tide-forecast.com) and was reported to vary during the eight months of culture from 0.71 m to 1.65 m. With the cage structure offering complete protection to the farmed fishes against the physical forces of winds, waves and currents; the structure and the associated cost seems to be apt for the tropical waters. Water and sediment quality monitoring during the culture period is essential for advocating long-term sustainability of the selected sites for cage farming. At all the four sites, during culture, water and sediment quality (Table 7) were within the optimum limits as stated by Philipose *et al.* (2012) for finfish farming. Therefore, cage farming in clusters, with 6 to 15 cages at each cluster appears safe from an environmental perspective. At the estuarine sites, there were three to four clusters at one location, and the clusters were separated by a distance of 100 m. Further, proliferation in the number of cages per cluster or on the number of clusters will depend on the carrying capacity of the site.

Mariculture development, however, if not prudently managed would trigger spatial conflicts with small-scale fishers due to scarcity of nearshore coastal waters. Declines in available fishing grounds, navigational hindrances for free movement of crafts and boats and market competition are the major expected issues for contention (Ramos *et al*., 2015). Eroding the distrust that often exists, ensuring that all stakeholders feel involved in the decision making process, and securing their access to sustainable marine resources through spatial right-based approaches is therefore, the key to future development. Comprehensive marine spatial planning has emerged as an important tool for reducing or eliminating conflicts among mariculture and fishery stakeholders by allocating different uses to marine spaces and trade-offs to support decision making. A thorough understanding of the potential interactions between marine capture and mariculture is thus essential and evaluating strategies for managing these interactions is paramount for future management decisions in promoting positive ecological and economic outcomes (Clavelle *et al*., 2019). Cage structure influences the distribution and abundance of marine species in an area, and the addition of anchors and associated mooring structures affect the marine habitat. In fact, the use of artificial structures and installations and the supply of uneaten/excess feed from cages results in them acting as fish aggregating device with varying relevance for fisheries management (Dempster *et al*., 2009). Also globally, there is little perceived evidence of a direct link between nutrient enrichment due to feed and faecal matter and harmful algal blooms (Price *et al*., 2015).

Use of wild caught forage fish for feed and high feed cost, coastal water pollution, inadequate financial capital, climate change impacts and lack of insurance facilities are major constraints in cage fish farming of developing countries (Aswathy and Imelda, 2020). Ecosystem-based approach, proper site selection and aquaculture zoning, institutional mechanisms to address risk and uncertainties, credit support and capacity development are widely suggested as adaptation strategies for accelerating the adoption of cage mariculture technology (Soto *et al*., 2008; Shinoj *et al*., 2017; Aswathy and Imelda, 2020). Realising the necessity in India, National Mariculture Policy was drafted collaboratively in 2019 by NFDB and ICAR-CMFRI, which is presently in the process

Table 7. Water and sediment quality during culture period at the culture sites

Water/Sediment parameters	Ramakrishna Beach	Nagayalanka	Edurumondi	Peddapalem
Temperature (^{0}C)	28.7-30.9	28.4-30.4	28.4-30.2	28.5-30.3
Salinity (ppt)	32.6-33.8	24.1-30.9	23.2-31.6	22.7-31.4
Dissolved oxygen (ppm)	4.56-5.64	3.25-5.12	3.21-5.60	3.06-4.52
Water pH	8.04-8.36	7.76-8.09	7.93-8.27	7.88-8.21
Ammonia (ppm)	0.009-0.051	0.012-0.078	0.013-0.065	0.003-0.028
Nitrate (ppm)	0.013-0.260	0.021-0.416	0.018-0.312	0.008-0.086
Nitrite (ppm)	0.001-0.033	0.002-0.041	0.002-0.026	0.001-0.012
Phosphate (ppm)	0.001-0.106	0.003-0.159	0.006-0.122	0.002-0.133
Sediment pH	7.38-7.75	7.15-7.53	7.23-7.66	7.20-7.67
Organic carbon (%)	1.09-3.44	1.24-4.62	0.87-3.88	0.95-3.13

of acceptance by the Ministry of Fisheries, Animal Husbandry and Dairying (MoFAHD), Government of India. Comprehensive guidelines on various aspects of cage farming have been categorically spelled out in the policy. The fisheries department of the coastal states shall lease out the waters for cage mariculture as per the guidelines prescribed in this policy. The leasing policy shall adhere to the principles of responsible fishing, and ensure limits to biological production based on carrying capacity and environmental sustainability. National Bank for Agriculture and Rural Development (NABARD) has been earmarked to develop new schemes to support cage mariculture. Suitable fish crop insurance and personal or group insurance schemes at affordable premium are envisaged to be essentially developed to cover the risks in cage mariculture. Subsequently, Pradhan Mantri Matsya Sampada Yojana (PMMSY), a flagship project was launched for a duration of five years (2020-2025) with a total outlay of ₹20,050 crores. Establishment of marine and estuarine cages is one among the prime activities proposed in the scheme.

The government of India is striving to enhance the skills and capabilities of the small-scale fishers for undertaking cage mariculture, with the aspirations of doubling their income by 2022 through enabling interested fishers to move from fishing to more efficient and economic mariculture activities. Cage farming of Indian pompano, in marine and estuarine waters offers tremendous promise on an industrial scale. However, the potential is not infinite, and when the numbers increase manifold in the nearshore coastal waters, caution should be exercised with respect to their ecological and environmental impacts. Taking into account the equity in interests for all stakeholders, proliferation in numbers should be aligned to other cross-cutting sectors, policies and legal provisions; and for this, the access rights and the licensing issues should be clearly defined. Empowering small-scale fishers through finfish cage farming would however, ensure their contribution to enhance global food security, improve their socio-economic status and achieve sustainable and maximum utilisation of fishery resources. The adoption of cage culture technologies has reduced the uncertainty associated with fishing due to its inherent stock dynamics, raised the productivity and have increased the income. All of these together, coupled with minimal requirements of land and labour makes this farming method ideal for small-scale fisherfolks as an alternative or diversified income source.

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