Impact of Technologies and Policies on Marine and Inland Fish Culture Systems in India

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भा.कृ.अ.प.– राष्ट्रीय कृषि आर्थिकी एवम् नीति अनुसंधान संस्थान
ICAR – NATIONAL INSTITUTE OF AGRICULTURAL ECONOMICS AND POLICY RESEARCH

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P Shinoj, A Suresh, N K Barik, R Geetha, A Ekka, and R Jain (Eds) (2025). *Impact of Technologies and Policies on Marine and Inland Fish Culture Systems in India*. ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi

ISBN : 978-93-342-3364-3

Published
March 2025

Published by
Dr P S Birthal
Director
ICAR-National Institute of Agricultural Economics and Policy Research (NIAP)
New Delhi-110012

Printed at
M/s Chandu Press, 469, Patparganj Industrial Estate, Delhi 110 092.

Preface

The aquaculture sector in India has witnessed unprecedented growth in recent decades, driven by technological advancements that have significantly enhanced the productivity and efficiency of culture systems. The emergence of mariculture in the open sea and coastal water bodies has added a new dimension to aquaculture, as with this technology, marine and brackishwater species that were not previously amenable to culture can be farmed under controlled conditions. Cage culture of marine, brackishwater, and freshwater species has made rapid strides in the fish culture arena, enhancing the productivity of fish per unit area, and thereby enabling fish farmers to realize greater input-use efficiency and farm incomes. Similarly, the latest developments in post-harvest processing and value addition have opened new vistas in the efficient utilization of fish and its products. This book explores the profound impact of such technologies on the income and livelihood development of fish farmers and fishers in India.

Through rigorous research and analysis, the authors of this compilation have delved into the transformative potential of aquaculture technologies in enhancing the economic well-being of those involved in the sector. Specifically, they have examined a wide range of innovations, from improved breeding and hatchery techniques to advanced aquaculture systems and sustainable practices. Recent advances in technology impact assessment at micro- and macro levels were utilized to empirically evaluate the impact of selected technologies on the respective production systems, associated stakeholders, and the overall fish-based economy.

The book is organized into seven chapters, each dealing with innovations in a particular sub-sector of the marine/inland aquaculture economy with detailed analysis and findings regarding the economic and social impacts of selected technologies. Furthermore, the chapters also discuss policy implications associated with the shifting regimes of technology and future investment and governance requirements towards further development of the sector.

This book is intended to serve as a valuable resource for researchers, academics, policymakers, students, professional practitioners, and the industry. ICAR-NIAP is proud to take the initiative to commission the studies that led to the compilation of this book under a National Network Project funded by the ICAR and hopes that this work will inspire further research and innovation in the field of aquaculture and allied sectors toward a more inclusive and sustainable fisheries community. We believe that by harnessing the power of aquaculture technologies, India can build a more prosperous and resilient rural economy.

(Pratap Singh Birthal)
Director, ICAR-NIAP

Acknowledgements

This book is an outcome of the efforts of a large number of researchers and we acknowledge with all humility the help and support provided by them. First and foremost, we would like to express our sincere thanks to all the authors of the book chapters for their contributions within the stipulated time.

We express our sincere gratitude to Dr P S Birthal, Director, ICAR-National Institute of Agricultural Economics and Policy Research (NIAP), New Delhi for his generous funding support and invaluable overall guidance, which were instrumental in initiating this important line of research and in completing this study satisfactorily.

We extend our deepest appreciation to Dr Grinson George, Director, ICAR-Central Marine Fisheries Research Institute (CMFRI), Kochi; Dr Kuldeep K Lal, Director, ICAR-Central Institute of Brackishwater Aquaculture (CIBA), Chennai; Dr B K Das, Director, ICAR-Central Inland Fisheries Research Institute (CIFRI), Barrackpore; Dr P K Sahoo, Director, ICAR-Central Institute of Freshwater Aquaculture (CIFA), and Dr George Ninan, Director, ICAR-Central Institute of Fisheries Technology (CIFT), Kochi. Their unwavering support in facilitating the conduct of this research, including access to resources and expertise, is gratefully acknowledged. We also express our deep indebtedness to Dr A Gopalakrishnan, former Director of ICAR-CMFRI for his unconditional support in initiating and carrying forward with this study. The support extended by field enumerators, fish farmers, and fishers in providing valuable field data that forms the backbone of the insights arising from the study is thankfully acknowledged.

We also wish to express our profound thanks to the anonymous reviewers for their meticulous review reports. Their insightful comments and constructive feedback significantly enhanced the quality and clarity of this book, "Impact of Technologies and Policies on Marine and Inland Fish Culture Systems in India." The publication committee of the institute has done internal review of the book and provided useful suggestions and comments to improve the quality of the book.

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Contents

Acronyms and Abbreviations

ACF	Autocorrelation Function
AIC	Akaike Information Criterion
ARIMA	Auto-Regressive Integrated Moving Average
ASI	Annual Survey of Industries
BCR	Benefit Cost Ratio
BIC	Bayesian Information Criterion
BIS	Bureau of Indian Standards
CAC	Codex Alimentarius Commission
CADA	Command Area Development Authority
CAGR	Compound Annual Growth Rate
CBDR-RC	Common but Differentiated Responsibilities and Respective Capabilities
CCP	Critical Control Point
CGIAR	Consultative Group on International Agricultural Research
CIBA	Central Institute of Brackishwater Aquaculture
CIFA	Central Institute of Freshwater Aquaculture
CIFRI	Central Inland Fisheries Research Institute
CIFT	Central Institute of Fisheries Technology
CLCS-TUS	Credit Linked Capital Subsidy and Technology Upgradation Scheme
CMFRI	Central Marine Fisheries Research Institute
CSIR	Council of Scientific & Industrial Research
CSMCRI	Central Salt and Marine Chemicals Research Institute
DANIDA	Danish International Development Agency
DDU-GKY	Deen Dayal Upadhyaya Grameen Kaushalya Yojana
EEZ	Exclusive Economic Zone
E-SDP	Entrepreneurship-cum-Skill Development Programme
EU	European Union
FAO	Food and Agriculture Organisation
FFDA	Fish Farmers' Development Agency
FISHCOPFED	National Federation of Fishermen Co-operatives Limited
FPOs	Farmer Producer Organisations

FSI	Fishery Survey of India
FSSAI	Food Safety and Standards Authority of India
GDP	Gross Domestic Product
GFCF	Gross Fixed Capital Formation
GHP	Good Hygienic Practices
GIFT	Genetically Improved Farmed Tilapia
GMP	Good Manufacturing Practices
GoI	Government of India
GVA	Gross Value Added
HACCP	Hazard Analysis and Critical Control Points
ICAR	Indian Council of Agricultural Research
IDA	International Development Association
IDRC	International Development Research Centre
IMTA	Integrated Multi-Trophic Aquaculture
IRDP	Integrated Rural Development Programme
IRR	Internal Rate of Return
IUU	Illegal, Unreported and Unregulated Fishing
IV	Instrumental Variable
KCC	Kisan Credit Card
KVK	Krishi Vigyan Kendra
MAE	Mean Absolute Error
MAP	Modified Atmospheric Packaging
MAPE	Mean Absolute Percentage Error
MASE	Mean Absolute Scaled Error
MISS	Modified Interest Subvention Scheme
MPE	Mean Percentage Error
MPEDA	Marine Products Export Development Authority
NABARD	National Bank for Agricultural and Rural Development
NCSCM	National Centre for Sustainable Coastal Management
NFDB	National Fisheries Development Board
NGOs	Non-Governmental Organizations
NIOT	National Institute of Ocean Technology
NOI	Net Operating Income
NP	Net profit

NPF	National Fisheries Policy
NPV	Net Present Value
NSSO	National Sample Survey Office
OCOF	Overcapacity and Overfishing
OPR	Operational Research Project
OR	Operating Ratio
PACF	Partial Autocorrelation Function
PCI	Principles-Criteria-Indicators
PIB	Press Information Bureau
PMMSY	Pradhan Mantri Matsya Sampada Yojana
PMSBY	Pradhan Mantri Suraksha Bima Yojana
PSM	Propensity Score Matching
RASFF	Rapid Alert System for Food and Feed
R & D	Research and Development
RAS	Recirculatory Aquaculture System
RGCA	Rajiv Gandhi Centre for Aquaculture
RMSE	Root Mean Squared Error
ROI	Return on Investment
RRB	Regional Rural Bank
S&DT	Special and Differential Treatment
SFDA	Small Farmers' Development Agency
SHGs	Self-Help Groups
SI	Sustainable Intensification
SIFFS	South Indian Federation of Fishermen Societies
SPS	Sanitary and Phyto Sanitary measures
SSF	Small Scales Fisheries
TE	Triennium Ending
TRYSEM	Training of Rural Youth for Self Employment
UNCLOS	United Nations Convention on the Law of the Sea
WITS	World Integrated Trade Solution
WSS	White Spot Syndrome
WTO	World Trade Organisation
WQM	Water Quality Monitoring

Executive Summary

Fisheries and aquaculture play a crucial role in India's economy, contributing significantly to food security, employment, and foreign exchange earnings. With vast resources and a growing aquaculture industry, India is a major global fish producer and a leading supplier of fish and fish products. While marine fishing has historically been important, inland aquaculture, particularly carp and freshwater species farming, now dominates production, exceeding marine catches. The success of modern fisheries and aquaculture in India despite their traditional origins, can be attributed to strategic research and development programs that have driven commercialization and post-harvest activities. These technological advancements have significantly boosted production, increased farm incomes, and created new job opportunities. The impacts extend beyond the sector, influencing food prices, consumer diets, and labour markets. To effectively guide resource allocation, it's crucial to assess the economic impact of technologies that have the potential to propel the sector in the future. This involves considering factors like yield enhancement, resource efficiency, product value, climate resilience, and the socioeconomic context associated with varying production systems. In this book, various methods, including field surveys, partial budgeting, cost-benefit analysis, statistical tools, and econometric impact assessment techniques are employed to evaluate the impacts of selected technologies in various sub-sectors of India's marine and inland aquaculture economy.

A broad summary of India's fisheries and aquaculture economy is presented, focusing on its present status, growth trends, and development priorities, before delving deeper into the impact of technologies and implications of associated policies. It begins with an overview of the sector, including its global position, production trends, workforce demographics, trade dynamics, and the role of government. The sector has been noted to be growing at an average rate of 8.63% per annum during the past decade (2011-12 to 2022-23) and presently contributing 7.2% to Agriculture and allied GVA and 1.32% to total GVA. In 2022-23, India's total fish production reached 17.5 million tonnes, with three-fourths contributed by the inland sector and the rest being marine origin. Over 28 million people depend on inland and marine fisheries combined for their livelihood. Fish and fish products constitute the second largest exported product from India among the primary commodities. India's fish products export witnessed a record-breaking year in 2023-24, reaching an all-time high of 1.78 million tonnes of seafood exports, valued at US$ 7.38 billion (₹ 6,05,238.90 million). Capital formation and investment in India's fisheries sector have been crucial for enhancing productivity, modernizing infrastructure, and supporting long-term sustainability. Since the early 1990s, the share of fisheries in agricultural Gross Fixed Capital Formation (GFCF) rose from 3.4% to nearly 10% by 2015, driven by mechanization, modernization, and adoption of capital-intensive technologies in both marine and inland fisheries. However, among various heads of revenue expenditure in the fisheries sector, the share of research and extension expenditure relative to GVA has shown a steady declining trend over the past decade, falling from 0.58% in 2011-12 to 0.14% in 2020-21. This requires urgent attention, as allocation for fisheries research and extension is essential to maintain productivity gains, foster innovation, and ensure the sustainable development of the sector.

In India, mariculture is predominantly a small-scale enterprise but offers considerable potential for sustainable expansion. Some of the promising ventures include open sea and 'coastal water' cage farming of finfish and shellfish, seaweed culture, and Integrated Multi-Trophic Aquaculture (IMTA), among others. Empirical analysis carried out based on primary surveys in selected locations covering a total of 159 sample farm units indicates that mariculture farms in India often exhibit suboptimal performance due to inadequate mechanization, low stocking densities, and various external factors like delays in seed supply and water pollution. These enterprises were found to be economically viable in general, with most of the sample farms showing favourable estimates of Return On Investment (ROI), Benefit-cost ratio (BC ratio), and Operating Ratio (OR). An evaluation of the impact of cage farming on household income using a Propensity Score Matching (PSM) framework and considering factors like age, gender, and access to credit, found significant differences between adopter and non-adopter households. After matching based on propensity scores, the study estimated that cage farming significantly increased household income by approximately ₹ 0.66-0.71 million, highlighting its potential as a valuable livelihood option for coastal communities. Some of the key policy-oriented recommendations arising from the study that can lead to sustainable intensification of mariculture include: the implementation of Marine Spatial Plans for efficient ocean space allocation; establishment of clear legislation for leasing and licensing, prioritizing marginalized communities; ensuring an adequate supply of quality seed and feed through public-private partnerships; strengthening food safety and health management protocols; developing and enforcing mandatory guidelines on good farming practices, including measures for anti-fouling, water quality monitoring, crop holiday management, and safety and security measures; enhancing multi-disciplinary research in mariculture; implementing market reforms to foster competitive value chains; introducing specialized schemes for credit, insurance, and other support services; and promoting group farming and cooperative models among mariculture farmers. If adopted scrupulously, these measures can contribute to the sustainable growth and development of India's mariculture sector.

Cage culture in inland open waters offers significant potential to boost fish production in India. The adoption of cage culture in reservoirs has been increasing in states like Tamil Nadu, Karnataka, Gujarat, Jharkhand, Chhattisgarh, and Madhya Pradesh, driven by factors such as the availability of suitable water bodies, government support, and training programs. Compared to traditional pond culture, it demonstrates higher economic returns. Based on data from state governments, an analysis of the techno-economic feasibility of cage culture for various fish species in Indian reservoirs reveals that *Pangasius pangasius* in HDPE cages and *Labeo bata* in GI cages demonstrate the highest economic returns with strong benefit-cost ratios, while Nile Tilapia and *Ompok bimaculatus* also show promising economic viability, albeit with varying levels of productivity (BC ratios ranged between 1.25 to 1.63 depending on species). The estimated economic value of fish produced through cage culture in Chhattisgarh was ₹1720 million, resulting in an economic surplus of ₹ 1710 million, demonstrating its superior economic viability compared to pond culture. When this surplus is normalized per hectare, cage culture generates an economic surplus of ₹ 20 million per hectare. This substantial difference in economic surplus indicates that cage culture is a more economically advantageous and efficient method for fish farming and is capable of significantly enhancing the economic output of fisheries in reservoir areas. However, realizing this potential requires targeted policy interventions. These include investments in infrastructure, subsidies for cage construction, and training programs to equip fishers with the necessary skills. By addressing these issues, reservoir cage culture can significantly enhance fish production, improve livelihoods, and contribute to India's food security and economic growth.

The current state of Asian seabass aquaculture in India was analysed, examining its farming systems, production economics, efficiency, and prospects. In commercial seabass farming systems, fingerlings from the nursery are stocked in pre-grow-out ponds, and subsequently, marketable-sized fish are cultivated in ponds and cages for 8 to 16 months. Empirical assessment based on primary surveys indicates that advancements in seed production and feeding methodologies hold significant potential for enhancing survival, growth, and yields across all stages of cultivation. The production economics of major Asian seabass aquaculture systems provides important insights. Nursery and pre-grow-out ponds perform better financially, with superior profitability metrics

(BC ratio of 1.54 in nursery and 1.62 in pre-grow-out; IRR of 51% and 59.8% respectively), benefiting from lower costs and higher biomass yields. Among grow-out cultures, ponds in Andhra Pradesh demonstrate higher operating costs and lower BC ratio (1.69) and ROI (51.8%), whereas West Bengal ponds can achieve higher BCR (1.87) and return on investment (87.6%). Cage culture exhibits variability across states, although Karnataka farms can reach break-even more quickly (BC ratio ranged from 1.28 to 1.78; IRR ranged from 51.8% to 81% across states). Additionally, the study highlights diversified cost structures, break-even points, and profitability profiles across multiple farming systems. Overall, the analysis provides robust economic insights to support upgraded Asian seabass aquaculture practices and commercial progress. To facilitate large-scale, sustainable expansion, the study recommends strategic interventions, including upgrading hatchery and feed infrastructure, enhancing farmer capacity through training and skill development, improving access to credit and insurance mechanisms, and strengthening market linkages. Key constraints, such as limited access to quality seed and feed, can be addressed through the establishment of additional hatcheries, the development of cost-effective formulated feed, and the expansion of domestic and global market opportunities.

Carp polyculture is the mainstay of freshwater aquaculture in India as more than 80% of the cultured fishes in the country are carps (Indian major carps, exotic carps, and minor carps). The present level of technological progress in carp culture was complemented through achievements of major milestones such as the development of induced breeding technology, composite carp culture, the introduction of exotic fish, and the successful implementation of a series of government schemes that enabled widespread adoption of these technologies. At present, the carp production system is highly diversified, fitting into various ecological and socio-economic conditions. The impact of technological advancements in carp-based freshwater aquaculture production systems was assessed by identifying and categorizing seven distinct levels of carp culture technology, all based on fundamental polyculture methods, and then evaluating their impact using historical data from 1985 to 2022. In the initial phase, before the development of composite fish culture technologies, the productivity recorded was 600 kg/ha/year. Considering that a productivity of 1113 kg/ha/year was recorded in 1975-76 by following traditional culture practices, it is expected that a maximum productivity of 1500 kg/ha/year could be attained through local innovations (taken as the counterfactual level). The analysis revealed that yield from carp farms progressed from 7500 kg/ha/year in 2000 to 12000 kg/ha/year by 2020, indicating the impact of carp polyculture technologies supported by innovations such as efficient feed formulations, diagnostics and therapeutics and indoor aquaculture techniques such as RAS, biofloc, aquaponics, and raceways. While varying levels of technical and economic efficiency exist across these systems, they effectively address farmer needs within the constraints of local ecological, social, and market conditions. Insights from the study suggest that the success of improved carp production technologies stems from their large-scale adaptation and refinement by farmers, enabling them to incorporate scientific principles into their farming systems, thereby enhancing efficiency and sustainability.

A comprehensive investigation was carried out into India's dried fish industry covering the scale and nature of the units, the socio-economic profile of the operators, diversity of operations and product profile, the level of adoption of good management practices, and measures in place for quality assurance and certification. The study notes that approximately 16% of the total fish produced in India is utilized for processing and drying. Broadly, a decreasing trend in dried fish production was observed. Estimates show that the total dried fish production declined from about 0.6 million tons in 1999-2000 to 0.5 million tons during 2020-21. Further, there has been a noticeable decline in per capita consumption of dried fish, possibly due to the perception that consuming dried fish may lead to health issues, skepticism about the processing techniques used, and concerns regarding the use of potentially harmful chemicals in the drying and preservation of fish. However, the exports of dried fish showed a significant upward trend over time. Between 1995 and 2022, the quantity of exported dried fish increased significantly from 4056 tonnes to 12908 tonnes, recording an increase in export earnings from US $6.3 million to US $96 million during the period. India's dried fish industry has undergone a significant transformation, marked by a considerable increase in informal operations. While some states exhibit a trend toward industry formalization, the informal sector continues to be expanding. Insights into the industry's evolution and growth can be gleaned from economic performance indicators, workforce and capital dynamics, and shifts in the state-wise distribution. Although overall employment in the formal sector remains relatively low, it is emerging as a significant source of job opportunities. Based on survey data from Visakhapatnam (Andhra Pradesh), Veraval (Gujarat), Cochin (Kerala), and Mumbai (Maharashtra), the study assessed the size and scale of operation of sample dried fish processing units, analysed their gendered nature, and examined labour force participation and diversity of processing methods followed. Major constraints and policy shortcomings were explored, leading to a set of recommendations for improvement. They mainly include: measures for technology penetration, promotion of producer collectives, better regulatory framework, following Good Management Practices (GMP), extension, training and capacity building, social protection for fish workers, creating market linkages, and institutional support for entrepreneurship development.

Chapter- 1

Introduction and Overview

Shinoj Parappurathu, Ramachandran C and Preethi VP

1. Fish Economy of India: An Overview

Fisheries and aquaculture are integral to India's economy, contributing significantly to food and nutritional security, livelihood generation, and foreign exchange earnings. During 2022-23, they contributed as much as ₹2885 billion to the national Gross Value Added (GVA), accounting for 7.2% of the GVA of agricultural and allied sectors and 1.3% of the total GVA (PIB, 2023). Fisheries and aquaculture employ over 16 million people at the primary level and almost twice the number indirectly in various segments of the fish and fish product value chains (PMMSY, 2020). With a vast coastline spanning over 8118 kilometers, extensive inland water bodies, and rich aquatic biodiversity, India possesses immense potential for the development of fisheries and aquaculture. In recent years, the sector has witnessed remarkable growth, catalyzed by technological advancements and policy interventions aimed at enhancing productivity, sustainability, and competitiveness. According to the latest data from the Food and Agriculture Organization (FAO), India ranks among the top fish-producing nations globally, with an annual fish production exceeding 17 million metric tons in 2023. The country's aquaculture sector has emerged as a powerhouse, accounting for nearly 7% of the global aquaculture output.

The relative composition of capture fishing and aquaculture in total fish production has undergone significant changes over time, especially after independence. During the 1950s, about 70% of total fish production was of marine origin. The marine fish landings experienced steady improvement in the subsequent decades, which rose from 0.5 Million tons in 1950-51 to 4.12 Million tons in 2021-22, assisted by the mechanization of fishing and intensification of fishing efforts through technological interventions in gear management, fish scouting, and fish finding (CMFRI, 2022). However, the growth in aquaculture was faster, especially post-1970s with advances in scientific carp farming and shrimp farming, thereby gradually enhancing its relative share in total fish production. Presently, inland aquaculture, primarily focused on carp and other freshwater species, contributes to roughly 65% of the total production, surpassing the production from marine capture fisheries (~25%). The rest is accounted for by inland capture fisheries (~10%) practiced in inland water bodies, reservoirs, and estuaries.

2. Technology and Policy Paradigms in Fish Culture Systems

Despite their status as traditional livelihoods, the advancement of fisheries and aquaculture into commercial-scale production and post-harvest activities has been propelled by meticulously devised research and development programs. Recent endeavors towards enhancing the production of economically valuable marine and brackish water species are centered around mariculture and other modern farming practices. Mariculture entails the culture of these organisms in saltwater settings, predominantly within enclosure structures positioned in open oceans, internal waters, or onshore culture systems utilizing seawater. Technological breakthroughs in areas like breeding, seed production, larval culture, cage culture systems, and feed development transformed mariculture from a research-oriented activity to a commercially viable industry. In recent years, the focus has expanded to include diverse finfish species like seabass, cobia, groupers, snappers, shrimp, bivalves, crabs, ornamental fishes, and a range of seaweeds. Both coastal water and open sea farming are practiced along India's coastline, mostly by small-scale fishers, self-help groups, and other farmer organizations. Reservoir cage farming is another fast-spreading culture method adopted by small-scale inland fish farmers. The National Policy on Marine Fisheries (GoI, 2017) has set a roadmap for future development for mariculture by addressing crucial aspects like infrastructure, leasing policies, and the creation of designated mariculture parks. Continuous research and innovation by institutions such as ICAR-CMFRI remain essential in driving technological advancements and sustainable practices in the sector. Balancing ecological considerations with production goals is crucial, necessitating the adoption of environmentally responsible practices (Parappurathu et al, 2023). Apart from the above, a range of modern farming practices such as biofloc-based nursery and grow-out systems, recirculatory aquaculture systems (RAS), and intensive raceway culture systems are taking root as promising options for enhancing productivity and cost-effective culture of fish and other economically important species. Research trials involving these modern culture technologies have shown encouraging results both in laboratory settings as well as frontline demonstration fields (Gopalakrishnan et al, 2022).

Brackishwater aquaculture is another key segment that supports the production of a wide variety of brackishwater fish species, shrimp, crab, seaweed, and microalgae. Traditionally, it was practiced in 'bheris' or low-lying areas where tide-fed fish and shrimp were raised. However, scientific advancements in the 1990s propelled the sector, marked by the introduction of the giant tiger prawn (*Penaeus monodon*). The development of scientific shrimp breeding and seed production technology was initiated in the mid-1970s to lay the groundwork for modernizing and commercializing the sector (Muthu and Laxminarayana, 1977; Silas et al., 1985). Subsequently, the opening up of the economy commenced with the adoption of the New Economic Policy (1991), which facilitated the establishment of commercial hatcheries, which were backed by large-scale private investment (Krishnan and Birthal, 2002). The 1990s witnessed significant growth and the adoption of semi-intensive shrimp farming by private entrepreneurs, which in turn led to a dramatic rise in the area under shrimp farming. This sparked a boom that also brought forth environmental and social concerns. Following setbacks caused by disease outbreaks, the focus shifted towards the Pacific white shrimp (*Litopenaeus vannamei*), which offers greater disease resistance[1]. The introduction of Specific Pathogen Free (SPF) *L. vannamei* in 2009, coupled with the establishment of strict quarantine and biosecurity protocols, revolutionized India's shrimp farming sector, leading to sustainable improvements in the production system (Salunke, et al, 2020). Apart from shrimp, brackishwater farming systems are currently being augmented by advanced culture techniques for promising fish species such as seabass, milkfish, grey mullet, pearl spot, etc.

Freshwater aquaculture continues to stand as the driving force behind India's remarkable growth in the fish-based economy. The nation's extensive network of ponds, tanks, reservoirs, and rivers offers vast potential for controlled fish farming. The initial impetus for freshwater aquaculture development came with the introduction of Fish Farmers' Development Agencies (FFDAs) in the 1970s. These agencies provided vital technical, financial, and extension support to fish farmers nationwide. A focus on Indian major carp (catla, rohu, and mrigal) and exotic carp (silver carp, grass carp, and common carp) has been central to the success of freshwater aquaculture. This was made possible with the breakthrough achieved in the induced breeding of carp by hypophysation in 1957, followed by several other technological advancements such as multiple spawning, cryopreservation, strain improvement, vaccine development, biofertilization, and intensive farming techniques (Chaudhuri, 1960; Alikunhi 1972; Gupta et al, 1995). Subsequently, the introduction of several new species such as silver barb, African catfish, striped catfish, tilapia, and red-bellied pacu added to the diversity of the culture system. Technological advancements in seed production, feed formulation, disease management, and water quality control have significantly boosted productivity (Ayyappan et al, 2015; Jena et al, 2022). The average yield has increased multifold, with some regions achieving an impressive 8-12 tons per hectare per year. Nevertheless, many farmers still operate small-scale, less intensive farms with productivity below

[1] SPF *L. vannamei* is disease resistant so long as the seed stocked as SPF seeds purchased from certified SPF hatcheries and stocked as per CAA guidelines. The same would apply if SPF *P. monodon* are stocked. It is *P. indicus* that is naturally disease resistant since it is a hardier local Indian species, but unfortunately the same is not being given much attention despite ICAR-CIBA (during 2016-21) trying to give it its rightful place.

national averages. Initiatives aimed at technology dissemination, training, and infrastructure enhancement hold the key to unlocking the full potential of freshwater aquaculture in India, ensuring its continued contribution to food security, livelihoods, and economic growth. Furthermore, market demand must drive investments in freshwater aquaculture. Focus must be directed towards North East India which perhaps is the biggest market for freshwater fishes in India.

Processing and value addition play a significant role in transforming perishable raw fish into more stable, convenient, and profitable products. While India boasts a strong fish production base, a substantial portion of the catch is still sold fresh or undergoes basic preservation techniques like icing and drying. This results in limited shelf-life, economic losses due to spoilage, and fluctuating market prices. Sun-drying, salting, pickling, and smoking have been the backbone of fish preservation in coastal communities for centuries. These techniques extend the shelf-life and add unique flavours, but often face quality and hygiene limitations. Modern fish processing methods such as chilling, freezing, canning, and heat treatments such as thermal processing have gained popularity over time, and are being used widely by the export industry. Low-cost, energy-efficient, and eco-friendly solar dryers developed by ICAR-CIFT have emerged as viable and hygienic alternatives to open sun drying and have been widely adopted by small and medium firms (Gopal, 2011). The eco-friendly model of a community smoking kiln is another technological intervention that enables highly stable smoked fish products. Innovative technologies such as high-pressure processing (HPP), pulse-light technology, e-beam radiation, radio-frequency heating, etc. constitute upcoming high-impact advancements that can impart quality and safety for fish products. The growing popularity of packaging technologies like vacuum packaging, and modified atmosphere packaging (MAP) that facilitate extended shelf life of seafood products signifies a positive shift towards sustainable and efficient seafood processing practices in India (Biji et al, 2015).

3. Impact Assessment of Technologies

Technological changes brought about through the intensification of research efforts in fisheries and aquaculture in India as outlined above have resulted in significant improvements in fish production, better farm income and employment opportunities, diversified utilization of main and by-products, the emergence of new value chains, development of ancillary industries and so on. Such direct effects on the economy can also have multiple indirect ramifications which include changes in food prices, changes in food and nutritional intake by people, labor market effects, demand-supply impacts on the input markets, and so on. It would be worthwhile to clearly understand and estimate the effects of specific technologies on relevant economic variables so that resource allocation decisions can be streamlined more effectively and efficiently. Recent advances in technology impact assessment at micro- and macro levels have made it easier to empirically evaluate technological changes on various subsectors of the economy and associated stakeholders.

Technologies can vary widely in terms of their effects on the production system. In general, they can be categorized as yield-enhancing technologies, resource- and cost-saving technologies, product utility- and value-enhancing technologies, climate-resilient and risk-mitigating interventions. The appropriate tools and techniques for assessing a technology's impact depend on multiple factors, including its characteristics, potential outcomes, the socioeconomic and resource environment in which it is deployed, and the specific groups of people it is intended to benefit. Generally, the primary goal in performing an impact analysis for a technological innovation is to estimate the total effect of the new technology on a set of outcome variables, after some amount of diffusion has taken place (Maredia, 2009). As indicated above, technological changes can have long-term macroeconomic impacts in addition to immediate micro-economic effects on the production system with direct implications for adopters. Therefore, estimating the total effects of a technological change depends on the researcher's assumptions on how big the general equilibrium effect that a particular technology has on the economy. In open economies where trade allows the free flow of goods and services, even significant enhancement of production as a result of technological interventions causes only limited changes in commodity prices or the level of employment. Under such circumstances, the impact assessment of technology adoption mostly focuses on (i) measuring the effect of the technology on adopters for selected outcome variables, (ii) establishing causality by isolating the effects of technology adoption on observed outcomes from other extraneous factors, and (iii) including the spillovers from adoption in estimates of a technology's impact (de Janvry et al, 2011). Commonly considered outcome variables in most of the technology impact assessment studies include crop yield, farm-level profits, household income, and welfare changes, labor employment on the farm, food and nutrition intake by household members, etc.

The methodological approaches and tools used to estimate the effect of technological innovations at the farm level vary considerably depending on the context. At a qualitative level, field surveys and focus group discussions with people affected by technological change can reveal relevant facts. Even though it is useful to contextualize and explain the broad factors at play, such methods usually lack rigor, and the results can suffer from objectivity and robustness. On the other hand, quantitative techniques based on sound conceptual frameworks, robust empirical strategy, and in-depth datasets can aid in estimating the impacts of technology with reasonable levels of accuracy. Some of the commonly followed quantitative techniques include production function analysis, cost-benefit analysis, Randomized Control Trials (RCTs), regression-based methods such as Instrumental Variable (IV) regression, Difference-In-Differences (DID) method, and Propensity Score Matching (PSM) technique. The choice of the above methods has to be made carefully by considering the specific context of the technology adoption in question, the stage of diffusion, the type and nature of data at hand, observability of relevant variables, the outcome variables to be measured, the time and resources available to the researcher, and many more such considerations.

Assessing the partial equilibrium impact of technology at the farm level requires a clear understanding of the dynamics of technology adoption and diffusion, the type and characteristics of adopters, criteria for selection of valid counterfactual non-adopters, and major determinants that drive adoption. Further, the conceptual framework under which the adoption of the technology is modelled is equally important, wherein, adoption is viewed as a rational decision by adopters with the primary intention of profit maximization subject to constraints such as cost of adoption, incremental use of inputs if any, availability of capital, and other similar observable conditions (Heckman, 1979). The selection of counterfactual non-adopters while estimating the effect of adoption determines the quality of the results, as selection bias can lead to biased estimates of the adoption of outcome variables. Counterfactual non-adopters are those farm operators who are observationally similar members within the population of potential adopters, but who have not adopted the technology due to various reasons. The selection bias increases when there is a greater correlation between the unobserved variables in the adoption function and that of the outcome function (Foster and Rosenzweig, 1996). The effect of adoption is estimated either as the average effect of adoption for all potential adopters in the population (Average Treatment Effects (ATE)) or the effect of adoption on adopters which is generally referred to as Average Treatment Effect on the Treated (ATT).

4. Outline of the Study

This study is the outcome of collaborative research efforts focusing on the impact of technological and policy changes in selected sub-sectors of India's fish production system, viz., mariculture, inland aquaculture, brackishwater aquaculture, freshwater aquaculture, as well as post-harvest processing of fish and fish products. Chapter 2 presents a broad overview of India's fisheries and aquaculture economy, focusing on its present status, growth trends, development priorities, and key areas that need policy attention. Chapter 3 undertakes a comprehensive economic assessment of selected mariculture enterprises in India and delves deeper into the impact of cage farming on the household income of the adopter households vis-à-vis observationally similar non-adopters. Chapter 4 focuses on the emerging practice of reservoir cage culture associated with inland water bodies in India, driven by factors such as the availability of suitable water bodies, technological advancements in culture practices, and government support through subsidies and training programs. Chapter 5 presents the specific case of Asian Seabass (Lates calcarifer) culture, a promising brackishwater enterprise taking roots across the country, and the role played by technology and policies in driving its widespread adoption. Chapter 6 chronicles the technology-led development of freshwater fish culture, especially carp polyculture and composite culture technology, over the past few decades and the sector's role in enabling India to emerge as one of the major fish-producing countries in the world. Chapter 7 analyzes the status of the dry fish economy in India and presents various strategies and options to turn it into a modern sector with the aid of the latest developments in processing and value addition.

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Chapter-2

Fisheries and Aquaculture in India: Recent Trends, Development Priorities and Policy Context

Anuja AR, Shinoj Parappurathu and Suresh A

1. Background

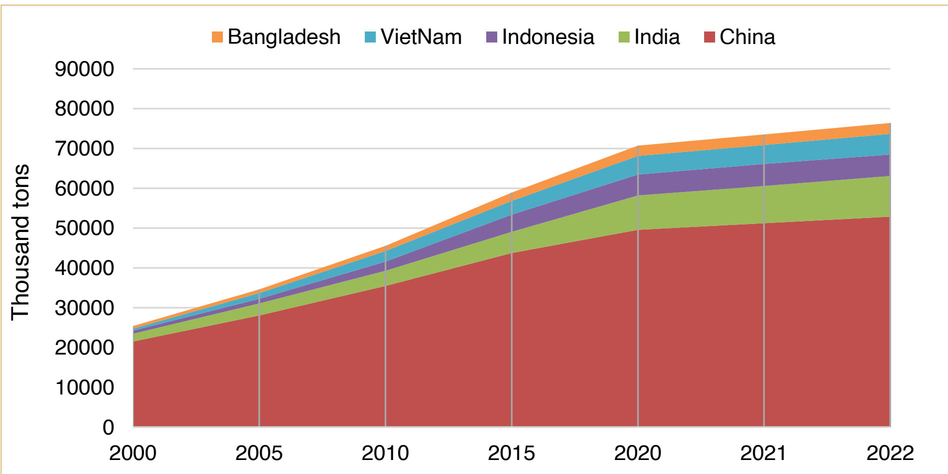
This chapter, conceived as a prologue to the overall compilation, provides a comprehensive overview of the nation's fisheries and aquaculture sector. The overview encompasses India's global standing in the sector, the demographic and socio-economic profile of the associated workforce, production and trade growth trends, demand-supply and value chain dynamics, and the role of institutions and government in fostering sustainable development. Such a contextual understanding will not only provide valuable insights into the current state and recent developments within the sector but will also facilitate a deeper appreciation of the evolving dynamics and the critical role of technologies and policies in propelling further growth.

Ranking second globally, India accounts for about 8% of global fisheries and aquaculture production, though China leads by a significant margin (FAO, 2024). In capture fisheries, India ranks third globally, producing 6% of the total global output in 2022, trailing behind China and Indonesia (FAO, 2024). India ranks sixth in marine capture fisheries, with a share of 4.5% of global production. The country is also a global leader in inland fisheries, holding the largest share of inland aquaculture production worldwide (FAO, 2024). Figure 1 illustrates the growth in aquaculture production over the past two decades (2000 to 2022) among major global producers, including China, India, Indonesia, Vietnam, and Bangladesh. India's aquaculture, particularly in freshwater species like carp, continues to expand rapidly, strengthening its leadership in global aquaculture production.

India has rich marine and aquatic resources that support a diverse fisheries sector, including marine capture fisheries, mariculture, coastal aquaculture, inland fisheries, freshwater aquaculture, cold-water fisheries and ornamental fisheries. Table 1 highlights the fisheries sector's growing contribution to the Gross Value Added (GVA) in India's agricultural and allied sectors as well as the overall economy. In 2022-23, the sector contributed 7.2% to the total

GVA from agriculture and 1.32% (at current prices) to the overall national GDP (MOSPI, 2024). Beyond these contributions, the sector plays a vital role in employment generation, livelihood support, and foreign exchange earnings. These contributions highlight its considerable significance, with the 'Blue Economy' framework offering pathways to build on this foundation for future growth (Gopalakrishnan et al, 2024).

Fig. 1. Aquaculture production by major global producers



Source: FAO. 2024.

Table 1. Contribution of fisheries sector to agriculture GDP/GVA (at current prices) India

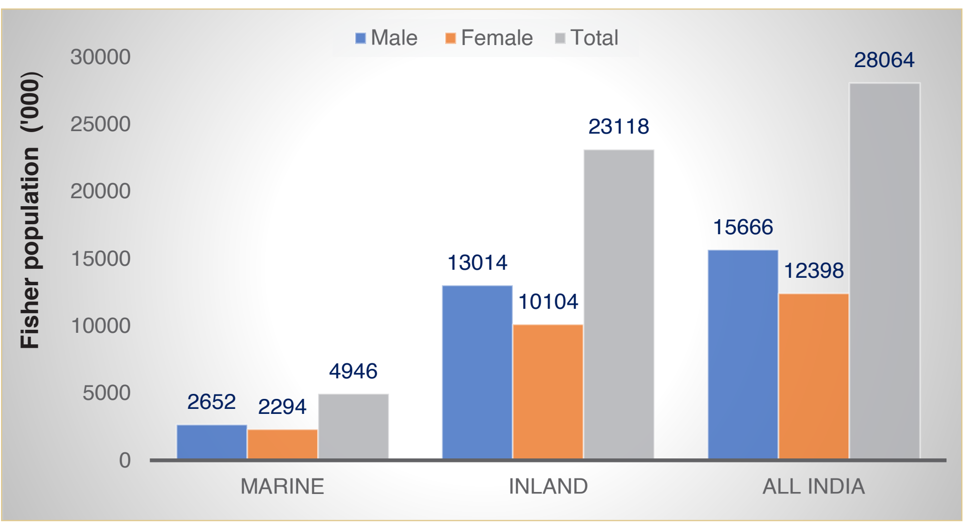
Year	GDP/GVA at current prices (million)			% Share of Fisheries & Aquaculture to Agriculture and allied sector GDP/GVA	% Share of Fisheries & Aquaculture in total GDP/ GVA
	Fisheries and Aquaculture	Agriculture, Forestry, and Fishing	All		
1960-61	820	70900	165120	1.2	0.50
1970-71	2450	181920	429810	1.3	0.57
1980-81	9170	473120	1325200	1.9	0.69
1990-91	46310	1508000	5150320	3.1	0.90
2000-01	114060	2866660	11985920	4.0	0.95
2011-12	680270	15019470	81069460	4.5	0.84
2015-16	1327200	22275330	125744990	6.0	1.06
2022-23	3250070	44842680	246590410	7.2	1.32

Source: National Statistics Office, Ministry of Statistics & Programme Implementation, Government of India (MoSPI, various years)

2. Demographics and Workforce Engagement

Ensuring sustainable employment opportunities for resource-poor masses is utmost important for countries and regions where opportunities for alternate employment is scarce. Coastal and inland water bodies act as lifeline for the people inhabiting their shores with ample opportunities to engage in wild fishing and aquaculture, both of which can offer remunerative employment and 'decent work' (Bavinck et al, 2024). Fisheries and aquaculture provide livelihood support to over 28 million people, highlighting their critical socio-economic role in a developing tropical country like India. Inland fisheries accounts for approximately 82% of the fisher population, and the rest constituted by the marine counterpart. Gender divide in occupation is apparent in both inland and marine sub-sectors due to the inherent differences in the nature of work and societal preconceptions regarding job-roles. Males constitute 53.6% of the population in marine fisheries and 56% in inland fisheries (Fig. 2). In the marine sector, men predominantly engage in fishing activities, while women contribute significantly to post harvest operations and marketing (CMFRI-FSI-DoF,2020).

Fig. 2. Marine and inland fisher population of India by gender (2020-21)

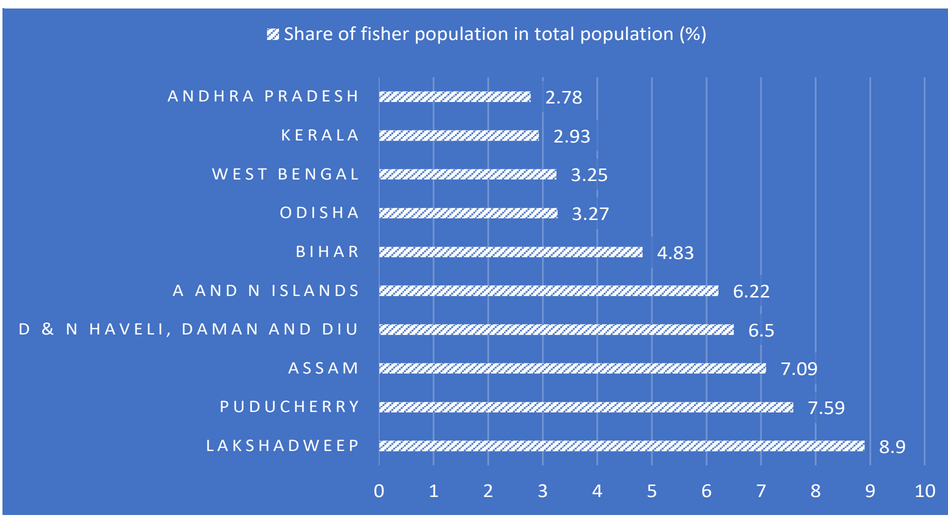


Source: GoI DoF, 2023

Regional variations in fisher demographics are evident, with certain states and union territories exhibiting a high concentration of fisher populations relative to their overall population. Coastal and island regions such as Lakshadweep (8.9%), Puducherry (7.6%), and the Andaman and Nicobar Islands (6.2%) have high proportions of their populations engaged in fisheries, reflecting their heavy dependence on fisheries resources for livelihood. Inland states like Assam (7.1%), and Bihar (4.8%) also show a substantial share of fisherfolk, indicating the significance of inland aquaculture in these regions. (Fig. 3).

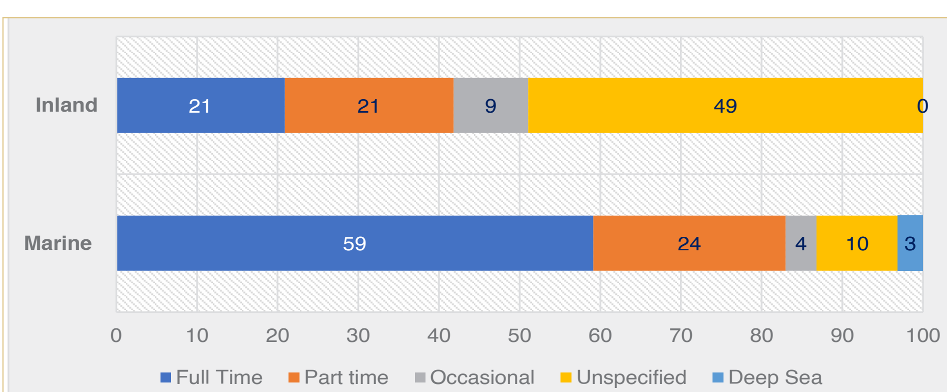
The extent of occupational engagement among fishers shows notable differences between the inland and marine sectors, reflecting the distinct nature of their operations (Fig. 4). In the marine sector, 59% of fishers are engaged full-time in fishing activities, 24% work part-time, and 4% are occasional fishers, with 3% involved specifically in deep-sea fishing. The inland sector exhibits a broader range of engagement, with 21% each working full-time and part-time, 9% as occasional fishers, and 49% classified as unspecified. These differences highlight the varying nature of fishing activities across different regions and types of fisheries. The above data, however, do not present any clear distinction between activities such as marine and inland fishing, fish seed collection, inland aquaculture, mariculture, etc. for detailed assessment.

Fig. 3. States/UTs with the highest proportion of fisher population, 2020-21



Source: GoI DoF, 2023

Fig. 4. Distribution of workforce by extent of engagement in fishing activities (2020-21)

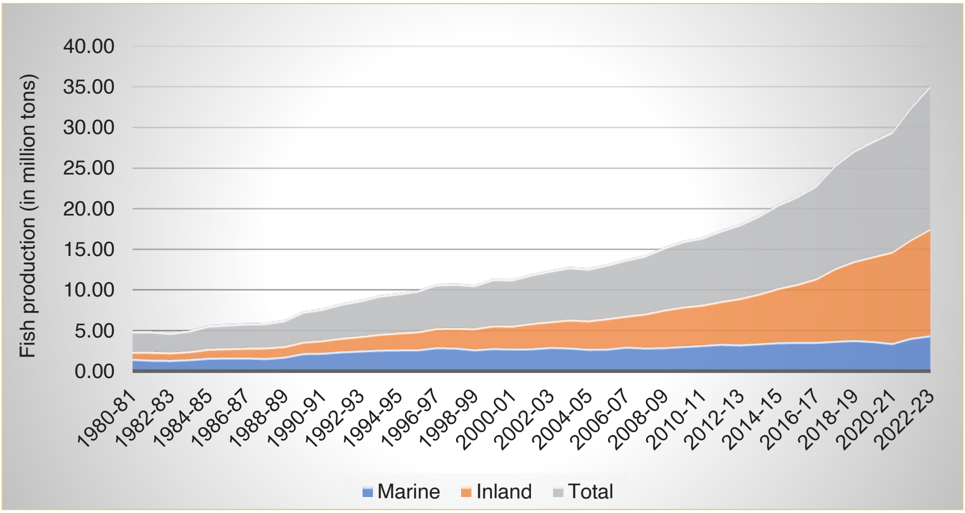


Source: GoI DoF, 2023

3. Production Trends and Sectoral Composition

India's fisheries sector is broadly classified into marine fisheries and inland fisheries, with the latter gaining increasing prominence over recent years. Fig. 5 portrays the trends in marine and inland fish production in India during the period 1980-81 to 2022-23. Since the early 2000s, the inland fisheries sector has overtaken marine fisheries in terms of production volume, marking a significant shift in the sector's composition. While both segments have experienced consistent growth, inland fisheries have outpaced marine fisheries, reflecting a Compound Annual Growth Rate (CAGR) of 6.44%, compared to 2.30% for marine fisheries during the period 1980-81 to 2022-23. Overall, the country's total fish production grew at a CAGR of 4.58% during this period, reflecting sustained growth in the sector. Looking at recent trends, the fisheries sector (inclusive of aquaculture) has grown at an average annual rate of 8.63% during the past decade (2011-12 to 2022-23).

Fig. 5. Trends in marine, inland and total fish production in India (1980-81 to 2022-23)

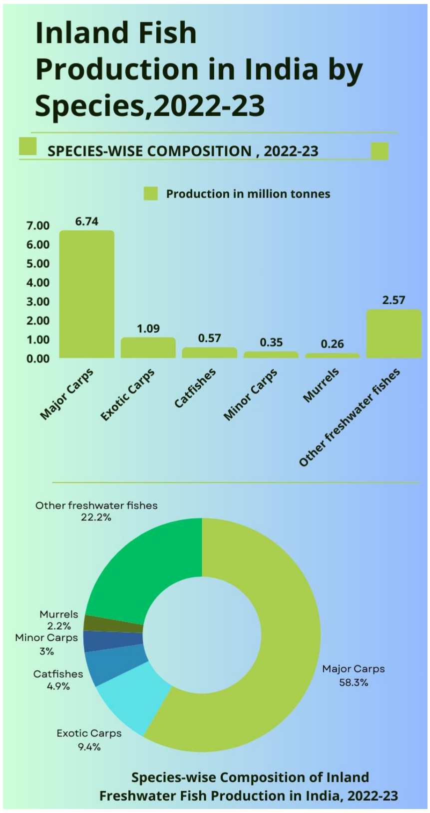


Source: GoI DoF, 2023

In 2022-23, India's fish production reached 17.55 million tons (GoI DoF, 2023), with three-fourths of this coming from the inland sector. Based on the quinquennial average from 2017-18 to 2022-23, Andhra Pradesh, West Bengal, Uttar Pradesh, Odisha, and Bihar were the leading states, accounting for more than two-thirds of the country's total inland fish production. Simultaneously, major maritime states such as Gujarat, Andhra Pradesh, Tamil Nadu, Kerala, and Karnataka contributed approximately three-fourths of the total marine capture fish production.

Notwithstanding the technology-driven surge in India's capture fisheries during the mid-1980s and early 2000s (Ghosh, 1998; Salagrama, 2004), persistent economic and operational challenges in offshore and deep-sea fishing constrained the sector's ability to meet rising fish demand (James, 2014; Parappurathu et al., 2020). At the same time, the remarkable success of large-scale freshwater carp (Ayyappan and Gopalakrishnan, 2008) and brackish water shrimp farming redirected focus toward aquaculture, a shift that has driven inland aquaculture production to nearly triple over the past two decades. This transformative growth underscores the pivotal role of aquaculture in ensuring sustainable fisheries development and advancing India's blue economy objectives (GoI DoF, 2024a). Mariculture, a growing sector, bridges capture fisheries, which rely on wild fish stocks, and culture-based fisheries, focusing on controlled farming to supplement supply without depleting natural stocks. Through sea-cage farming of species like cobia and sea bass, and seaweed cultivation, the sector aims to achieve its estimated potential of over 4 tonnes, though current production remains below 0.1 million tonnes (Gopalakrishnan et al., 2022).

Fig. 6. Species-wise composition of inland freshwater fish production in India, 2022-23

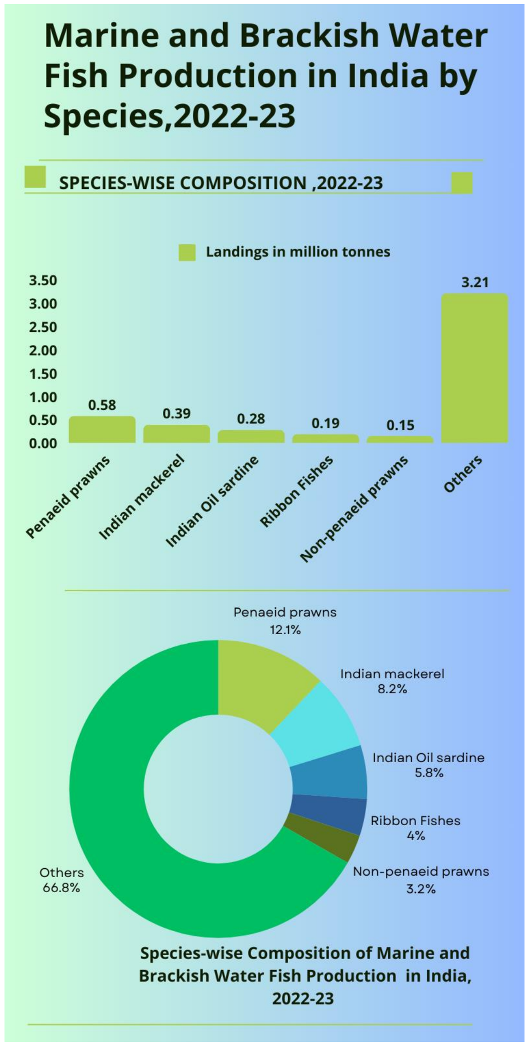


Source: GoI DoF, 2023

Inland fisheries, too, hold immense potential, with resources such as 3,41,907 km of rivers and canals, 2.84 million hectares of reservoirs, 2.75 million hectares of tanks and ponds, 0.61 million hectares of brackish water, and 1.45 million hectares of beels/oxbow lakes and derelict water bodies (GoI DoF, 2023). Tanks and ponds contribute 8.5 million metric tons annually through culture-based fisheries, while brackish water aquaculture, primarily focused on shrimp farming, produced 0.75 million metric tons in 2020 (GoI DoF, 2024a). This sector has significant potential for expansion in Gujarat and Odisha due to the high tidal amplitude in this region. Brackish water shrimp aquaculture has been a major driver of India's export growth, accounting for approximately 80% of the country's total shrimp exports. Additionally, saline water aquaculture is being promoted to transform wastelands into productive wetlands, focusing on states like Haryana, Punjab, Rajasthan, and Uttar Pradesh with high soil salinity. Ornamental fisheries and cage culture in reservoirs represent further growth opportunities, with reservoirs seen as "sleeping giants" due to their unexplored potential. Cold-water fisheries in the Himalayan states mainly target high-value trout production, while riverine fisheries focus on river ranching and species conservation. Species composition in the inland freshwater sector is dominated by major carp like Catla, Rohu, and Mrigal, with additional contributions from exotic carp, catfishes, and murrels (Fig. 6).

In 2023, the major marine fish resources landed in India included Indian mackerel, oil sardine, ribbonfish, and non-penaeid prawns. In the marine sector, species vary by coast: the east coast features Penaeid prawns, Indian Oil sardines, and catfish, while the west coast is dominated by Indian mackerel, Ribbonfish, Bombay duck, and croakers. Penaeid prawns are especially vital for exports, significantly contributing to economic returns (Fig. 7). During the 1990s and early 2000s, shrimp aquaculture was dominated by tiger shrimp (*Penaeus monodon*) and Indian prawn (*P. indicus*). However, production suffered a significant setback due to white spot syndrome (WSS) outbreaks. The introduction of Pacific white shrimp (*Litopenaeus vannamei*), an exotic species, in 2009 revitalized the sector (Salunke et al., 2020), with the species now accounting for approximately 96% of total cultured shrimp production in 2020-21, followed by the tiger shrimp (*Penaeus monodon*) (MPEDA, 2024b). The focus on species diversification and productivity enhancement across all fisheries sectors is key to the sustainable development of India's fisheries.

Fig. 7. Species-wise composition of major marine and brackish fish production in India in 2022-2023

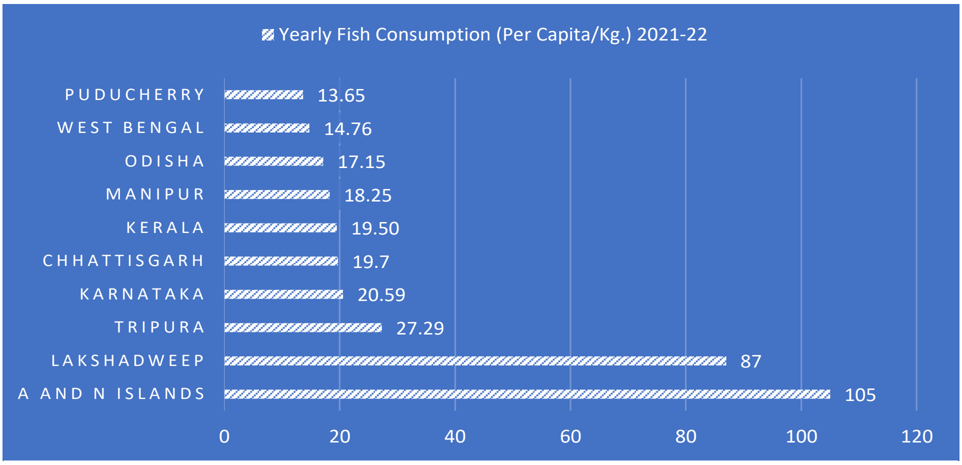


Source: GoI DoF, 2023

4. Fish Consumption and Demand-Supply Dynamics

India, a largely vegetarian nation, exhibits significant regional variation in fish consumption. The estimates of the National Statistical Office based on its 68th round of nationwide surveys on household consumer expenditure show that the annual fish consumption in India was around 3.24 and 3.07 kg respectively for rural and urban areas (MoSPI, 2014). There has been a transformation in fish consumption since then, driven by a surge in inland aquaculture production, mainly freshwater species. Fig. 8 illustrates the annual per capita fish consumption in the major fish-consuming states and union territories of India for 2021-22. It highlights the regional variations, with coastal and island territories leading in fish consumption, underscoring the significant role of fish in their diets. The top three major fish-consuming states/UTs for 2021-22 are the Andaman and Nicobar Islands, Lakshadweep, and Tripura followed by coastal states such as Karnataka, Kerala, and Odisha and inland states like Chhattisgarh and Manipur.

Fig. 8. Major fish consuming states and UTs of India (2021-22) based on annual per capita consumption



Source: GoI DoF, 2023

India's fish demand is projected to rise due to shifting dietary preferences toward animal-source proteins and growing export markets. Currently, over three-fourths of the fish produced is consumed domestically. According to NITI Aayog projections, household fish demand will reach 11 million tons by 2030 and escalate to 20-23 million tons by 2047 (NITI Aayog Working Group report, 2024). When factoring in additional uses such as seed, feed, and wastage, total demand could rise to 37 million tonnes under a Business-As-Usual (BAU) scenario and to 41-48 million tons under a High-Income Growth (HIG) scenario by 2047. Table 2 indicates the fish demand projections and supply growth required to meet the expected demand. Meeting these targets will require sustained growth in fish production, with Compound Annual Growth Rates (CAGRs) ranging from 3.62% to 4.63%, depending on the scenario. Export targets further increase the challenge, demanding an additional surplus of fish production, with a required CAGR of 5.0% in the HIG scenario. Strategic investments in infrastructure, cold chains, sustainable fishing, and aquaculture practices, as well as tapping into non-conventional resources like seaweed and other marine products, will be crucial in meeting both domestic and export demand.

Table 2. Fish demand projections and supply growth required to meet the expected demand

Particulars	Business-as-Usual (BAU) scenario		High-Income growth (HIG) scenario	
	Target (2029-30)	Target (2046-47)	Target (2029-30)	Target (2046-47)
Baseline demand (2019-20) (in million tons)	12			
Demand projections* (in million tons)	20.0	37.0	21.0	48.0
Demand projections including trade (assuming 10% to be exported)	22.0	40.7	23.1	52.8
Estimated annual growth rate (%) in production to meet the target demand	3.51	3.62	4.05	4.63
Estimated annual growth rate (%) in production to meet the target demand (assuming 10% to be exported)	4.50	4.05	5.01	5.0

**Source: Author's estimation. Demand projections are taken from the NITI Aayog working group report (NITI Aayog, 2024);*

Note: Fish production in the baseline year 2019-20: 14.16 million tons

5. Value Chain Dynamics and Market Infrastructure

India's fisheries sector value chain is diverse and complex, covering all stages from capture/production to consumption across marine and inland fisheries. The structure ranges from simple chains, where suppliers connect directly with consumers, to more intricate systems involving multiple actors, such as fishers/fish farmers, auctioneers, input vendors, traders, retail fish vendors, processors, and consumers.

India's marine capture fish value chain begins at landing centers along the coast, where fishers bring in their catch. Initial handling and sales occur here, typically through informal auctions managed by intermediaries, charging pre-determined commission charges. Larger government-managed harbors provide comprehensive services, while smaller, community-managed centers lack essential infrastructure, like cold storage, leading to post-harvest losses (Siddique and Aktar, 2011). After harvesting, fish move through a layered domestic marketing system, including primary wholesale markets near the coast and secondary markets in inland regions, both of which suffer from inadequate cold storage and sanitation. Retail channels are diverse, ranging from supermarkets to local wet markets, with most consumers still relying on wet markets. In southern regions, mobile vendors deliver directly to households, while online platforms are emerging as alternative retail channels, offering convenience and reducing reliance on intermediaries. The value chain for inland capture fish in India typically involves small-scale fishers who harvest from rivers, lakes, and reservoirs, with products moving through local markets, wholesalers, and retailers before reaching consumers, often in fresh, dried, or minimally processed forms. The value chain for cultured or farmed fish in India generally involves hatcheries, fish farmers, feed suppliers, processors, and distribution networks, with a focus on controlled production environments that enhance quality, reduce supply variability, and improve profitability through efficient farming practices.

India's post-harvest infrastructure associated with marine capture fisheries is extensive, with 1,457 notified fish landing centres spread across the country. The major fishing harbors—Visakhapatnam, Chennai, Kochi, Mangalore, Kolkata, Paradip, Mumbai, Veraval, and Petuaghat—serve as key hubs for the disposition of fish catches. These harbors are critical in facilitating both domestic distribution and international exports. Despite these resources, the industry faces challenges related to post-harvest losses, particularly due to inadequate cold-chain logistics.

Post-harvest losses, estimated at about 20% (GoI DoF, 2024b), mainly arise from inefficiencies in handling, transportation, and inadequate cold chain facilities which cause quality degradation leading to reduced profitability for small-scale fishers and traders. Infrastructure improvements at landing sites and wholesale markets are essential to address these issues and enhance the sector's economic potential. Modernization efforts under the Pradhan Mantri Matsya Sampada Yojana (PMMSY) a flagship government scheme focus on addressing these challenges by developing robust infrastructure, enhancing cold storage, and implementing traceability systems for quality control. The PMMSY also supports digital platforms for auctions and online marketplaces, providing fishers with direct consumer access and reducing intermediary dependency.

Landed fish catch is primarily disposed off through various methods, including fresh marketing, freezing, curing, reduction, and canning. Fig. 9 illustrates the various methods of fish catch disposition in India for 2022-23. Fresh marketing remains the dominant method, accounting for approximately 78% of the total fish catch in 2022-23, reflecting the high domestic demand for fresh fish. The remaining 22% of the catch is distributed between different modes of processing. Frozen fish account for around 12% of the catch, with a steadily increasing share due to advancements in freezing technologies and rising export demand. On the other hand, curing and reduction together make up about 5%, while canning is less common. Curing, which historically played a larger role, is now in decline. It includes traditional preservation methods such as salting, smoking, drying, and fermentation. Reduction, another post-harvest process, converts whole fish into fishmeal and fish oil, valuable by-products used in livestock feed and other industries. The growing trend toward freezing, coupled with the declining use of curing, indicates a shift in consumer preferences toward more convenient and higher-quality preservation methods.

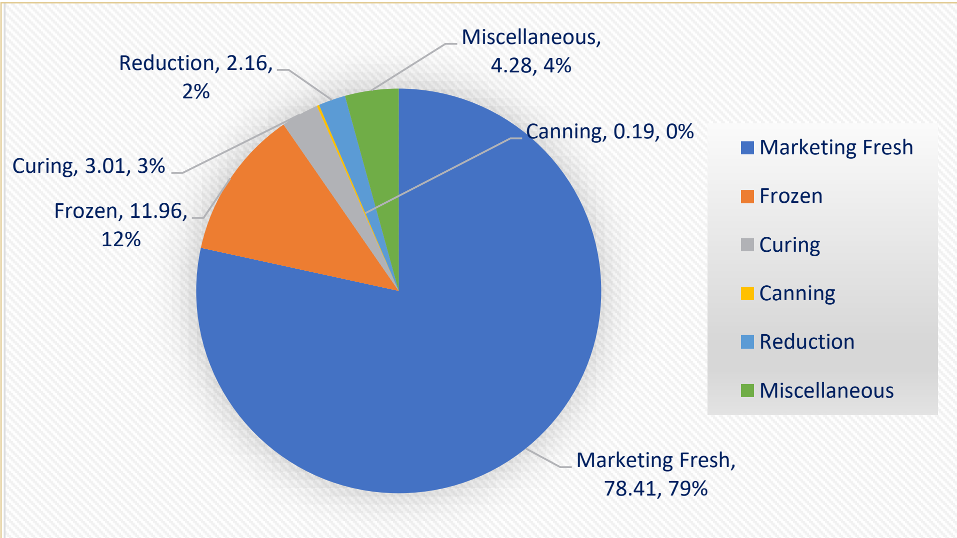


Fig. 9. Methods of fish catch disposition in India (% share), 2022-23

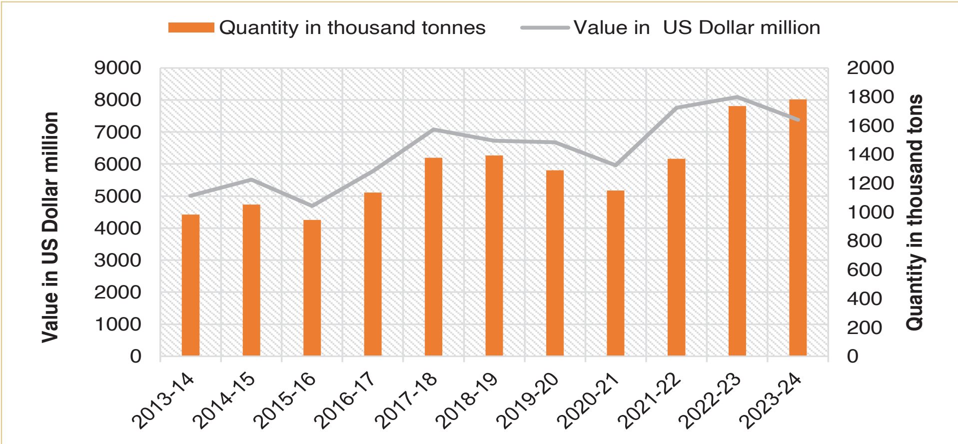
Source: Department of Fisheries, State / UT Administration, Handbook on Fisheries Statistics, 2023

6. Export Trends and Market Dynamics

India has been a world leader in seafood exports for several decades. Fish and fish products constitute the second largest exported product from India among the primary commodities (Suresh et al, 2023). India's fish products export witnessed a record-breaking year in 2023-24, reaching an all-time high of 1.78 million tonnes of seafood exports, valued at US$ 7.38 billion (₹ 6,05,238.90 million) (Fig. 10) (MPEDA, 2024a).

Frozen shrimp remains the cornerstone of the export basket, contributing about 41% of the total export volume and 66% of the earnings (Fig. 11) (MPEDA, 2024a). This category includes key species such as Vannamei shrimp, Black Tiger shrimp, and Scampi, with the United States, China, and the European Union being the top three importers. Frozen fish ranked second in the export portfolio, contributing approximately 21% of the total volume and 9% of the earnings. Other items in the export basket included fish and shrimp meal and feed, frozen squid, surimi and surimi analogue products, and frozen cuttlefish. The aquaculture sector played a critical role in this growth, contributing 62% of total earnings and 37% of the export volume, while capture fisheries provided 62% of the volume but only 38%

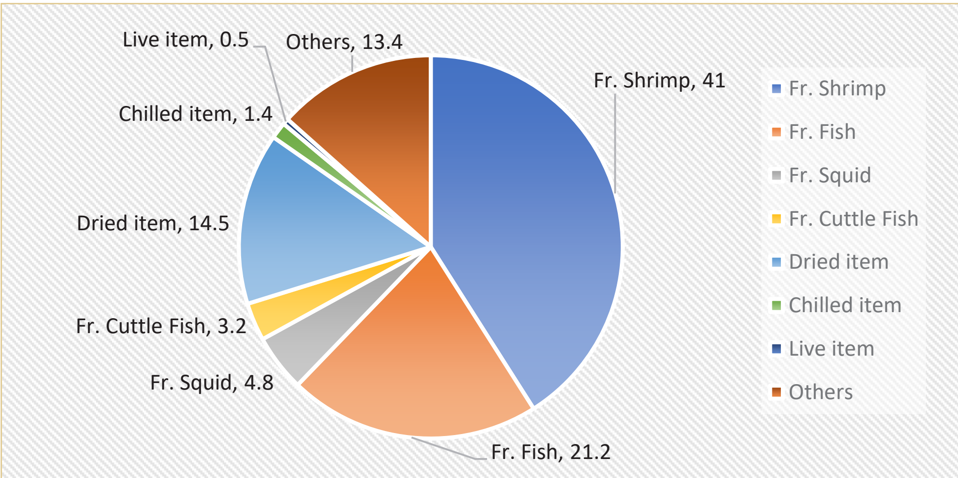
Fig. 10. Recent trends in export quantity and value of Indian marine products (2013-14 to 2023-24)



Source: MPEDA, 2024a

of the value (MPEDA, 2024a). India's fish products were exported to about 132 countries, with the USA being the largest market, contributing 32.2% of total earnings, largely driven by frozen shrimp (Fig. 12). China followed as the second-largest destination market with 18.8% of earnings, primarily from Vannamei and Black Tiger shrimp. Japan, Vietnam, and Thailand were also major destinations, with Japan focusing on frozen shrimp, Vietnam on shrimp, and Thailand on frozen fish (MPEDA, 2024a). The strategic importance of major Indian ports such as Visakhapatnam, JNPT-Mumbai, Kochi, Chennai, and Kolkata was evident, as these five ports together handled about 65% of India's marine export cargo (MPEDA, 2024b).

Fig. 11. Item-wise export share (%) of marine products from



India in quantity terms, 2022-23

Source: MPEDA, 2024a

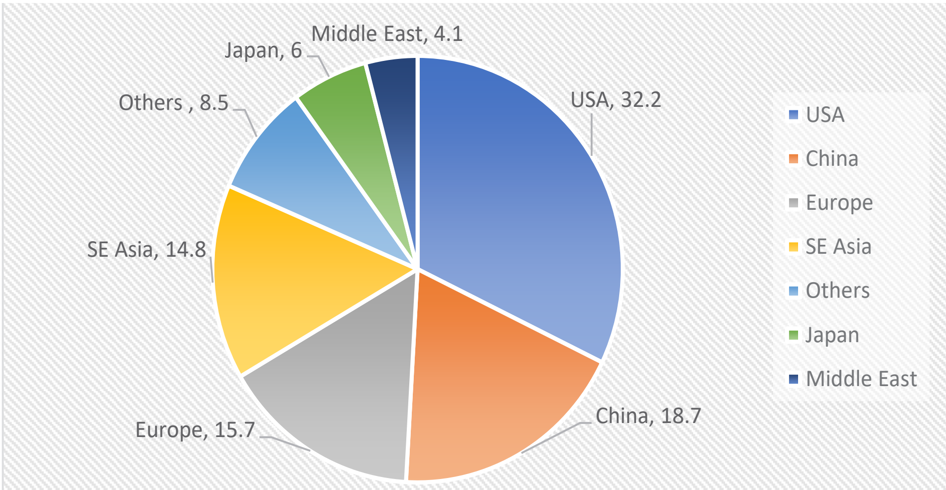


Fig. 12. Market-wise value share (%) of marine product export from India, 2022-23

Source: MPEDA, 2024a

Improving value addition is one of the key steps for enhancing exports. Currently, over three-fourths of the fish produced in India is marketed fresh, and only about 22 % is processed. Most of the fish processing happens with minimal value addition in terms of products like ready-to-eat or ready-to-cook etc. and different forms of it as is demanded by the importers. A bulk of the products are exported in frozen forms, rather than undergoing advanced value addition, leading to poor unit value realization in export markets. For example, the export of sashimi-grade tuna fetches much higher than that in the domestic markets but needs improved harvest and post-harvest handling methods (Yang and Lin, 2017). India has to promote value addition through technological and policy interventions (Suresh et al., 2023).

The export of marine products attracts stringent quality and safety standards, warranting the exporters to develop such quality assurance systems in the entire value chain. Even though the Codex Alimentarius Commission (CAC) of WTO encourages members to use its common standards to govern food safety and quality, different standards are followed by various countries. For example, the USA follows a system of Hazard Analysis and Critical Control Points (HACCP) while the European Union (EU) follows the Rapid Alert System for Food and Feed (RASFF), which is stricter than HACCP (Suresh et al., 2023). The food safety regulations set by the EU are harmonized, periodically updated, and are based on principles of risk assessment.

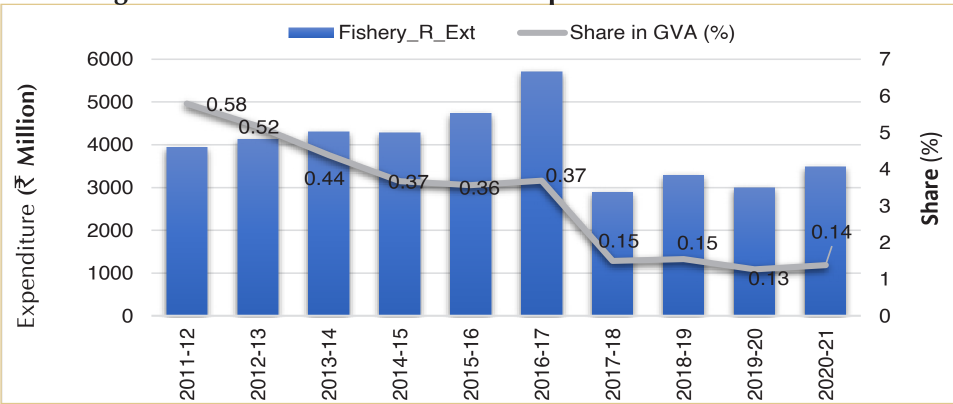
Compliance with international Sanitary and Phyto Sanitary (SPS) measures warrants a strong quality assurance system in the domestic markets. While the Export Inspection Council functions as the competent authority for trade compliance to external markets, the Food Safety and Standards Authority of India (FSSAI) oversees the quality assurance system in the domestic market. Due to these stringent interventions, the rejections of Indian consignments in the export markets have reduced drastically in terms of absolute number and unit rejection rates (number of rejections per US$ 1 million of exports). However, given the faster reductions in export rejections by our competing countries, India has to further improve its quality assurance system. Still, sanitary and Phytosanitary measures account for 71% of all export rejections due to non-tariff measures in the year 2022. Bacterial contaminations, unhygienic conditions, and veterinary drug residues continue to be the major specific reasons for rejections. In a nutshell, boosting seafood exports requires investing in modernized processing, implementing stringent quality control and sustainable practices, developing a robust traceability system, fostering stakeholder collaboration, and promoting value addition through supportive policies.

7. Investment, Government Expenditure and Capital Formation

Capital formation and investment in India's fisheries sector have been crucial for enhancing productivity, modernizing infrastructure, and supporting long-term sustainability. Both government funding and private investments contribute significantly to the sector's growth. Capital formation in fisheries primarily involves fixed assets such as fishing vessels, aquaculture farms, and processing equipment, all vital for increasing sectoral efficiency and competitiveness. Since the early 1990s, the share of fisheries in agricultural Gross Fixed Capital Formation (GFCF) rose from 3.4% to nearly 10% by 2015, driven by mechanization, modernization, and adoption of capital-intensive technologies in both marine and inland fisheries. Notably, investment growth in fisheries has consistently outpaced agriculture, with the fisheries sub-sector showing a stronger GDP performance relative to agriculture (Suresh and Parappurathu, 2018).

However, rapid capital influx in fishing aquaculture and allied areas has introduced various challenges. Overcapitalization in segments like marine fisheries, where there is an excess of fishing vessels, and brackish water aquaculture, a highly capital-intensive area, has led to resource depletion and efficiency losses. Although government schemes have supported the sector, recent trends indicate that private investment now drives capital formation in fisheries (Suresh and Parappurathu, 2018). Despite this accelerated investment growth, the efficiency gains in GDP from fisheries have not matched, indicating declining capital productivity in recent years, and highlighting the need for more balanced, sustainable investment strategies.

Fig. 13. Recent trends in revenue expenditure in fisheries and



aquaculture research and extension (inclusive of education and training) and its share in fisheries GVA

Data Source: Reports of the Comptroller and Auditor General of India (CAG), Government of India (various years)

Fig. 13 presents the trends in fisheries and aquaculture research and extension expenditure (inclusive of education and training) and its corresponding share in Gross Value Added (GVA) over the period 2011-12 to 2020-21. The expenditure exhibited a consistent upward trend in the initial years, peaking in 2016-17. Subsequently, it showed signs of stagnation in absolute terms. More strikingly, the share of research and extension expenditure relative to GVA has shown a steady declining trend falling from 0.58% in 2011-12 to 0.14% in 2020-21. While the sector is experiencing robust growth at a steady 8% annually, the diminishing investment in research and extension is a strategic oversight that demands immediate attention. Enhancing the allocation for fisheries research and extension is essential to maintain productivity gains, foster innovation, and ensure the sustainable development of the sector.

8. Credit Disbursement

Credit is a vital catalyst for advancing India's fisheries and aquaculture sector, facilitating the shift from traditional practices to capital-intensive operations, with both formal and informal sources playing significant roles. The formal sector is supported by a network of financial institutions, including the National Bank for Agriculture and Rural Development (NABARD), the scheduled commercial banks such as public sector banks, private banks, and Regional Rural Banks (RRBs) as well as cooperative credit institutions, and microfinance entities. NABARD plays a crucial role as a refinancing agency, channelling funds to banks for lending to the fisheries sector. The cooperative sector plays a major role in institutional financing in the Indian fisheries sector.

The recent initiatives of the Government of India have facilitated enhanced flow of formal credit into the sector, especially with the expanded coverage of the Kisan Credit Card (KCC) scheme to include fishers and fish farmers in 2018-19. Since then, the formal credit system for the fisheries sector primarily operates through the KCC scheme. The KCC facilitates loans to meet working capital requirements such as purchasing fishing gear, boat maintenance, pond development, and fish seed and feed requirements. Till December 2024, approximately 440 thousand KCCs have been issued, disbursing about ₹28100 million (Fig. 14) (PIB, 2024b). Additionally, the Modified Interest Subvention Scheme (MISS) provides short-term credit up to ₹0.3 million at 7% interest, with an effective rate of 4% for prompt repayment. Despite these advancements, access to institutional credit remains limited by a lack of awareness, high collateral requirements, poor insurance penetration, and weak loan recovery performance of past lending (Tietze et al., 2007, Parappurathu et al, 2019)

Informal credit sources—including auctioneer-middlemen, private money lenders, and third-party shareholders—dominate due to their flexibility in procedures, though often at high interest rates (Tietze, 2007; Parappurathu et al., 2019; Suresh, 2023). In capture fisheries, market-linked and labour-linked credit contracts often lead to exploitative practices like under-pricing or under-weighing of catch (Parappurathu et al., 2019; Suresh, 2023). However, traditional transactions based on trust and informal societal control are shifting to formal systems due to market integration, occupational diversification, and migrant labour in marine fishing (Suresh, 2023).

Microfinance institutions and self-help groups (SHGs) have emerged as vital players in bridging the credit gap. SHG-bank linkage programs enhance credit flow and encourage community-driven financial inclusion, particularly in aquaculture (Tietze, 2007). To overcome barriers in the existing credit delivery systems, it is essential to simplify loan procedures, expand collateral-free options, raise awareness of existing schemes, strengthen cooperatives, leverage digital technologies, and integrate insurance with credit, thereby fostering equitable growth and sustainable development in India's fisheries sector

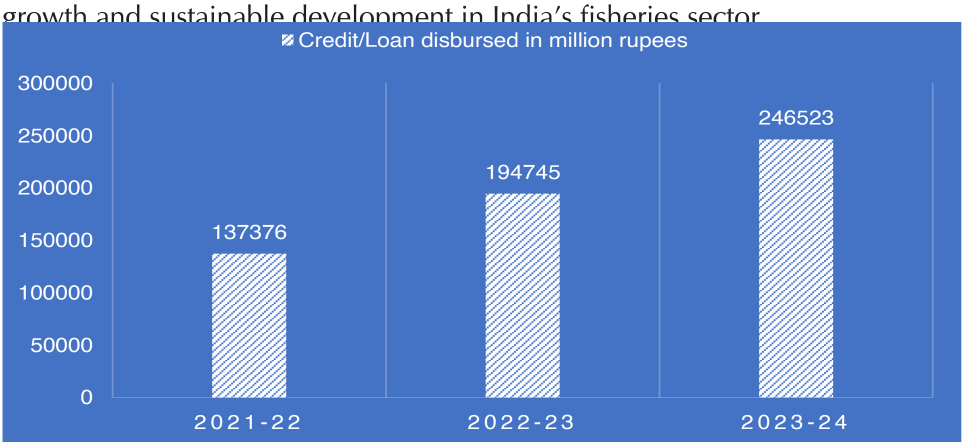


Fig. 14. Credit disbursement to the fisheries sector, including the KCC

Source: Press Information Bureau, 3 December 2024

9. Access to Insurance Coverage

The occupational risks inherent in fishing, exacerbated by frequent extreme weather events, underscore the urgent need for robust insurance systems in India's fisheries and aquaculture sector. Over the past decade, government-administered schemes have predominantly managed capture fisheries insurance, whereas aquaculture insurance has been primarily demand-driven and offered by public insurance companies, with limited involvement from the private sector (Van Anrooy et al., 2022).

One of the most widely available insurance products in the capture fisheries sector is accident insurance, which covers life and disability risks for active fishers during fishing operations. The Group Accidental Insurance Scheme (GAIS) for Active Fishermen, introduced in 1991–92, was later integrated into the Pradhan Mantri Suraksha Bima Yojana (PMSBY) umbrella in 2015. The broader acceptance rate of GAIS schemes was primarily due to their greater flexibility (Van Anrooy et al., 2022). In 2024, these key insurance schemes were consolidated under the Pradhan Mantri Matsya Sampada Yojana (PMMSY), simplifying access and expanding coverage (PIB, 2024a). Under this scheme, fishers receive fully subsidized coverage, which includes compensation of ₹0.5 million in the event of death or total permanent disability, ₹ 0.25 million for partial disability, and ₹25,000 for hospital expenses related to accidents. Vessel insurance, offered by public sector insurers, is often credit-linked as banks insist on insurance cover for the vessels they finance (Van Anrooy et al., 2022). Non-governmental organizations (NGOs) and fisher organizations/ societies such as the National Federation of Fishermen Co-operatives Ltd. (FISHCOPFED), Matsyafed, and the South Indian Federation of Fishermen Societies (SIFFS) have been instrumental in extending the reach of these schemes among fishers.

In the aquaculture sector, two major public insurance schemes were introduced in the early 1990s: The Brackish Water Shrimp Insurance Scheme and the Inland Fish Insurance Scheme. Both schemes were demand-driven and administered by public insurance companies. However, after operating successfully during their initial years, they were eventually discontinued due to the excessive risks involved in the sector (Van Anrooy et al., 2022). Nevertheless, the government is re-introducing aquaculture insurance schemes under the PMMSY schemes, for which efforts are currently underway.

Critical gaps persist in India's fisheries and aquaculture insurance sector. Public sector insurance companies have yet to develop viable packages to cover fishing and farming equipment, gear, and infrastructure. Additionally, the private sector has struggled to establish a stable presence in this domain. Technological and institutional interventions are urgently needed to bridge the trust deficit between service providers and beneficiaries, ensuring better access to and adoption of insurance products.

10. Role of Institutions in Fisheries and Aquaculture Development

India's fisheries sector thrives on a collaborative network that includes government bodies, research institutions, cooperatives, Fish Farmer Producer Organizations (FFPOs), Non-Government Organisations (NGOs), private companies, and fisher associations (Rohit et al., 2022). The Department of Fisheries (DoF) under the Ministry of Fisheries, Animal Husbandry, and Dairying leads the sector's development, focusing on inland, marine, and coastal fisheries policy. Supporting organizations under the DoF include the Fishery Survey of India (FSI) for stock assessments, the Central Institute of Fisheries Nautical and Engineering Training (CIFNET) for workforce training, the Central Institute of Coastal Engineering for Fishery (CICEF) for coastal infrastructure development and the National Fisheries Development Board (NFDB) for aquaculture enhancement. The Indian Council of Agricultural Research (ICAR), under the Ministry of Agriculture and Farmers' Welfare, supports these efforts through research and technological advancements across specialized fisheries research institutes. The Marine Products Export Development Authority (MPEDA), under the Ministry of Commerce, promotes the export of fish and fishery products, supporting market development, quality control, and value addition in India's fisheries sector.

State Fisheries Departments play a vital role in fisheries governance and development, implementing central and state schemes tailored to regional needs. They work through dedicated research, extension networks, public sector undertakings, welfare boards, and quasi-government entities such as the Tamil Nadu Fisheries Development Corporation Ltd. (TNFDC) and the Kerala State Coastal Area Development Corporation (KSCADC), to support fishers' welfare, production, and marketing. Additionally, the National Agricultural Research System (NARS), including three Central Agricultural Universities and 63 State Agricultural Universities, bolsters sectoral research, education, and capacity building.

To support the increasingly capital-intensive nature of fisheries and aquaculture, a diverse network of financial institutions, including public and private sector banks, the National Bank for Agricultural and Rural Development NABARD, and cooperative credit institutions, play a crucial role in providing credit and financial services to fishers and fish farmers.

Cooperatives, with roots in India's first fishery cooperative in 1913, have expanded to over 3.35 million members organized in a federated structure (Rohit et al., 2022). Led by the National Federation of Fishers Cooperatives Ltd. (FISHCOPFED), these cooperatives offer credit, insurance, technical resources, and market access, benefiting fishers nationwide.

The FFPOs, designed to strengthen fishers' incomes through organized input and market services, are expanding under the PMMSY, with a target to establish 500 Fish Farmer Producer Organizations. NGOs such as the South Indian Federation of Fishermen Societies (SIFFS), Dakshin Foundation, and Centre for Aquatic Livelihood-Jaljeevika contribute to sustainable practices, conservation, and fisher welfare. The private sector further supports aquaculture by providing quality seeds, feed, and processing equipment, boosting production efficiency. Fishermen and Fish Farmers' Associations, like the National Fish Workers Forum (NFF), advocate for fisher rights and provide resources and bargaining power.

Additionally, international organizations, including the Food and Agriculture Organization of the United Nations (FAO), the Bay of Bengal Large Marine Ecosystem (BOBLME), the World Fish Centre, and the International Fund for Agricultural Development (IFAD), among others, collaborate with India to promote sustainable practices and foster regional cooperation, reinforcing the resilience and productivity of India's fisheries sector.

11. Developmental Schemes of the Government

As fisheries are a state subject under the 7th Schedule of the Constitution, their development is the primary responsibility of the state governments. The state governments undertake various schemes to augment fish production and productivity, input supply, credit, and insurance support, as well as to strengthen monitoring, control, and surveillance (MCS). The Union government supports the sector through various development schemes from time to time routed through the Department of Fisheries (DoF), under the Ministry of Fisheries, Animal Husbandry, and Dairying. The flagship schemes implemented by DoF for fisheries development include the PMMSY, the Fisheries and Aquaculture Infrastructure Development Fund (FIDF), the KCC facility for fishers, and integrated insurance schemes under the PMMSY. The PMMSY launched in 2020 with an investment outlay of ₹2,00,500 million over five years, is India's flagship initiative for the "Blue Revolution," targeting holistic development across the fisheries sector. Its comprehensive approach focuses on boosting productivity, modernizing the value chain, enhancing traceability for quality and safety, and prioritizing the welfare of fishers, with strategic support for marine and inland fisheries, post-harvest management, and infrastructure development. In 2022-23, the PMMSY scheme allocated

₹11699.10 million, primarily for upgrading fishing harbors, developing cold storage and processing facilities, and supporting research institutions for innovation in aquaculture and fish health management. Table 3 highlights the key targets of the PMMSY. Launched in 2018-19, FIDF focuses on providing concessional finance for the development of crucial fisheries infrastructure.

Table 3. Key targets of PMMSY for fisheries sector development

Targets	Baseline (2018-19)	Target (2024-25)
Fish Production (million metric tons)	13.75	22
Aquaculture Productivity (tons per hectare)	3	5
Domestic Fish Consumption (kg per capita)	5	12
Contribution to Agriculture GVA (%)	7.28	9
Export Earnings (million rupees)	4,65,890	10,00,000
Post-Harvest Loss Reduction (%)	20-25	10
Employment Generation (direct and indirect)	-	5.5 million jobs
Income of Fishers & Fish Farmers	-	Double

Source: https://pmmsy.dof.gov.in/

12. Key Policy Interventions for Sustainable Fisheries Development and Global Competitiveness

National Fisheries Policy: The National Fisheries Policy 2020 (NFP) was drafted to provide a unified framework by consolidating the National Policy on Marine Fisheries (2017), the Draft National Inland Fisheries and Aquaculture Policy, and the Draft National Mariculture Policy (GoI DoF, 2020). This comprehensive policy seeks to enable sustainable fisheries growth while improving incomes for fishers and fish farmers and enhancing consumer choice through responsible resource management. By providing a model for states and Union Territories to develop local policies, the NFP promotes ecosystem-based fisheries management and modernization of fishing practices to align with both national and international standards. Central to the policy is the goal of doubling fishers' incomes, improving export competitiveness, and expanding shelf life and value addition in marine fish products. The policy incorporates elements from the Blue Growth Initiative, Agriculture Export Policy 2018, and Sustainable Development Goals, advocating for community partnerships, cooperative movements, and entrepreneurship. The sixth draft of the policy remains under review, with feedback from key maritime states continuing to shape its direction.

WTO Fisheries Subsidies and India's Negotiation Position: The World Trade Organization (WTO) negotiations on fisheries subsidies aim to balance sustainable fisheries management with the needs of fishing communities, focusing on curbing subsidies that lead to overcapacity and overfishing. Historically, these subsidies enabled developed nations to build large industrial fleets, causing significant environmental impacts and inequalities in resource distribution. India advocates for an approach that protects small-scale and artisanal fishers while encouraging sustainable growth in its fishing sector.

The WTO's framework for fisheries negotiations has three pillars: subsidies for Illegal, Unreported, and Unregulated (IUU) fishing; subsidies for overfished stocks; and subsidies contributing to overcapacity and overfishing (OCOF). Agreements on the first two pillars were reached at the 12th Ministerial Conference (MC12) in 2022, but discussions on the third pillar remain ongoing. At the 13th Ministerial Conference (MC13) in Abu Dhabi in 2024, India continued to push for an inclusive, balanced agreement that ensures sustainability and supports small-scale fisheries. The proposal calls for integrating Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC) and Special and Differential Treatment (S&DT) to address food security, livelihood needs, and sustainability. It also advocates expanding the scope to include non-specific fuel subsidies, government-to-government fishing rights transfers, and subsidies for distant water fishing, which indirectly contribute to overfishing and environmental degradation.

Further, India emphasizes protecting countries' sovereign rights to manage fisheries within their Exclusive Economic Zones (EEZs), as recognized under the United Nations Convention on the Law of the Sea (UNCLOS). A 25-year transition period for developing countries that are not classified as Least Developed Countries (LDCs) or meet the *de minimis* threshold (marine catch below 0.8%) is also proposed. This transition would allow these countries to address policy needs, food security, and fisher livelihoods. This position has gained support from other developing nations and LDCs, who view it as critical to protecting small-scale fisheries while closing gaps in the WTO draft text that might allow industrial fleets to exploit sustainability loopholes.

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Chapter-3

Small-Scale Mariculture in India: Status, Impact and Potential

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1. Background

Capture fisheries, finfish, and bivalve mariculture constitute the primary components of the blue economy. These sectors contribute approximately 17% of global edible meat production (Costello et al., 2020). By 2050, the intensification of mariculture (36-74% increase in yield) facilitated by technological advancements and policy reforms can enhance food production from the sea by 21-44 million tons (Edwards et al., 2019; Costello et al., 2020, Divu et al., 2020).

The Government of India has emphasized mariculture as a source for augmenting marine fish production and sustaining coastal livelihoods by addressing the institutional and commercial requirements of this emerging sector (GoI, 2017). Mariculture is predominantly practiced in shallow marine and internal waters and comprises capture and hatchery-based fin-fish and shell-fish culture, which includes cage culture (in the open sea and internal waters), bivalve culture, aquaculture systems such as seaweed culture, pearl and oyster culture, and ornamental fish culture. However, the current mariculture production in India is estimated to be negligible at less than 0.1 million tons against a potential of 4-8 million tons (Jena et al., 2022).

In India, mariculture is predominantly a small-scale enterprise. However, with continuous technological advancements and their adoption by small-scale fishing communities, there is potential for sustainable intensification (SI) of farming operations. Promising ventures for potential expansion include open sea and 'coastal water' cage farming of finfish and shellfish, cultivation of seaweed, and Integrated Multi-Trophic Aquaculture (IMTA), among others (Gopalakrishnan et al., 2017). The Government of India has recently initiated ambitious programs to support such farming endeavors (NFDB, 2018). However, their success is largely dependent on a comprehensive understanding of the suitability of each aforementioned technology in relation to the specific socioeconomic and demographic characteristics of the farming communities involved, as well as the prevailing status of the markets and institutions (Little et al., 2013; Bostock et al., 2010).

This chapter presents a comprehensive economic assessment of the selected mariculture enterprises in India[1].

2. Mariculture in India

2.1. Status

The earliest documented attempt towards the culture of marine fish species in India can be traced to the farming of milkfish, *Chanos chanos* in 1958-59 (Gopakumar et al., 2007). Subsequently, in the 1970s, experimental trials were conducted to standardize the culture of green mussels (*Perna viridis*) and brown mussels (*P. indica*) using rack, long-line, and raft methodologies (Appukuttan and Alagarswami, 1980; Kuriakose, 1980). The cultivation of pearl oysters (*Pinctada fucata* and *P. margaritifera*) was also investigated along the coast of Tamil Nadu (Alagarswamy, 1974). Other mariculture attempts include seaweed farming experiments initiated in 1964 in Gujarat (Thivy, 1964), followed by experimental trials and commercial exploitation along the southeast coast of Tamil Nadu for agar and algin production (Silas and Kalimuthu, 1987).

Initiatives in open-sea cage culture were taken in the mid-2000s with the Asian seabass (*Lates calcarifer*), which led to locally adapted innovations in the design and fabrication of cages and mooring systems, standardized guidelines, and farming practices, as well as the development of breeding, larval production, and grow-out technologies for several prioritized marine finfish species (Rao et al., 2013; Ayyappan et al., 2015). So far, the ICAR-Central Marine Fisheries Research Institute (CMFRI), India, has standardized techniques for breeding and seed production, including nursery protocols for Cobia (*Rachycentron canadum*) Orange-spotted grouper (*Epinephelus coioides*), Silver pompano (*Trachinotus blochii*), Indian pompano (*T. mookalee*), Pink-ear sea bream (*Lethrinus lentjan*), banded grunter (*Pomadasys furcatus*), John's snapper (*Lutjanus johnii*), Vermiculated spine foot (*Siganus vermiculatus*) and picnic seabream (*Acanthopagrus berda*) (Gopalakrishnan et al., 2019). The culture technology for Asian seabass in brackishwater has been standardized by the ICAR-Central Institute of Brackishwater Aquaculture (CIBA) (Arasu et al., 2009). ICAR-CMFRI has prioritized 76 finfish and shellfish species that could be targeted for the future expansion of mariculture (Ranjan et al., 2017). Most of these technologies have either been transferred or are at various stages of farm-level demonstration. The major candidate species

[1] Some sections of this chapter are featured in Parappurathu et al. (2023).

used in coastal water cage farming include Asian seabass, Silver pompano, Indian pompano, mullets (*Mugil cephalus*), milkfish (*C. chanos*), Mangrove red snapper (*Lutjanus argentimaculatus*), pearl spot (*Etroplus suratensis*), and Genetically Improved Farmed Tilapia (GIFT) (*Oreochromis niloticus*). Recent studies have shown that cage farming is economically viable, and spreading rapidly along the coasts (Aswathy et al., 2020; Jena et al., 2022).

Seaweed farming has been identified as a diversified livelihood option for coastal fishers in India. However, the enabling factors for significant commercial expansion and holistic development of allied industries have yet to materialize (Johnson et al., 2017; 2020). Previous studies (Kaliaperumal and Kalimuthu, 1997; Rao and Mantri, 2006) have identified several commercially important seaweed species, including red algae species such as *Gracilaria edulis, Gelidiella acerosa, and Kappaphycus alvarezii* and brown algae species such as *Sargassum wightii, Turbinaria conoides,* and *Cystoseira* spp. Several techniques using floating rafts, net tubes, longlines, and fin-fish-stocked cage-based IMTA systems have been standardized for seaweed culture. Recent literature indicates that farming of seaweed species, including *K. alvarezii*, *G. acerosa*, and *Gracilaria* spp. is economically profitable, and is therefore suitable for commercialization (Mantri et al., 2022).

Moreover, the demand for seaweeds has increased because of their utilization in the production of secondary bioactive metabolite-based nutraceuticals, plant growth promoters, and fertilizers (Chakraborty et al., 2018). Johnson et al. (2020) identified a potential area of 23,970 hectares suitable for seaweed cultivation along India's shallow coastal waters. Currently, seaweed farming is practiced on a limited scale along the Palk Bay areas of Tamil Nadu and is supported by carrageenan, agar, and seaweed-based fertilizer industries located in the vicinity. Previously, the cultivation of K. alvarezii experienced a period of rapid growth during 2000-2013 when local fishers along the coasts of Tamil Nadu, Gujarat, and Odisha entered into a contract farming arrangement with PepsiCo India Holdings Ltd., followed by Aqua Agri Processing Pvt. Ltd. for carrageenan production. However, this endeavor did not succeed because of numerous biophysical and economic constraints (Krishnan and Narayanakumar, 2013). Nevertheless, seaweed farming is re-entering a renewed phase, owing to substantial policy emphasis and technological and logistical advancements.

Integrated Multi-Trophic Aquaculture (IMTA) is another novel practice that has been gaining momentum because of its bio-mitigation potential, complementary ecosystem functions, and economic potential (Chopin et al., 2008). Integrated trials carried out by ICAR-CMFRI involving cobia in marine cages and *K. alvarezii* in floating rafts set around the cage in Palk Bay areas have shown encouraging results (Johnson et al., 2021). Similar trials involving different combinations of mullets (*M. cephalus and Liza parsia*), milkfish (*C. chanos*), pearl spot (*E. suratensis*), and shrimp (*Penaeus monodon, P. indicus*) as feed species, together with oysters (*Crassostrea cuttackensis, C. madrasensis*) and seaweed (*Enteromorpha* spp.) as extractive species, have found viable aquaculture options in brackishwater ecosystems of Sundarban in West Bengal and Sindhudurg in Maharashtra (Balasubramanian et al., 2018). Efforts to popularize IMTA with the integration of Silver Pompano, Asian Seabass, and Green Mussel in the Udupi and Uttara Kannada in Karnataka have been highly successful (Anuraj et al., 2022). Recognizing this potential, fishermen from Palk Bay and other parts of the southwest coast of India have recently started practicing IMTA-based farming.

2.2. Institutional and Policy Support

The research and development activities in mariculture in India are primarily conducted by public institutions and agencies. Research on the development of culture technologies and associated areas has been conducted by ICAR-CMFRI, Kochi, ICAR-Central Institute of Brackishwater Aquaculture (CIBA), Chennai, Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Bhavnagar, National Centre for Sustainable Coastal Management (NCSCM), and National Institute of Ocean Technology (NIOT), Chennai.

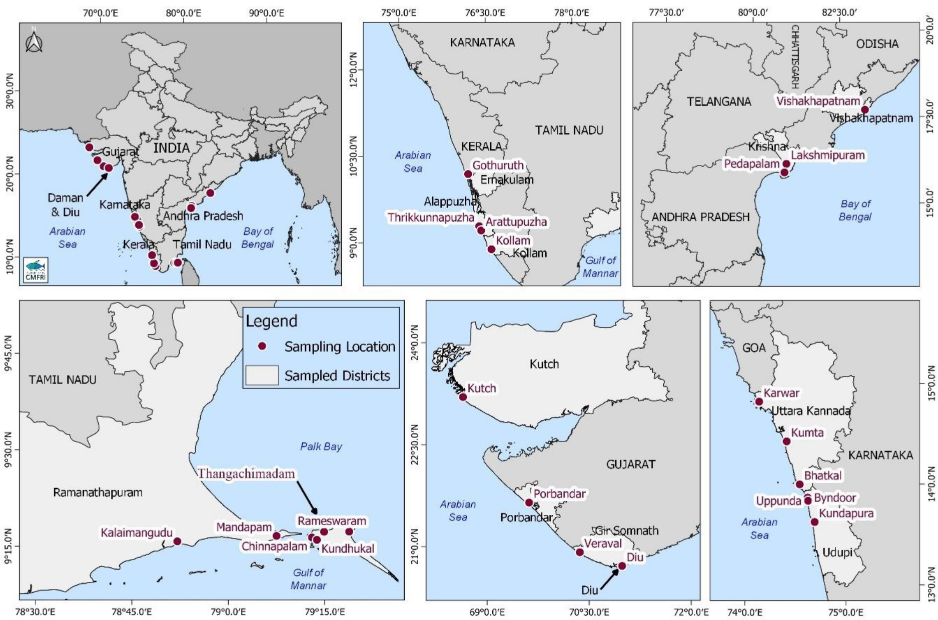
Initially, research endeavors were isolated and implemented in a project-based manner by individual institutes and universities. Recently, coordinated research has been established through network projects such as the 'All India Network Project on Mariculture' by the Indian Council of Agricultural Research (ICAR) and other inter-institutional collaborative research efforts involving NCSCM, CSIR-CSMCRI, and State Universities.

Moreover, developmental initiatives encompassing training, funding, and logistical support provided by government parastatals, such as the National Fisheries Development Board (NFDB), Hyderabad, and the Marine Products Export Development Authority (MPEDA), Kochi, have contributed significantly to the promotion of mariculture. Currently, the majority of these developmental programs are supported through budgetary allocations under the Pradhan Mantri Matsya Sampada Yojana (PMMSY). In 2019, the NFDB prepared a draft National Mariculture Policy that identified key areas for development and associated policy imperatives. Subsequently, this draft was incorporated into the 'National Fisheries Policy 2020,' which is currently awaiting notification by the Government of India.

Furthermore, various maritime state governments are in the process of establishing distinct state-level policies to facilitate mariculture at the grassroots level. The Government of Goa enacted the 'Goa State Mariculture Policy 2020' in June 2022, which represents the first such policy in the country. Under this policy, an open sea cage farm was established in Candolim, North Goa, a pioneering initiative, with technical guidance from the Karwar Regional Station of the ICAR-CMFRI (Anonymous, 2022).

In the following sections, we provide evidence on the adoption of different mariculture technologies and their impacts and identify indicators of their sustainability.

Fig. 1. Study locations



3. Data and Methods

3.1. Data

This investigation was motivated by the necessity to document and analyze the status and impact of mariculture enterprises in the coastal regions of India, as well as the potential for their sustainable intensification. Consequently, the study locations encompassed the emerging mariculture hotspots: Tamil Nadu and Andhra Pradesh along the east coast; Kerala, Karnataka, and Gujarat, on the west coast of India, and the Union Territory (UT) of Diu enveloped by Gujarat. The specific locations are illustrated in Fig.1, and the coverage of various mariculture enterprises is presented in Annexure A1.

The selection of locations for primary surveys was made based on predetermined criteria that include: (i) a substantial presence of operational mariculture units practicing one or more of the selected enterprises covered in the study, (ii) the presence of auxiliary enterprises such as seed production centers/hatcheries, fish markets, processing units, etc. in proximate locations, and (iii) established linkages of the entrepreneurs with research and development institutions and agencies involved in marine/ coastal aquaculture. These criteria were implemented to ensure that the multiple dimensions associated with viable and sustainable mariculture, including social and institutional preconditions, and forward and backward integration vis-à-vis fish input and product value chain nodes, could be adequately examined.

The first phase of the survey involved in-depth discussions with the scientists and practitioners engaged in mariculture regarding the details of farming activities being carried out in the locality. Subsequently, a set of semi-structured questionnaires was developed for each enterprise, which were pretested and fine-tuned to location-specific contexts. The survey findings were validated and triangulated with key informants and experts.

The selected mariculture enterprises included (i) open sea cage farming, (ii) coastal water cage farming, (iii) IMTA, and (iv) seaweed farming. The surveys were administered by randomly selecting farm units in purposively selected coastal regions where mariculture has recently been established as an alternative livelihood option. Care was taken to capture the diversity of farmed species and culture practices across the sample farms in a given location by following the broad principles of stratification (although no formal stratified sampling methods were adopted). The respondents were either owner-farmers or farm managers responsible for the daily activities of the farm units.

To assess the economic impact of cage farming (other mariculture enterprises were not considered), it was deemed necessary to collect data from comparable households that do not currently engage in cage farming (to serve as counterfactual units). These non-adopter farm households were selected to ensure that their household, demographic, and socioeconomic characteristics were similar or comparable to those of the adopter households in each locality. To ensure comparability, such households were selected from locations in close proximity to the water bodies where culture activities were conducted, such that given an opportunity, they possessed the circumstantial capacity to initiate mariculture activities.

Specific details of the sample units covered in each identified location are shown in Annexure A1 and A2 presents a separate sampling framework for data collection, covering adopters and non-adopters[2]. Secondary data were gathered from various published and unpublished sources to facilitate an objective assessment of mariculture potential.

[2] These two surveys were carried out separately with some time lag, but there are overlaps for adopters as sample units.

3.2. Analytical Framework

3.2.1. Heckman selection model

It is imperative to understand the primary factors that influence income variability in cage farming. However, a direct assessment based solely on a sample of cage farming adopters may result in sample selection bias. To mitigate this bias, the Heckman selection model was employed, wherein the probability of a unit being selected was determined using a selection equation (Heckman, 1979). Furthermore, it enables: (i) prediction of producer participation in cage farming and (ii) determination of the factors affecting net income from production for those with positive production. The behavior of a representative producer is represented by the following equation:

$$y_i = x_i'\beta + \varepsilon_i \qquad (1)$$

Where y_i is the amount or value of output for producer i, and x_i is a vector of explanatory variables. β is a vector of unknown parameters, and ε_i is an error term. The selection equation for cage farming was as follows:

$$z_i^* = w_i'\gamma + u_i \qquad (2)$$

$$z_i = \begin{cases} 1 & if\ z_i^* \geq 0 \\ 0 & otherwise \end{cases} \qquad (3)$$

Where $z_i = 1$ for participants in cage culture (i.e., y_i is observed), and zero otherwise; w_i is a vector of explanatory variables; and u_i is an error term. To analyze the factors determining net income from cage farming, the following Heckit model for cross-sectional data was used:

$$E(y_i|w_i, z_i = 1) = x_i'\beta + \beta_\lambda\lambda\,(w_i'\gamma) \quad (4)$$

Where $E(y_i|.)$ is the expected mean net income, conditional on selected sample, and the set of explanatory variables included in w_i. This expression can be written as a reduced-form equation:

$$y_i = x_i'\beta + \beta_\lambda\lambda\,(w_i'\hat{\gamma}) + \varsigma_i \qquad (5)$$

Where x_i is a vector of explanatory variables, $\lambda\,(w_i'\hat{\gamma})$ is the inverse Mills ratio, and β and β_λ are unknown parameters.

3.2.2. Propensity score matching

Propensity score matching (PSM) is a quasi-experimental technique in which the impact of an intervention (i.e., cage farming) is assessed by comparing how outcomes differ for adopters in relation to observationally similar non-adopters. PSM uses information from a pool of units that do not participate in the intervention to identify what would have happened to the participants in the absence of intervention (Rosenbaum and Rubin, 1983). The above method seeks to assess the impact of a treatment, 'd' for an individual 'i' by estimating the difference between the potential outcome in the case of treatment (Y_{1i}) and potential outcome in the absence of the treatment (Y_{0i}). The impact of the program denoted by 'δ_i' is expressed as:

$$\delta_i = Y_{1i} - Y_{0i} \qquad \text{...... (1)}$$

The mean impact of the program was obtained by averaging δ across all the treated individuals. This parameter is known as the average treatment effect on the treated (ATT).

$$\hat{\delta} = E(Y_{1i}|X_{i,}\, d_i = 1) - E(Y_{0i}|X_{i,}\, d_i = 1) \qquad \text{....... (2)}$$

Where, X_i is a set of observable characteristics of the individuals and *E (...)* denotes expected value.

Here, the term $E(Y_{0i}|X_{i,}\, d_i = 1)$ is the average outcome that the treated individuals would have obtained in the absence of treatment (*counterfactual*), which is unobserved. However, it is possible to obtain the term $E(Y_{0i}|X_{i,}\, d_i = 0)$, which is the value of Y_0 for the untreated individuals. Therefore, we can calculate:

$$\Delta = E(Y_{1i}|X_{i,}\, d_i = 1) - E(Y_{0i}|X_{i,}\, d_i = 0) \qquad \text{....... (3)}$$

Re-arranging Equation (3) can establish that, $\Delta = ATT + SB$, where SB is the selection bias, defined as the difference between the unobserved *counterfactual* for the treated individuals and the observed outcome for the treated individuals. If SB = 0, ATT can be estimated by taking the mean observed outcomes for the treated and untreated samples. In the literature, there is a consensus that by randomly assigning units to treatment and control groups, selection bias can be minimized. However, participation in most socio-economic programs being non-random and conditional based on X, an alternative approach called 'matching' can be followed that helps in obtaining unbiased estimator of ATT. Matching essentially helps in pairing a participant unit with an observationally similar non-participant unit so that the difference in their outcomes is as good as the difference between the treatment outcome and its *counterfactual*. With no underlying selection bias, this difference can be interpreted as an effect of the programme (Smith and Todd, 2005).

PSM matches the treated and untreated units based on the estimated propensity score, that is, the probability that a unit in the combined sample of the treated and untreated units receives the treatment, given a set of observable characteristics. The propensity score is generally estimated by fitting a probit or logit equation, with participation in the program as the dichotomous dependent variable (d=1 if participant; d=0 if not). All observed characteristics that the researcher found to be determining factors for participation in the program, thereby impacting the outcome variable Y, were included as explanatory variables. Several alternative algorithms, such as *nearest neighbor matching*, *radius matching, stratification matching,* and *kernel matching,* were used to match the treated units with those of the control. After matching, the ATT and the associated standard errors were estimated and compared to assess the impact of the program.

A probit model was fitted with cage farming adoption as the dependent variable and several household-specific demographic and socioeconomic determinants as explanatory variables. The estimation of the probit model and subsequent computations on propensity scores were carried out using the 'pscore.ado'[3] module in the STATA software. Subsequently, ATT estimates based on *the nearest-neighbor matching and stratification methods* were obtained and presented.

3.2.3. PCI framework for sustainable intensification

The concept of sustainable intensification (SI) aims to achieve at least one of the following objectives: (i) improved production and resource use efficiency with respect to land, water, feed, and energy; (2) enhanced environmental benefits; (3) strengthened economic viability and farmers' resilience; and (4) improved social acceptance and equality, while not compromising others (FAO, 2016). The concept originated in African smallholder agriculture (Pretty, 1997) and primarily addresses the production of increased output with reduced input, while minimizing negative environmental impacts and optimizing societal benefits (Little et al., 2018).

To establish a linkage between various dimensions of sustainability, different sets of farm-level indicators were constructed by broadly following the Principles-Criteria-Indicators (PCI) framework (Rey-Valette et al., 2008, 2010). PCI establishes a cascading relationship between principles (which express the values and issues of sustainability), criteria (variables that are most appropriate for expressing these principles), and indicators (variables to be measured). However, in this study, context-specific deviations were made to suit location/enterprise-specific realities without compromising the core ideas of the approach. Annexure Table A3 presents the key dimensions, criteria, and indicators used to assess the present level of economic viability, environmental sustainability, and social acceptability of mariculture enterprises, in addition to their future orientation for SI.

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[3] This module was developed by Becker and Ichino (2002) and is available for download at http://sobecker.userweb.mwn.de/pscore.html.

4. Results and Discussion

4.1. Farming profile of mariculture units

The majority of open-sea cage farms were operated by small-scale fishers possessing no more than two units with one crop per annum. As an exception, a limited number of farmers in Gujarat, Kerala, and Andhra Pradesh owned and operated 4-10 cages. The farm units were situated in clusters within suitable areas characterized by low tidal activity, predominantly within a one-kilometer radius from the shore, where the depth ranged from 10 to 15 m.

Sea cage farming in Tamil Nadu, Andhra Pradesh, and Gujarat was primarily practiced in circular marine cages constructed of high-density polyethylene (HDPE) or galvanized iron (GI), measuring 6 meters in diameter and 4 meters in depth (113 m^3). These cages were initially designed and disseminated by ICAR-CMFRI in the late 2000s, and subsequently refined. All sample farms in Tamil Nadu cultivated Asian Seabass sourced from the wild for a duration of 7-8 months, whereas those in Visakhapatnam of Andhra Pradesh state cultivated Indian pompano and Orange-spotted grouper sourced from hatcheries for an 11-month culture period. The spiny lobster (*Panulirus homarus*) was cultivated for a comparatively short duration of 4-6 months along the coasts of Gujarat and Diu.

Seeds required for cage culture were either collected from the wild or obtained directly from private and public hatcheries. Public hatcheries were primarily operated by research institutions, such as ICAR-CMFRI, ICAR-CIBA, Rajiv Gandhi Centre for Aquaculture (RGCA), and other state-funded agencies. Government agencies, such as the NFDB, through their network of Aqua One Centers and State-level aquaculture development agencies, also provided subsidized seeds sourced from certified hatcheries. The majority of farmers implemented a mixed feeding regime, that is, formulated pellet feed in the initial phases of the crop, with raw fish gradually substituted in advanced growth stages. Yields varied significantly depending on the location and the species, with the highest being 16 kg/m^3 in the case Indian Pompano in Vishakhapatnam (Table 1).

In comparison to open-sea cages, coastal water cages are characterized by smaller dimensions and a rectangular configuration, typically constructed from Galvanized Iron (GI). The volumetric capacity of these structures varied but generally did not exceed 75 m^3. Similar to sea cage farmers, coastal water cage farmers operate on a small scale, managing 1-2 units with a production cycle of 6-12 months. These aquaculture facilities were predominantly situated in internal backwaters or estuaries in close proximity to the shore (15-200 m), where water depths ranged from to 2-10 m. The ownership and management of these farms relied primarily on domestic labor. The Asian seabass was the predominant species cultivated across all locations, although other species, such as red snapper, silver pompano, and Indian pompano, were also reared. In certain localities, brackish water species, including pearl spots and mullets, are cultivated alongside the aforementioned species.

The formulated pellet feed was used to feed hatchery-based Asian seabass in Karnataka and Kerala, Indian pompano in Kerala, and silver pompano in Andhra Pradesh. In many cases, a combination of raw fish and pellet feed has been used depending on the growth phase of the crop at varying feeding rates. As in the case of marine cage farms, crop yields varied widely, ranging from 8 to 16 kg/m^3 across locations and species. The highest yield (18.3 kg/m^3 on average) was reported by farmers practicing polyculture of Asian seabass and red snapper for an extended crop duration of 8-18 months in Karnataka (Table 1).

Table 1. General features of sample farms practicing mariculture in the selected coastal regions of India

Feature		**Sample locations**		
I. Open sea cage farming				
		Tamil Nadu	**Andhra Pradesh**	**Gujarat**
Type of the cage		Circular HDPE cage (n = 20)	Circular HDPE cages (n = 7)	Circular GI & HDPE cages (n = 14);
Average number of units/ farm (owned by a person/ group)		1.3	$10^{\#}$	2.7
Size of the unit (DiaxD) in m		6x4	6x4	6x6 (HDPE); 5x4.5 (GI)
Distance from the shore (m)		1000	500-750	500-800
Depth of water (m)		5-6	10	8-15
Major species farmed		Asian seabass (ASB)	Indian pompano (IP), Orange spotted grouper (OSG)	Lobster
Crop duration (months)	Species 1:	7-8	IP: 11	4-6
	Species 2:	-	OSG: 11	-
Feed type (raw fish/locally formulated/ concentrate/ pellet)	Species 1:	Trash fish	IP: Trash fish, Formulated pellet feed	Trash fish
	Species 2:	-	OSG: Raw fish	-
Average Yield (kg/m^3/unit)	Species 1:	10.7 (SD: 1.5, n = 20)	IP: 16.0 (SD: 0.4, n = 4)	Lobster: 3.7 (SD: 0.2, n = 12)
	Species 2:	-	OSG: 13.3 (SD: 0.2, n = 3)	-

Feature		Sample locations		
II. Coastal water cage farming				
		Karnataka	**Kerala**	**Andhra Pradesh**
Type of the cage		Rectangular GI (n = 34)	Rectangular GI cage (n = 30)	Rectangular GI cage (n = 10)
Average number of units/ farm (owned by a person/ group)		1.5	1.1	1.6
Size of the unit (LxBxD) in m		6x3x2 (n = 21); 4x4x3 (n = 7); other (n = 6)	4x4x3 (27); 6x6x4 (3)	5x5x3
Distance from the shore (m)		10-200	10-100	15-100
Depth of water (m)		3-6	2-5	4-10
Major species farmed		Asian seabass (ASB) Red snapper (RS)	ASB, Pearl spot (PS)	ASB, Indian Pompano (IP)
Crop duration (months)	Species 1:	ASB: 8-12	ASB: 8-12	ASB: 6-7
	Species 2:	RS: 8-18	PS: 8-12	IP: 5-7
Feed type (raw fish/locally formulated/ concentrate/ pellet)	Species 1:	ASB: Raw fish, Formulated pellet feed	ASB: Formulated pellet feed	ASB: Trash fish
	Species 2:	RS: Trash fish	PS: Formulated pellet feed	IP: Formulated pellet feed
Average Yield (kg/m^3/unit)	Species 1:	ASB: 9.2 (SD: 4.8; n = 21)	ASB: 16.6 (1.6, n = 16)	ASB: 6.3 (SD: 3.5; n = 4)
	Species 2:	RS: 8.9 (SD: 2.6; n = 7)	PS: 5.9 (3.5, n = 14)	IP: 8.3 (SD: 3.3; n = 6)
	Poly-culture:	ASB + RS: 18.3 (SD: 5.8; n = 6)	-	-
III. Integrated Multi-Trophic Aquaculture (IMTA)				
		Tamil Nadu	**Karnataka**	
Type of the unit	Fish/ shellfish cage	Circular (HDPE/GI) cages (n = 10)	Rectangular wooden cages (n = 4)	
	Mussel/ seaweed raft	Rectangular wooden rafts	Rectangular wooden rafts	
Average number of units/farm	IMTA	1.1	1.2	
Size of the unit (LxBxD)/ (DiaxD) in m	Fish/ shellfish cage	6x6	6x4x4 (rectangular)	
	Mussel/ seaweed raft	3.6x3.6	6x6	
Distance from the shore (m)		1000	10-300	

Feature		Sample locations	
Depth of water (m)		5-6	4-9
Major species farmed	Fed species	Cobia	Asian seabass (ASB); Red snapper (RS)
	Extractive species	Red seaweed (*Kappaphycus alvarezii*) (KA)	Green mussel (GM)
Crop duration (months)	Fed species:	Cobia: 7-8	ASB & RS: 8-12
	Extractive species	KA: 45 (days), (4 cycles/year)	GM: 5-7
Feed type (raw fish/locally formulated/ concentrate/ pellet)	Fed species:	Cobia: Trash fish	ASB& RS: Trash fish
Average Yield (kg/m^3/unit)	Fed species:	Cobia: 11.4 (SD: 1.1, n = 10)	ASB: 4.0 (SD: 0.2, n = 2); RS: 6.9 (SD: 3.93, n = 2)
	Extractive species	KA: 1254 (kg wet weight/raft for 4 cycles) (SD: 50.3, n = 10 units of 16 rafts each)	GM: 7.8 kg/rope (SD: 2.5, n = 4)

*Note: #Farming was carried out by a fisheries cooperative society and cages were established in clusters, each carrying a battery of 10. *Feeding rate is expressed as the average quantity fed through the crop duration; it might differ across growth phases, all of which pertain to the most recent cycle of the crop.*

The IMTA farms were of two types: (i) open sea cage farming of cobia integrated with red seaweed (*K. alvarezii*) in the Mandapam region of Tamil Nadu state and (ii) coastal water cage farming of Asian seabass and red snapper integrated with green mussel in the Byndoor region of Karnataka. In the former case, each unit consisted of one HDPE circular cage encircled by approximately 16 nearby seaweed rafts. The units were located approximately one km from the shore, at a water depth of 5-6 meters. The cages were stocked with cobia seeds mainly sourced from hatcheries. Seaweeds were raised in rectangular rafts in four cycles of 45 days each during a cropping season. Respondents practicing this system reported having realized an average yield of 11.4 kg/m^3 of cobia and 1254 kg of *K. alvarezii* per raft. The coastal water IMTA units were located very close to the shore and each unit consisted of one rectangular cage surrounded by 1-2 green mussel rafts. Each raft carried 50-100 seeded ropes suspended in the water body. Crop duration ranged from 8 to 12 months for the fed species and 5-7 months for the extractive species (green mussel). At the end of the harvest season, the average fish yield realized by the sample farmers was 4.0 kg/m^3 for Asian seabass and 6.9 kg/m^3 for red snapper. The average green mussel yield recorded was 7.8 kg/rope with a standard deviation of 2.5 (Table 1).

Seaweed farms were mainly located in adjoining areas along the Mandapam and Rameswaram coasts of Tamil Nadu. They were operated primarily by women-centric Self-Help Groups (SHGs) or independent smallholder families. All farmers grew *K. alvarezii*, the red seaweed species in floating bamboo rafts of 3.6x3.6 dimension at a distance of 10-30 meters from the shore. Each operator owned 10-20 rafts and raised 5-6 cycles of the crop for 45 days a year. About 50-60 kg of planting material from previous crops was used to stock each raft. An average wet yield of 1177 kg/raft was obtained per raft per year from the sample units, which translates to 14.0 tonnes of wet yield per farm unit per year.

4.2. Determinants of adoption of cage farming and farm income

Cage farming is an emerging enterprise in the coastal regions. Multiple factors may influence cage farming adoption. Table 2 compares the key characteristics of adopters and non-adopters. The majority of respondents were male and fell within the age range of 30–60 years. Educational status differed significantly between adopters and non-adopters, with adopters demonstrating higher levels of education. Fishing was reported as the primary occupation by more than half of the respondents in both categories (54% adopters and 62% non-adopters). Non-adopters possessed significantly more experience in fishing and related activities than adopters. As anticipated, adopters of cage farming had greater exposure to technical training in the field and a larger proportion reported access to technical support from institutional sources. Additionally, adopters had greater access to institutional credit. Conversely, non-adopters owned larger land areas than adopters did.

Table 2. Descriptive statistics of the main outcome variable and covariates: Adopters *vis-à-vis* non-adopters of cage farming

Covariate	Mean (standard error)		t-statistic/z-statistic (p-value)
	Adopters (n = 129)	Non-adopters (n = 129)	
Outcome variables			
Total household income	1199400 (172544.6)	321645 (18151.2)	-5.0784^{***} (0.00)
Demographic variables			
Family size	4.42 (0.09)	4.52 (0.10)	0.73 (0.46)
Gender (male) #	0.75 (0.04)	0.89 (0.03)	2.95^{***} (0.00)
Age of the farmer#			
Below 30 years	0.16 (0.03)	0.22 (0.04)	1.08 (0.27)
Between 30 and 45 years	0.39 (0.04)	0.28 (0.04)	-1.75^{*} (0.08)

Covariate	Mean (standard error)		t-statistic/z-statistic (p-value)
	Adopters (n = 129)	Non-adopters (n = 129)	
Between 45 and 60 years	0.35 (0.04)	0.41(0.04)	1.10 (0.27)
Above 60 years	0.10 (0.03)	0.08 (0.02)	-0.44 (0.65)
Education of the farmer#			
Illiterate	0.0 (0.0)	0.5 (0.0)	2.67*** (0.01)
Primary	0.05 (0.02)	0.04 (0.02)	-0.60 (0.54)
Secondary	0.57 (0.04)	0.68 (0.04)	1.84* (0.06)
Above secondary	0.37 (0.04)	0.22 (0.03)	-2.62*** (0.01)
Experience (fisheries/allied) (years)	6.80 (0.46)	11.76 (0.56)	6.78*** (0.00)
Number of earning family members	1.02 (0.11)	1.36 (0.12)	2.10** (0.04)
Economic/institutional variables			
Fishing as major occupation#	0.542 (0.04)	0.623 (0.04)	1.312 (0.18)
Number of relevant training attended	2.20 (0.21)	0.68 (0.11)	-6.39*** (0.00)
Access to technical support#	0.41 (0.04)	0.08 (0.02)	-6.12*** 0.00)
Land area owned (acres)	0.19 (0.04)	0.73 (0.17)	3.02*** (0.00)
Access to institutional credit#	0.58 (0.04)	0.16 (0.03)	-6.91*** (0.00)
Membership in societies#	0.46 (0.04)	0.37 (0.04)	-1.56 (0.11)

Note: # indicates the proportion of samples.

Table 3 presents the results of the Heckman model. The empirical strategy assumes that disparate sets of parameters determine a respondent's decision to adopt cage farming on the one hand, and the income obtained from the enterprise after taking it up on the other. Columns 3 and 4 present the results for the selection equation. Among the various demographic variables, factors like age and literacy of the respondents were found to determine the decision to adopt cage farming. Compared to respondents in the older age group, those below 30 years of age displayed a significantly greater inclination to take up cage farming. Similarly, the coefficients corresponding to the three educational attainment levels were significantly different. However, relatively greater educational attainment did not have any additional impact on the adoption of cage farming. Having fishing as a major occupation enhanced the odds of participating in cage farming. Nevertheless, a longer fishing experience had a negative impact on adoption. This suggests that older individuals who have been long engaged in fishing did not prefer cage farming, whereas younger individuals with some experience in fishing and allied activities were more inclined towards the activity compared to those with non-fishing backgrounds.

Table 3. Estimates of Heckman selection model for net income from cage farming

Covariate	Outcome equation		Selection equation	
	Coefficient	Std. Err.	Coefficient	Std. Err.
	(1)	(2)	(3)	(4)
Dependent variable: log (Net farm income from cage farming)				
Family size	0.175	0.105	0.022	0.143
Gender (male)	0.974***	0.347	0.897	0.510
Age (base = above 45 years)				
Below 30 years	1.174**	0.541	-1.957***	0.630
Between 30 and 45 years	0.292	0.273	0.082	0.386
Education (base = No formal education)				
Primary	2.163**	0.877	4.006***	1.511
Secondary	0.578**	0.285	4.407***	1.577
Above secondary	-	-	3.955***	0.908
Major occupation (fishing = 1)	-	-	0.878***	0.489
Experience (fisheries/allied) (years)	-0.051	0.105	-0.495**	0.125
Cage farming only (yes = 1)	0.065	0.251	-	-
Number of cages installed	0.136***	0.046	-	-
Number of earning family members	-	-	0.053	0.154
Relevant training attended (yes = 1)	-	-	-0.180	0.490
Number of relevant training attended	-0.035	0.102	0.300**	0.169
Access to technical support (yes = 1)	-0.790	0.513	1.994***	0.444
Land area owned (acres)	0.160	0.875	-2.627***	0.985
Area of farm unit (acres)	-0.054	0.947	-	-
Access to institutional credit (yes = 1)	0.392	0.301	0.694	0.514
Membership in societies	-0.542	0.532	-1.031*	0.513
Distance from the market (km)	0.051***	0.016	-	-
Distance from the nearest road (km)	0.082	0.088	-	-
Number of observations: 164; Wald chi2(17): 216.9***; Lambda: 0.599; Rho: 0.79; sigma: 0.757				

Training was found to significantly enhance the probability of cage farming adoption. Notably, a positive response to 'whether attended relevant training' alone was insufficient; rather, the greater the number of training sessions attended, the higher the likelihood of adoption. Access to technical support was another significant factor (at 1% level) that positively influenced adoption. The results also indicate that land ownership negatively influences the adoption of cage farming. This finding may be attributed to the availability of alternative income sources for those with larger land parcels. Access to institutional credit and membership in fishery/aquaculture societies has only a limited positive impact on facilitating adoption.

The results of the outcome equation presented in columns 1 and 2 of Table 3 provide notable insights into the factors that influence net income. Farms operated by male respondents and those below the age of 30 years were observed to generate significantly higher net incomes. The education level of the respondents was another positive factor that contributed to greater net farm income. As anticipated, farms with more cages earned higher net income. Other factors, such as exposure to relevant training, access to technical support, area of the farm unit, land area owned, access to institutional credit, membership of societies, and similar variables, did not demonstrate any significant relationship with farm income. Notably, farms that sold their harvested produce in distant markets realized better net income than those that found markets in closer proximity to their farms. This could be attributed to the better value realization in wholesale markets than in nearby primary markets.

4.3. Economic impact of cage farming: Evidence based on PSM analysis

The robustness of the impact of cage farming on income of adopters vis-à-vis non-adopters was checked by applying the PSM technique. The conditional probability of the households' adoption of cage farming was estimated using a probit regression framework, wherein the dependent variable assumed a value of '1' if the household is an adopter and '0' otherwise. The model included all observable covariates that affected cage farming adoption. The model was statistically significant at 1 % (Table 4).

Table 4. Estimated probit model for adoption of cage farming by sample households

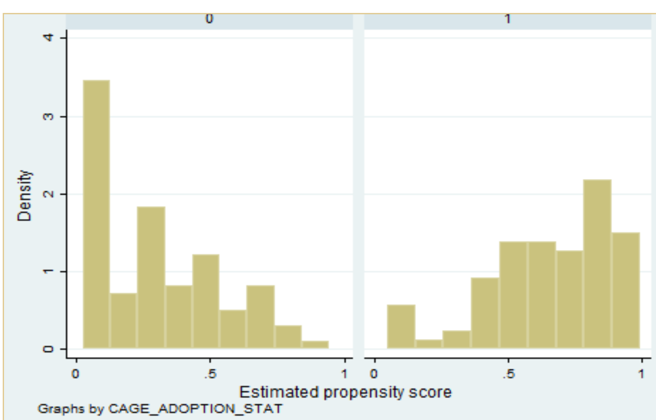
Covariate	Coefficient	Std. Err.
Dependent variable: Adoption status of cage farming (adopter = 1)		
Family size	-0.160	0.096
Gender (male)	0.736**	0.326
Age (base = above 45 years)		
Below 30 years	-0.974***	0.380
Between 30 and 45 years	-0.074	0.272
Education (base = No formal education)		
Primary	5.601***	1.008
Secondary	5.362***	0.819
Above secondary	5.261***	0.841
Major occupation (fishing = 1)	0.628**	0.262
Experience (fisheries/allied) (years)	-0.142***	0.025
Number of earning family members	-0.104	0.079
Relevant training attended (yes = 1)	0.117	0.322
Number of relevant training attended	0.203**	0.083
Access to technical support (yes = 1)	1.141***	0.294
Access to institutional credit (yes = 1)	1.544***	0.336
Membership in societies	0.298	0.464

Covariate	Coefficient	Std. Err.
Dummy for coastal water cage (yes = 1)	-0.416	0.484
Dummy for Kerala (yes = 1)	0.586	0.684
Dummy for Tamil Nadu (yes = 1)	0.525	0.511
Constant	-5.230	
Number of observations: 254; LR chi^2 (17): 162.2***; Pseudo R^2: 0.46		

The results indicated a statistically significant difference between the treated and control groups with respect to age, gender, education, experience in fishing and allied activities, training, access to technical support, and availability of institutional credit. These findings are consistent with the results of the Heckman analysis.

Propensity scores were calculated for each observation in the treatment and control groups, and the region of common support was determined (0.045, 0.999) to facilitate an unbiased comparison. Of the 254 observations utilized in the estimation, 222 fell within the region of common support. Within this region, the mean estimated propensity score was 0.575, with a standard deviation of 0.33. The distributions of propensity scores for adopters and non-adopters after matching are shown in Fig. 2. The estimates were categorized into five optimal blocks, such that the mean propensity score in each block for the treatment and control blocks did not differ significantly. The balancing property was satisfied, indicating that after controlling for the observed covariates, the treatment was independent of the unit characteristics.

Fig. 2. Histogram of propensity scores of adopters and non-adopters of cage farming after matching



After achieving a balance of the covariates across the treatment and comparison groups, nearest-neighbor matching and kernel matching were applied. The estimated ATT of the impact of cage farming on the household income of treated households is presented in Table 5.

Table 5. ATT estimates (₹ Million) corresponding to the household income of the sample households

Matching method	Number of matched observations		ATT	Std. Err.	t-value
	Adopter	Non-adopter			
Nearest neighbour method	128	36	0.663***	1.93	3.439
Kernel matching method	128	94	0.707***	1.77	3.989

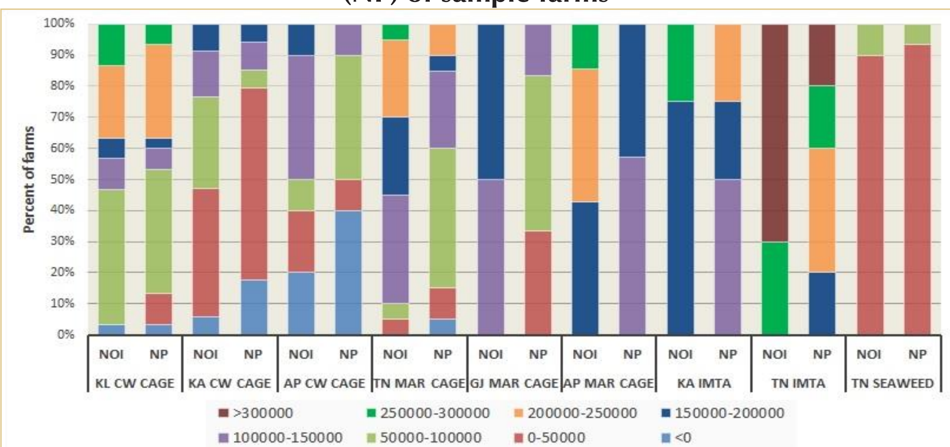
Note: The unit for the outcome variable is 000 rupees.

The ATT estimates were highly significant. The gains in household income attributable to cage farming were estimated to be ₹0.663 -0.707 million. The results indicate the notable economic impact of cage farming, pointing towards its future potential as a promising livelihood avenue for coastal fishermen.

4.4. Sustainability status of mariculture

The estimated techno-economic parameters for the selected mariculture enterprises are listed in Table 6. Significant variations exist in these parameters across enterprises and regions. Access to institutional credit and markets, as well as orientation towards value addition, is inadequate for enterprises. The open-sea cage culture units in Andhra Pradesh demonstrated higher profitability compared to other locations. Similarly, coastal water cage units in Kerala exhibited greater profitability (Fig. 3). Although marine cage farmers generally performed better in terms of absolute indicators of profitability due to the larger size of culture units, they underperformed in terms of relative profitability indicators, such as ROI, BCR, and OR (Fig. 4). Several open sea cage culture units in Tamil Nadu, and coastal water cage culture and IMTA in Karnataka and Andhra Pradesh incurred financial losses.

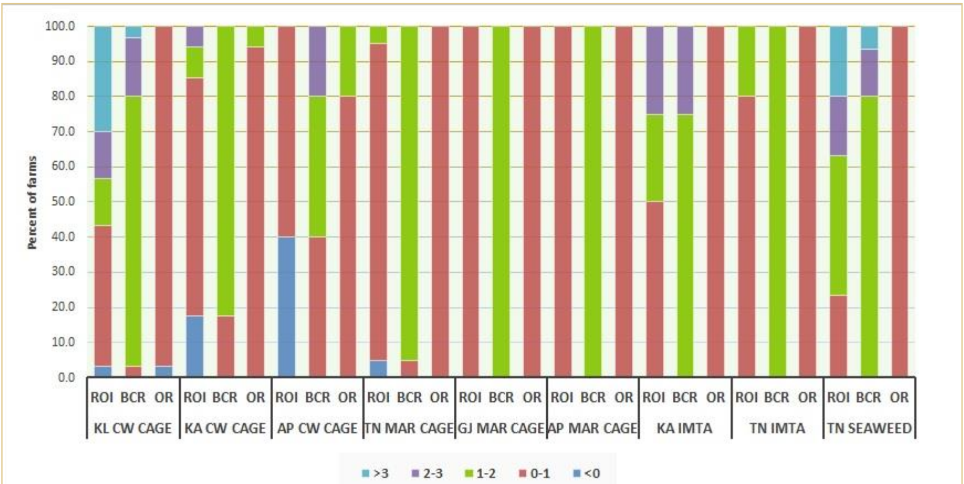
Fig. 3. Distribution of Net Operating Income (NOI) and Net Profit (NP) of sample farms



Notes: For seaweeds, income estimates are reported for a batch of 10 rafts each for the sample farmers; Profitability is expressed in Indian rupees (1 Indian Rupee (INR) = 0.012 US Dollars)

KL CW CAGE: Coastal water cage, Kerala; KA CW CAGE: Coastal water cage, Karnataka; AP CW CAGE: Coastal water cage, Andhra Pradesh; TN MAR CAGE: Marine cage, Tamil Nadu; GJ MAR CAGE: Marine cage, Gujarat; AP MAR CAGE: Marine cage, Andhra Pradesh; KA IMTA: IMTA, Karnataka; TN IMTA: IMTA, Tamil Nadu; TN SEAWEED: Seaweed, Tamil Nadu

Fig. 4. Distribution of economic viability indicators of sample farms



Notes: same as Fig. 2

Table 6. Estimated sustainability indicators associated with selected mariculture enterprises in sample locations in India, 2022

Key Indicators / metrics	Open sea cage farming			Coastal water cage farming			IMTA		Seaweed farming
	Tamil Nadu	Andhra Pradesh	Gujarat	Karnataka	Kerala	Andhra Pradesh	Tamil Nadu	Karnataka	Tamil Nadu
A. Techno-economic indicators									
Permanence in activity (PA)	1.7 (0.9)	11.4 (5.5)	7.3 (2.5)	4.9 (2.7)	5.1 (3.2)	2.8 (1.56)	4.9 (3.0)	8.8 (4.8)	7.8 (3.9)
Capital self-sufficiency (CS) (%)	20.0	28.6	100.0	29.4	80.0	10.0	0.0	NA	100
Family labour share (FL) (%)	36.6	0.0	14.4	84.3	58.8	81.3	47.8	87.2	54.5
The legitimacy of access (LA) (%)	0.0	0.0	0.0	100.0	16.7	0.0	0.0	100.0	0.0
Formal training (FT) (%)	100.0	85.7	100.0	79.4	100.0	100.0	100.0	100.0	100.0
Access to technology (AT) (%)	100.0	85.7	100.0	97.1	100.0	100.0	100.0	100.0	100.0
Quality seed (QS) (%)	100.0	100.0	25.0	47.1	100.0	100.0	100.0	100.0	-
Formulated feed (FF) (%)	0.0	100.0	0.0	23.5	83.3	70.0	0.0	0.0	-

Key Indicators / metrics	Open sea cage farming			Coastal water cage farming			IMTA		Seaweed farming
	Tamil Nadu	Andhra Pradesh	Gujarat	Karnataka	Kerala	Andhra Pradesh	Tamil Nadu	Karnataka	Tamil Nadu
Institutional credit access (IC) (%)	0.0	0.0	0.0	64.7	27.0	0.0	0.0	25.0	0.0
Institutional credit availed (ICA) (INR)	0.0	0.0	0.0	NA	1,10,570	0.0	0.0	NA	0.0
Diversity of markets (DIV)	1	1	3	4	3	1	2	5	1
Marketing agreement (MA) (%)	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0
Unfair market practices (UMP) (%)	0.0	0.0	0.0	100.0	13.0	70.0	70.0	100.0	100.0
Market commission rate (CR) (%)	Nil	5.0	Nil	7.0	Nil	3.5	Nil	Nil	Nil
Value addition orientation (VAO) (%)	0.0	0.0	0.0	0.0	47.0	0.0	0.0	0.0	0.0
Net operating Income (NOI) (INR)	Results depicted in Fig. 2 below								
Net profit (NP) (INR)									
Returns on Investment (ROI)	Results depicted in Fig. 3 below								
Benefit-Cost Ratio (BCR)									
Operating Ratio (OR)									
B. Techno-environmental indicators									
Species diversity (SD)	1	2	3	3	4	3	2	6	1
Mechanization (MCH) (%)	0.0	71.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Renewable energy access (RE) (%)	0.0	100.0	37.5	5.9	30.0	40.0	0.0	0.0	0.0
Management adequacy (MA) (%)	10.0	57.1	0.0	5.9	56.7	20.0	0.0	0.0	0.0
Farm surveillance (FS) (%)	0.0	85.7	0.0	100.0	93.3	90.0	0.0	0.0	0.0
Antifouling management (AFM) (%)	0.0	100.0	0.0	100.0	56.7	100.0	0.0	100.0	0.0
Water quality monitoring (WQM) (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Key Indicators / metrics	Open sea cage farming			Coastal water cage farming			IMTA		Seaweed farming
	Tamil Nadu	Andhra Pradesh	Gujarat	Karnataka	Kerala	Andhra Pradesh	Tamil Nadu	Karnataka	Tamil Nadu
Crop holiday management (CHM) (%)	100.0	100.0	100.0	47.1	63.3	100.0	100.0	50.0	100.0
C. Social indicators									
Institutional linkage (IL) (%)	100.0	85.7	100.0	100.0	100.0	100.0	100.0	100.0	100
Social engagement (SE) (%)	100.0	71.4	37.5	85.3	23.0	50.0	80.0	100.0	100
Employment generation (EG) (man-days/unit)	321.4 (56.6)	195.3 (23.8)	175 (54.2)	94.3 (41.9)	145 (45.4)	196 (70.3)	395.7 (111.0)	90.2 (4.2)	98.7 (36.0)
Gender inclusion (GI) (%)	33.3	24.8	8.3	20.6	13.3	34.5	51.8	19.6	57.9
Crew insurance (CI) (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crew safety (CS) (%)	0.0	85.7	37.5	94.1	10.0	100.0	0.0	100.0	0.0
Social protection (SP) (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Number of observations	20	7	14	34	30	10	10	4	30

Note: Figures in parentheses indicate estimates of standard deviation; 1 Indian Rupee (INR) = 0.012 US Dollars

The majority of farms were observed to understock their culture units primarily due to a shortage of quality seeds and their relatively high cost. Only the lobster cage farms in Gujarat exhibited a stocking density greater than that recommended, as they were Capture-Based Aquaculture (CBA) units. Numerous farmers practicing coastal water cage farming in Kerala have also reported overstocking their cages. Except those in Visakhapatnam (71.4%), none of the farm units reported any mechanization or automation of their operations. In the latter case, farmers reported attempting automated feeding in their cages on a trial basis with technical support from the Visakhapatnam Center of ICAR-CMFRI. The utilization of solar energy in farms for lighting, surveillance, and powering other minor farm operations is gradually becoming more prevalent in cage farms. Management Adequacy (MA), a measure to determine the level of adoption of disease control, hygiene management, and general health management of farm stock, was observed to be relatively higher among marine cages in Andhra Pradesh (57.1%) and coastal water cage farms in Kerala (81.8%). Almost all coastal water cage farms adopted farm surveillance measures, such as closed-circuit cameras or watch-and-ward mechanisms; however, their adoption in marine-based enterprises (except in Visakhapatnam) was low.

Among the indicators of social sustainability, farms demonstrated high scores in Institutional Linkage (IL) and Social Engagement (SE), as they maintained strong connections with various research and extension agencies. These linkages were primarily utilized to acquire technological updates on farming; gain access to financial, technical, and extension assistance; develop skills through training programs; and enhance farm management capabilities. The indicators also suggest that mariculture enhanced employment opportunities and gender inclusion. Employment estimates varied across enterprises and locations, ranging from 94 to 396 person-days per unit per crop. The highest average person-day requirement was observed for IMTA (395.7 person-days/unit) and marine cage farms (321.4 person-days/unit) in Tamil Nadu, whereas coastal water IMTA in Karnataka (90.2 person-days/crop) and seaweed farming (98.7 person-days/crop) in Tamil Nadu exhibited lower employment figures. The results pertaining to crew insurance (CI) and social protection (SP) were absent at all locations, indicating significant gaps in the social dimensions of sustainability. However, the farm units in Andhra Pradesh and Karnataka maintained effective measures to ensure crew safety at work (floaters, life jackets, hand gloves, rubber shoes, etc.).

Farms generally exhibit poor performance in terms of technical and environmental indicators. Significant deficiencies were observed in mechanization, utilization of renewable energy, disease and hygiene management, farm surveillance, antifouling, and water quality. Notably, most farms, with the exception of cage farms engaged in lobster fattening in Veraval (Gujarat) and coastal water cage farms in Kerala, were predominantly observed to under-stock fish seeds, resulting in suboptimal crop yields. Addressing this deficiency through enhanced seed availability and extension interventions could substantially improve the economic viability of these units. The profitability of farms at numerous locations was also affected by several input-side constraints and other extraneous factors. For instance, coastal water cage farmers in Andhra Pradesh reported that delays in obtaining fish seeds resulted in the late commencement of culture, thereby curtailing the culture period. Some farmers also reported mortality due to wastewater infusions from neighboring industrial units.

Yield enhancement, a primary pillar of SI, requires attention, which can be achieved through optimal seed stocking, increased culture intensity via polyculture of suitable species, and scientific management of various biotic and abiotic constraints. Prospective interventions include regular carrying capacity and water quality assessments, utilization of disease-free SPF seeds, disease surveillance, implementation of aquatic animal health codes applicable to open water bodies, measures to prevent siltation and biofouling, monitoring of invasive species incidence, and realignment of crop schedules to accommodate salinity and temperature fluctuations in water bodies through regular monitoring (OIE 2019; Fox et al. 2020; Wanja et al. 2020). The adoption of IMTA is limited. However, the enhanced growth and higher yields of extractive species, as well as the potential for biofouling mitigation around cages, present considerable future opportunities in India. Similarly, the seaweed farming sector requires an increased supply of planting material, either through genetic improvement, mass multiplication, or the introduction of suitable exotic species, following appropriate screening for potential negative ecological consequences (Johnson et al., 2021).

5. Conclusions

Although predominantly smallholder-oriented, mariculture is a potential source of marine fish. Over the past 15 years, significant advancements have been made in the breeding, seed production, and growth of marine finfish and shellfish species in artificial enclosures and structures, facilitating their economically viable cultivation in open, coastal, and estuarine waters. The results of this study indicate that cage farming can substantially increase farm incomes.

Given the early stages of development, the technical and human resource prerequisites for enabling resource-poor coastal inhabitants to engage in capital-intensive mariculture activities are substantial. There are significant deficiencies in the key indicators of sustainability, including the legitimacy of access to water bodies, quality seed and feed, institutional credit and market, automation of farms and renewable energy, farm surveillance, crew safety, and social protection.

Specific recommendations in regard to the aforementioned include: (i) development of marine spatial plans (MSP) for optimal allocation of available ocean space; (ii) introduction of legislation at appropriate levels to support leasing and licensing arrangements, with particular consideration for marginalized coastal communities; (iii) implementation of measures to ensure adequate supply of quality seed and feed through channelling public funding and incentivizing the private sector; (iv) strengthening of food safety and health management protocols in mariculture farms; (v) development of mandatory guidelines on good farming practices (e.g., measures for anti-fouling, water quality monitoring, crop holiday management, safety and security measures) to obtain farm registration; (vi) enhancement of multi-disciplinary research on mariculture systems; (vii) implementation of market reforms for the development of competitive value chains; (viii) introduction of specialized schemes to support auxiliary prerequisites such as credit, insurance, and other support services; and (ix) promotion of group farming, cooperative farming, and FFPOs among mariculture farmers (FAO, 2016). The mariculture farmers can be brought under the ambit of collective farming groups such as FFPOs through initial government patronage and facilitation for group mobilization, technical backstopping, skill upgradation, provision of credit and insurance support, and awareness generation hinging on successful examples. Attracting entrepreneurs to mariculture requires attention by showcasing its profitability, growth potential, and sustainability while reducing barriers to entry. This involves streamlining regulations, improving access to resources and technical support, and fostering a supportive ecosystem. Addressing concerns about risk, environmental impact, and social responsibility is also crucial. A multi-pronged approach focusing on economic viability, environmental consciousness, and social responsibility will attract innovative entrepreneurs to this promising sector.

The governance of mariculture presents significant complexities due to the presence of diverse stakeholders with conflicting interests as well as concerns regarding equity and enforcement challenges. Numerous contentious issues require prompt resolution, including ownership and operational structures (cooperative/corporate/private/other), engagement within various social and political domains, and alignment with intersecting sectors (Percy et al. 2013; Davies et al. 2019). Of paramount importance is the establishment of appropriate institutions and governance mechanisms to ensure that the future expansion of mariculture development adheres to a precautionary approach to environmental sustainability and is guided by the Ecosystem Approach to Aquaculture (EAA) to maintain the resilience of interconnected social-ecological systems.

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Annexure A1. Sampling framework for primary data collection in selected coastal states of India, 2022

State	District	Location	Number sample respondents under			
			Marine cage farming	Coastal water cage farming	IMTA	Seaweed farming
Andhra Pradesh	Visakhapatnam	Visakhapatnam	07			
	Krishna	Lakshmipuram		03		
		Pedapalem		07		
Tamil Nadu	Ramanathapuram	Kalaimangundu	07			
		Chinnapalam	04			
		Thankachimadam	03			
		Kundhukal	06			
		Mandapam			10	25
		Rameswaram				05
Kerala	Ernakulam	Gothuruthu		05		
	Alappuzha	Thrikkunnapuzha		08		
		Arattupuzha		07		
	Kollam	Kollam		10		
Karnataka	Uttara Kannada	Karwar		08		
		Kumta		07		
		Bhatkal		05		
	Udupi	Uppunda		04		
		Byndoor		04	04	
		Kundapura		06		
Gujarat	Gir Somnath	Veraval	4			
	Porbandar	Porbandar	2			
	Kutch	Kutch	4			
Diu	Diu	Diu	4			
All			**41**	**74**	**14**	**30**

Annexure A2. Sampling framework for data collected covering adopters and non-adopters of cage farming, 2023.

State	District	Sample size		Total
		Adopters	Non-adopters	
Kerala	Ernakulam	40	40	80
	Alappuzha	39	40	79
Tamil Nadu	Ramanathapuram	30	30	60
Karnataka	Udupi	20	20	40
Total		**129**	**130**	**259**

Annexure A3. Summary of key dimensions, criteria, and indicators as per PCI approach to assess the level of sustainability associated with selected mariculture enterprises in sample locations in India, 2022

Dimension (Principle)	Broad Criteria	Key Indicators /metrics
A. Techno-Economic dimensions		
I. Entrepreneurial readiness of farmers/ entrepreneurs	Farming experience; Access to capital; General education / Technical skills; Access to technology and outside technical expertise; Availability of family/hired labour; Owned land/leased land/ water body; Technical training	Permanence in activity (PA) = Average farming experience of the farmer in years
		Capital self-sufficiency (CS) = Percent of farm operators in the sample having met more than half of capital expenditure from own funds
		Family labour share (FL) = Average share of family labour in total labour across sample farms
		The legitimacy of access (LA) = Percent of the sample farm units that reported ownership rights or existence of legal contract over the water body used for culture
		Formal training (FT) = Percent of sample farms that reported having acquired formal training by the proprietor in mariculture
		Access to technology and institutions (AT) = Percent of sample farms reported accessing technological support from a formally recognized source (Research institute/KVK, etc.)
II. Backward linkages with input markets and support services	Level of access to quality fish seeds/ fingerlings, quality feeds, and other inputs; Access to institutional credit	Quality seed use (QS) = Percent of sample farms that reported sourcing quality seeds from credible sources (%)
		Formulated feed use (FF) = Percent of sample farms that reported using formulated feeds
		Institutional credit access (IC) = Percent of sample farms that have reported an outstanding credit from institutional sources
		Institutional credit availed (ICA) = Average value (Indian Rupees, INR) of the institutional loan across sample farms

Dimension (Principle)	Broad Criteria	Key Indicators /metrics
III. Market access and value chain integration	Access to markets for the sale of fish harvested; Fair choice of markets (diversity of markets) to sell harvested fish; Assured price at farm gate; Absence of unfair trade practices; Linkage with value addition /processing facilities	Diversity of markets (DIV) = Number of marketing options (first sale) exercised by sample units
		Marketing agreement (MA) = Percent of sample farms that reported entering into a prior formal contract for marketing their produce
		Unfair market practices (UMP) = Percent of sample farms that reported one or more unfair market practices encountered while selling their produce
		Market commission rate (CR) = Prevailing commission rate (%) at the point of the first sale
		Value addition orientation (VAO) = Percent of sample farms having direct linkages with value addition centers
IV. Profitability and viability of the enterprise	Level of existing production and yield; Economic returns over the cost incurred; Scope for scale-up	Net operating Income (NOI) = (Gross returns) – (Operating costs) (INR)
		Net profit (NP) = (Gross returns) – (Total cost) (INR)
		Returns on Investment (ROI) = (Net profit)/(Initial investment costs)
		Benefit-Cost Ratio (BCR) = Present value of benefits/Present value of costs
		Operating Ratio (OR) = Operating cost/Gross revenue
B. Techno-environmental dimensions		
I. Technical measures for crop sustenance	Adoption of recommended stocking density; Diversity of products; degree of mechanization; Use of renewable sources of energy; Measures adopted for disease control; Standard management practices for hygiene and healthy fish stock; farm surveillance mechanisms	Stocking density deviation (SDD) = Percent deviation w.r.t recommended stocking density* for each species cultured
		Species diversity (SD) = Number of all farmed species (fish/shellfish/seaweed) across sample farms over the last three crop seasons
		Mechanization (MCH) = Percent of sample farms having reported using any major means of farm mechanization (automation of farm operations/ climate control, etc.)
		Renewable energy access (RE) = Percent of sample farms that depend mainly on renewable sources (solar, wind, etc.) for energy
		Management adequacy (MA) = Percent of sample farms with at least one scientific measure adopted for disease control, hygiene management, and maintenance of healthy fish stock
		Farm surveillance (FS) = Percent of sample farms with measures in place for surveillance of the farm against poaching risk

Dimension (Principle)	Broad Criteria	Key Indicators /metrics
II. Measures in place to ensure environmental sustainability	Measures for antifouling; Measures to check water body pollution; Crop calendar and crop holidays practiced	Water quality monitoring (WQM) = Percent of sample farms with at least one measure in place for water quality monitoring
		Crop holiday management (CHM) = Percent of sample farms observing crop holidays for at least 3 months in a year
C. Social dimensions		
I. Social capital/ community capital for sustainable intensification	Access to scientific /technical institutions for technical/ extension support; Co-operatives/ FPOs/NGOs; Government policies/ legislations.	Institutional linkage (IL) = Percent of sample farms having reported working linkage with scientific and technical institutions for technical and extension support
		Social engagement (SE) = Percent of the sample respondents having reported membership in Co-operatives/FPOs/other similar organizations
II. Potential for enhancing social welfare	Measures in place for crew safety; Potential for employment generation; Potential for gender inclusivity and women empowerment; Measures adopted for social protection; Contribution to the local economy through the local sale of produce	Employment generation (EG) = Average employment generated per crop (man-days)
		Gender inclusion (GI) = Average women-labour days generated as a share of the total labour generated per crop
		Crew insurance (CI) = Percent of sample farms reported having farm crew insurance
		Crew safety (CS) = Percent of sample farms reported having to have safety gears for the farm crew
		Social protection (SP) = Percent of sample farms reported having enrolled in government social protection programs

*Notes: *The recommended stocking density estimates were mainly obtained from NFDB (2018). Standard stocking density recommendation from ICAR-CMFRI was used for species that are not included in NFDB (2018). Mid-point is taken in cases where recommended stocking density is expressed as a rang*

CHAPTER-4

An Economic Evaluation of the Potential of Cage Farming in Reservoirs in India

Anjana Ekka, Arun Pandit, Archan Kanti Das, Basanta Kumar Das and Rajni Jain

1. Introduction

Cage culture in reservoirs has the potential to contribute significantly to the enhancement of income and employment opportunities and the nutritional status of resource-constrained rural households. Inland open-water fisheries account for 20-30% of the total inland fish production in India.

Reservoir fisheries are particularly important. While marine fish capture has reached a plateau, inland open-water ecosystems are deteriorating due to habitat alterations, climate change, and anthropogenic pressure. Aquaculture is capital-intensive and has adverse environmental effects. Reservoirs, with their vast but underutilized potential, are considered the future of the fisheries sector in India. Reservoir fisheries offer several advantages over other fish-production systems. Compared with alternative systems, reservoir fisheries require less capital investment, and their benefits are distributed among a larger fishing community.

Estimates indicate that reservoirs account for approximately two million tons of fish production in India. The fish yield from reservoirs is low, approximately 82 kg/ha, despite their high production potential of 500 kg/ha in small reservoirs, 250 kg/ha in medium reservoirs, and 100 kg/ha in large reservoirs (NFDB, 2018). Realizing this potential presents a significant challenge, as the majority of reservoirs are either overgrown with aquatic vegetation or contain physical obstructions such as boulders or tree stumps, which impede the effective deployment of fishing gear. This factor, combined with the suboptimal utilization of available food niches due to the absence of efficient fish grazers, is primarily responsible for low fish yield (Singh and Lakra, 2011). Therefore, it is necessary to explore alternative production methods to augment fish yield and, thereby, fish production. Enclosure culture systems play a significant role in this regard. This approach can mitigate several limitations of lake and reservoir fish production environments by maintaining a captive population on artificial feed, protecting them from predators, and facilitating harvest operations (Radhakrishnan et al., 2019).

2. Status of Cage Culture in Reservoirs

Cage culture in reservoirs typically involves the installation of cages or net enclosures to raise fry to fingerlings and ultimately to table fish. Prominent reservoirs where cage culture is practiced include the Hirakud Reservoir in Odisha, Gangrel reservoir in Chhattisgarh, Maithon reservoir in Jharkhand, and Indira Sagar Reservoir in Madhya Pradesh.

The prevalence of cage culture in reservoirs has been increasing, driven by factors such as availability of suitable water bodies, government support, and training programs. Fig. 1 illustrates the heterogeneous distribution of the aquaculture cages in India. A few states are frontrunners because of favorable conditions, whereas others are at the nascent stage. Conversely, some states in the north western and eastern regions have no cage aquaculture. States such as Punjab and parts of the northeast have a minimal (1-50) number of installations, indicating the early stages of cage aquaculture or limited potential owing to geographical or economic constraints. States, such as Tamil Nadu and Karnataka, represent a more established presence of cage aquaculture. Furthermore, Gujarat, Jharkhand, Chhattisgarh, and Madhya Pradesh have a substantial number of cage units (> 2000), reflecting the significant focus on cage aquaculture as a key component of their fisheries and aquaculture strategies. However, the scale of cage culture in reservoirs remains relatively small compared with other aquaculture practices in India, such as pond culture and marine aquaculture (Pandit et al., 2020).

Fig. 1. Status of cage units installed in India

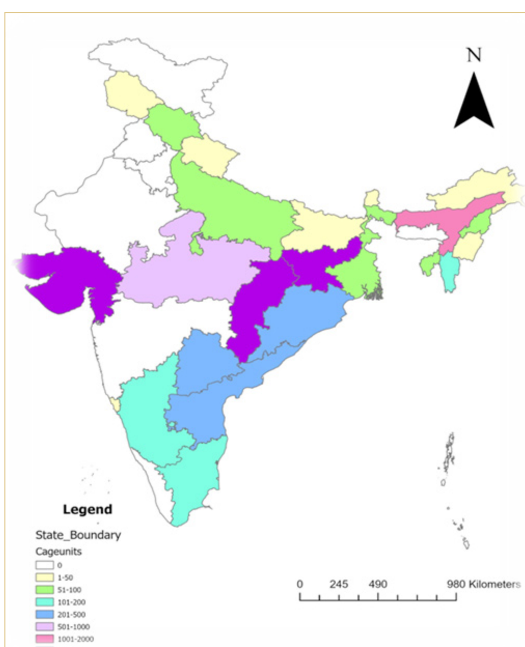


Table 1 provides a comprehensive overview of the diverse range of fish species cultivated in various states, elucidating distinct aquaculture practices and priorities in different regions. Andhra Pradesh, Arunachal Pradesh, and Assam focus on a variety of species including Indian Major Carp (IMC), Tilapia, and Pangasius due to their favorable climatic conditions and water resources. Conversely, in Haryana and Punjab, cage culture is not implemented owing to arid environments.

Table 1. An overview of the variety of species cultivated in different states of India

States	***Species cultured***
Andhra Pradesh	*Catla catla, Labeo rohita, Cirrhinus mrigala, Oreochromis niloticus,*
Arunachal Pradesh	*Catla catla, Labeo rohita, Cirrhinus mrigala, L. gonius,* Cyprinus *carpio, and* Ctenopharyngodon *idella*
Assam	*Catla catla, Labeo rohita, Cirrhinus mrigala, L. bata, Hypophthalmichthys molitrix &* Ctenopharyngodon *idella*
Bihar	*Pangasius hypophthalmus, Oreochromis niloticus*
Chhattisgarh	*Pangasius hypophthalmus, Oreochromis niloticus*
Goa	*Pangasius hypophthalmus, Oreochromis niloticus*
Gujarat	*Pangasius hypophthalmus*
Haryana	*NC **
Himachal Pradesh	*Catla catla, Labeo rohita, Cirrhinus mrigala, Common Carp, Pangasius, Silver carp, Rainbow Trout*
Jharkhand	*Pangasius hypophthalmus, Oreochromis niloticus*
Karnataka	*Pangasius hypophthalmus, Oreochromis niloticus*
Kerala	*NC*
Madhya Pradesh	*Pangasius hypophthalmus, Oreochromis niloticus*
Maharashtra	*Oreochromis niloticus*
Manipur	*Catla catla, Labeo rohita, Cirrhinus mrigala,* Oreochromis *niloticus & Osteobrama belangeri*
Meghalaya	*Pangasius hypophthalmus*
Mizoram	*Catla catla, Labeo rohita, Cirrhinus mrigala), Oreochromis niloticus & Osteobrama belangeri*
Nagaland	*Catla catla,* Labeo *rohita, Clarias batrachus, Cirrhinus mrigala*
Odisha	*Pangasius hypophthalmus, Oreochromis niloticus*
Punjab	*NC*
Rajasthan	*Pangasius hypophthalmus, Oreochromis niloticus*
Sikkim	*Oncorhynchus mykiss*

States	*Species cultured*
Tamil Nadu	*Oreochromis niloticus*
Telangana	*Pangasius hypophthalmus,* Oreochromis *niloticus, Ompok bimaculatus*
Tripura	*Catla catla, Labeo rohita, Cirrhinus mrigala, Pangasius hypophthalmus and* Oreochromis *niloticus*
Uttar Pradesh	*Ctenopharyngodon idella,* Pangasius *hypophthalmus &* Cyprinus *carpio*
Uttarakhand	*Pangasius hypophthalmus*
West Bengal	*Pangasius hypophthalmus*

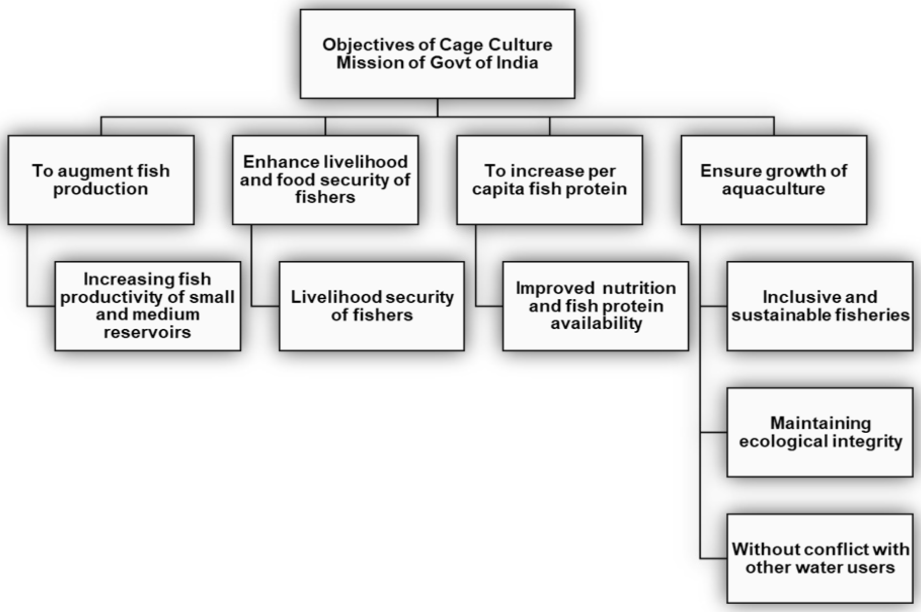
* *NC - Not cultured*

The presence of states such as Himachal Pradesh and Sikkim in reservoir fisheries, focusing on species such as Rainbow Trout, demonstrates the adaptability and versatility of India's aquaculture in addressing niche markets and environmental conditions (Singh, 2020). Tilapia and Pangasius have emerged as prevalent choices for cage aquaculture in several states, indicating their suitability for Indian farming conditions and potential to meet the increasing demand for fish (Panemangalore, 2022; Ramteke et al., 2023).

3. Regulatory Framework for Cage Culture

The Ministry of Fisheries, Animal Husbandry, and Dairying, Government of India, provides guidance to states regarding the regulation of inland cage culture. In 2020, the Government of India initiated the Pradhan Mantri Matsya Sampada Yojana (PMMSY) to facilitate a second Blue Revolution encompassing various segments of fisheries and aquaculture, including cage culture. The primary objective of the Cage Culture Mission (Fig. 2), a key component of PMMSY is to enhance fish production while ensuring sustainable and inclusive growth. Key goals include increasing fish production by utilizing per unit inland open water area and improving the per capita availability of fish protein. The Mission emphasizes the livelihood and food security of fishers by enhancing productivity (DAHF, 2022). These objectives underscore the significance of area-specific need-based approaches to enhance productivity. Additionally, the promotion of culture-based fisheries (CBF) in open water bodies is essential and requires the identification of suitable sites, raising awareness, and providing necessary support for large-scale implementation. Collectively, these objectives aim to establish a robust, sustainable, and productive aquaculture industry capable of meeting the increasing demand for fish while ensuring environmental and economic sustainability.

Fig. 2. Objective of cage culture mission, Govt. of India



Source: Department of Animal Husbandry, Dairy and Fisheries, Mission cage culture, action plan, 2022

As indicated in Fig. 2, the delineated objectives aim to enhance fish production through cage aquaculture by focusing on various strategies, including implementing policy- and scheme-level interventions to address demand-supply gaps and ensuring supportive frameworks and incentives for the sector's growth. An integrated approach was proposed to increase fish production in targeted water bodies, involving coordinated efforts across different sectors. The expansion of cage infrastructure is emphasized, with a focus on installing new cages and upgrading existing ones for scale-up operations. Diversification of cultured species is encouraged to mitigate risks and cater to market demands, thereby promoting a balanced and economically viable aquaculture system.

Leasing policies in reservoirs across India significantly impact the development of cage culture, influencing access rights, investment incentives, and sustainability. For example, in states like Chhattisgarh and Telangana, longer lease durations of up to 10 years provide fishers and investors with the security needed to invest in cage culture infrastructure, leading to enhanced fish production and economic benefits. On the other hand, , states such as Tamil Nadu and Uttar Pradesh, with shorter lease periods ranging from 1 to 5 years, may face challenges in attracting sustainable investments due to the uncertainty associated with brief leasing terms. For instance, the Odisha

State Reservoir Fishery Policy emphasizes leasing fishing rights to Primary Fishermen Cooperative Societies, with a lease value of ₹ 300 per hectare per year for minor reservoirs, aiming to augment fish production and support local fishing communities.

Different states follow varying ownership and leasing frameworks, broadly classified under state fisheries departments, revenue departments, and cooperative societies. While some states promote long-term leases to fisher cooperatives, encouraging investment in cage culture, others have restrictive policies that limit private sector participation. The lack of uniform leasing policies often affects the adoption of cage culture, particularly in states where short-term leasing discourages sustainable practices.

4. Techno-Economic Feasibility of Cage Culture

The techno-economic feasibility of cage culture for various fish species in reservoirs, based on data collected from state governments (Table 2), indicates varying degrees of productivity and economic returns. Nile Tilapia, cultured in HDPE cages with a stocking density of 50 fishes/ m^3, achieves a productivity of 32 kg/m^3 and a benefit-cost ratio of 1.25, suggesting moderate economic viability. *Pangasius pangasius*, also reared in HDPE cages but with a slightly higher stocking density of 52 fish/m^3, and it has higher productivity at 47 kg/m^3 and a better benefit-cost ratio of 1.30, making it more economically attractive. *Ompok bimaculatus*, using GI cages with a lower stocking density of 35 fish/m^3, has a productivity of 5 kg/m^3 but a high benefit-cost ratio of 1.63, indicating significant economic returns despite lower productivity. *Labeo bata*, also cultured in GI cages with a high stocking density of 50 fish/m^3, showed a productivity of 8 kg/m^3 and a benefit-cost ratio of 1.57, indicating a strong balance between productivity and economic feasibility. Overall, *Pangasius pangasius* in HDPE cages and *Labeo bata* in GI cages stand out for their strong economic returns, whereas *Nile Tilapia* and *Ompok bimaculatus* are also viable options.

Table 2. The techno-economic feasibility of different species grown in cage culture in reservoirs in India

Species	Cage type	Stocking density	Productivity (kg/m^3)	Benefit-Cost- ratio	References
Nile Tilapia	HDPE	50 fish/ m^3	32 kg	1.25	Author's estimation
Pangasius pangasius	HDPE	52 fish/m^3	47 kg	1.30	Author's estimation
Ompok bimaculatus	GI cage	35 fish/m^3	5 kg	1.63	Karnatak et al. (2021a)
Labeo bata	GI cage	50 fish/m^3	8 kg	1.57	Karnatak et al.(2021b)

Furthermore, the profitability of cage culture was examined in relation to pond culture using the economic surplus approach (Varian, 2014). The economic surplus is the sum of the consumer and producer surpluses. This represents the total net benefit to producers and consumers.

Economic surplus was calculated using the following formula:

$$Economic\ Surplus = Consumer\ Surplus + Producers\ Surplus$$

Mathematically, it can be written as

$$Economic\ Surplus = \int_0^Q [P(Q) - P_m]\, dQ + \int_0^Q [P_m - C(Q)] dQ$$

Where,

P(Q) is the demand curve or the maximum price consumers are willing to pay for quantity Q; *C(Q)* is the supply curve or the minimum price at which producers are willing to sell the quantity. P_m is the market price, and Q is the quantity of the goods consumed.

The operational cost for cage culture was substantially higher at ₹3592/m^2 compared to ₹12 /m^2 for pond culture. Despite the higher costs, the gross value of output from cage culture was significantly higher, ₹4687 /$m^{2)}$. Consequently, the net value of output from cage culture is ₹1095/m^2, with a net return of ₹ 75,420 per cage unit per year.

Table 3. A comparative assessment of cage culture with pond culture in Chhattisgarh

Particulars	***Cage culture (Rs per sq.m)***	***Pond culture (Rs per sq.m)***
Operational cost	3592.20	12.32
The gross value of Output	4687.50	32.20
Net value of output	1095.30	19.98
Reservoir area under fisheries in the state (million ha)	0.086	
Potential area under cage culture (0.1 %) in the state (ha)	86	
Estimated value of fish from pond culture in the state (million)	6.4	
Estimated value of fish from cage culture in the state (million/ha)	1720	
Economic surplus (million)	1710	
Economic surplus (million/ha)	20	

Source: Author's estimation, 2024 based on Inputs from Chhattisgarh state

In terms of scale, the reservoir area under fisheries is 0.086 million hectares, with only 0.1% (86 hectares) utilized for cage culture (estimated for Chhattisgarh). The estimated economic value of fish produced through pond culture was ₹1720 million. This results in an economic surplus of ₹1710 million for cage culture, demonstrating its superior economic viability. When this surplus is normalized per hectare, cage culture generates an economic surplus of ₹20 million per hectare. This substantial difference in economic surplus indicates that cage culture is a more economically advantageous and efficient method for fish farming and is capable of significantly enhancing the economic output of fisheries in reservoir areas. The higher productivity and profitability of cage culture render it a highly favorable option for maximizing the economic benefits of aquaculture (Datta et al., 2014).

5. Impacts of Cage Culture in Reservoirs: A Case Study

By confining fish to cages, aquaculturists can regulate factors that influence production growth. Increased stocking densities facilitate optimal resource utilization, thereby maximizing production. Enhanced yield, in conjunction with year-round production, ensures a consistent supply of fish for household consumption and markets. This section evaluates the economic benefits of the cage culture in Chhattisgarh.

5.1 Increase in Average Productivity of Reservoirs

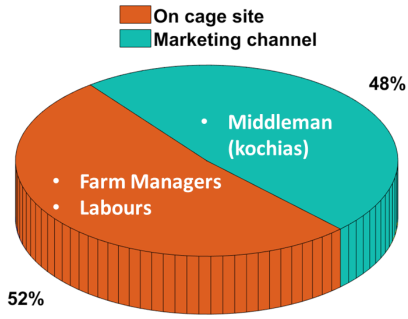
The adoption of cage culture in Chhattisgarh has significantly increased fish production. Before the adoption of cage culture, the average productivity in large, medium, and small reservoirs was 61.64 kg ha^{-1} $year^{-1}$, 94.82 kg ha^{-1} $year^{-1}$, and 349.8 kg ha^{-1} $year^{-1}$, respectively (Table 4). Averaged across all types of reservoirs, the productivity before cage culture stood at 168 kg ha^{-1} $year^{-1}$. With the introduction of cage culture, there has been a significant increase in productivity to 229.6 kg ha^{-1} $year^{-1}$. This increase in production indicates the effectiveness of cage culture as a method to boost fish yields.

Table 4. Increase in the average productivity of reservoirs in Chhattisgarh

Average Productivity (kg/ha/year)				
Large reservoir	**Medium reservoir**	**Small reservoir**	**Before cage culture (average of all types of reservoirs)**	**After Cage culture (average of all types of reservoirs)**
61.64	94.82	349.8	168	229.6

5.2 Employment Generation

Fig. 3. Employment generation through cage culture technology in reservoirs of Chhattisgarh



Cage culture generates year-round employment directly in cage culture operations and indirectly in the fish value chain. Each cage unit generates approximately 53 man-days of labor annually, and with all 4936 operational cages, a total of 250 thousand man-days are generated (Fig. 3). The net return from each cage unit was estimated to be ₹ 75,420 per year.

5.3 Women Empowerment

Cage culture in reservoirs can serve as an effective mechanism for women's empowerment by providing numerous opportunities for economic, social, and personal advancement (Fig. 4). In Chhattisgarh, 20% of cage culture sites are operated by female fish farmers. Additionally, there is a female fish farmer self-help group (SHG). These initiatives have facilitated women's economic independence, thereby enabling them to participate in financial decision-making. However, it is imperative to address gender-specific barriers to ensure equitable access to resources, programs, and policies.

Fig. 4. Cage culture by female-led SHG in the Kuwarpur reservoir in Chhattisgarh.

6. Challenges and Prospects for Cage Culture in Reservoirs

From a policy perspective, several key areas require attention to promote and enhance the adoption and efficacy of cage cultures (Fig. 5). First, it is necessary to extend financial support, including subsidies, low-interest loans, and grants, for the construction and maintenance of HDPE and GI cages (Pandit et al., 2021). Second, strengthening the capacity of fishermen through educational programs and extension services is essential to impart best practices, advanced techniques, and efficient management of cage culture systems. Third, investment in research and development is vital for optimizing cage culture practices, including improving cage designs, stocking densities, feed formulations, and disease management, while focusing on developing sustainable practices to minimize environmental impacts (Mane et al., 2019). Enhancing market access and developing robust value chains will ensure economic viability, necessitating improved transportation, storage, and market linkages to ensure fair prices for fish farmers.

Environmental sustainability must be ensured through regulations pertaining to cage establishment, stocking density, water quality, and other related factors. Furthermore, a supportive regulatory framework is essential for streamlining the licensing process, mitigating bureaucratic obstacles, and ensuring compliance with the regulations. Additionally, community engagement is crucial to ensuring that small-scale and marginalized fishers benefit from cage culture through cooperatives, group ventures, and community-based approaches (Ekka et al., 2012).

Fig. 5. Policy challenges in cage culture in reservoirs

Cage culture farming models, which can empower local communities and promote equitable resource sharing, often encounter difficulties due to the absence of supportive policies and frameworks. Similarly, private and corporate entities interested in investing in cage culture face obstacles stemming from unclear regulations and potential conflicts over resource use. The lack of a cohesive policy framework can lead to resource-use conflicts, environmental concerns, and challenges in ensuring equitable benefits distribution among stakeholders. Establishing a transparent regulatory environment can encourage investment, promote sustainable practices, and facilitate the growth of cage culture in reservoirs. Collaborative efforts between government agencies, research institutions, and industry stakeholders are essential to create policies that balance economic growth with environmental sustainability and social equity.

6.1 Prospects for Cage Culture in Reservoirs

The prospects for cage culture in reservoirs are becoming increasingly promising, driven by advancements in technology and management strategies. Innovations such as drone surveillance, automated feeding systems, and species diversification not only enhance productivity but also ensure sustainability, rendering this method a viable solution for future aquaculture expansion (Fig. 6).

- **Environmental Monitoring Systems**: Integrating comprehensive environmental monitoring systems that can measure parameters such as water temperature, pH, dissolved oxygen, and nutrient levels in real-time can help manage water quality more effectively. Such systems can alert managers to changes that might require intervention, thus maintaining the health of fish and the stability of the ecosystem within the reservoir.
    - **Drone-based monitoring system:** Drones can be used for the real-time monitoring of water quality and cage conditions. They provide an aerial view that helps in assessing the spatial distribution of cages, monitoring the behavior and health of fish, and detecting early signs of disease outbreaks or pollution incidents. This technology enhances management efficiency and can lead to better decision-making.
    - **Camera Surveillance**: Underwater cameras can be installed to continuously monitor fish health and behavior directly within the cages. This technology aids in close observation without disturbing the fish, allowing for immediate responses to potential problems, such as predator attacks or cage integrity issues.
- **Renewable Energy Integration**: Utilizing renewable energy sources, such as solar panels, in cage culture operations can reduce reliance on non-

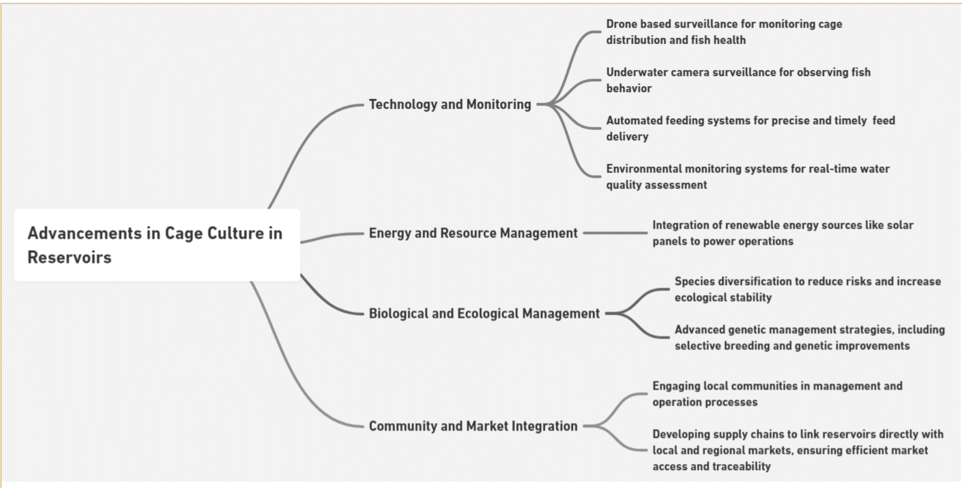
renewable energy and decrease operational costs. This is particularly effective in remote areas where connecting to the grid can be costly and challenging.

- **Species Diversification**: Introducing a variety of species to cage cultures can mitigate the risks associated with market fluctuations, disease outbreaks, and environmental changes. Diversification may also cater to different market demands and improve the ecological sustainability of operations by mimicking natural ecosystems.
- **Automated feeding systems**: The implementation of automated feeding technologies can improve feed efficiency and reduce waste. These systems can be programmed to release feed based on the optimal feeding times and quantities, which can be monitored and adjusted using data collected via drones and cameras. This leads to better growth rates and minimizes the environmental impact of overfeeding.
- **Advanced Genetic Management**: Implementing genetic management strategies to enhance stock quality and disease resistance without compromising genetic diversity can result in healthier and more robust fish populations. Techniques such as selective breeding, marker-assisted selection, and potential biotechnological innovations can be explored within the regulatory and ethical frameworks.
- **Species Diversification**: Introducing a variety of species to cage cultures can mitigate risks associated with market fluctuations, disease outbreaks, and environmental changes. Diversification may also cater to different market demands and improve the ecological sustainability of operations by mimicking natural ecosystems to some extent.
- **Community Engagement and Co-management**: Engaging local communities in cage culture operations can create shared benefits and foster sustainable practices. Community-based management approaches can include training locals in aquaculture techniques, including monitoring and maintenance tasks, and ensuring a fair distribution of economic benefits. Successful cooperatives facilitate resource sharing, ensure fair prices, and promote responsible fishing practices. For example, cooperative models in reservoirs like Hirakud and Surada in Odisha have been effective in implementing conservation measures and enhancing livelihood opportunities (Tyagi et al., 2014).
- **Linking Reservoirs with Markets**: Developing efficient supply chains from reservoirs to local and regional markets is crucial. This involves establishing good transport links, maintaining fish quality during transit, and potentially employing technologies such as blockchains

for traceability and ensuring fair trade practices. Market linkage also involves understanding consumer preferences and market trends to adjust production practices accordingly.

- **FPOs and Start-ups in Reservoir Fisheries:** The introduction of FPOs and start-ups offers promising avenues for transforming cage culture in reservoirs. FPOs can provide small-scale fishers with access to institutional credit, high-quality inputs, and efficient post-harvest management, leading to increased incomes and reduced exploitation by intermediaries. In states like Andhra Pradesh, FPO-led models have demonstrated improved profitability and welfare for fishers (Chacko, 2019). Technological interventions such as real-time water quality monitoring and automated feed management have been shown to enhance fish yields and sustainability. These technologies should be linked with FPO's. These innovations not only boost productivity but also attract young entrepreneurs and investors to the fisheries industry.
- **Compliance with Corporate Social Responsibility (CSR)**: CSR initiatives play a vital role in bridging gaps in infrastructure, training, and sustainability in cage culture in reservoirs. Companies like Tata Trusts have successfully implemented projects in Andhra Pradesh, focusing on skill development, sustainable aquaculture, and community-based fishery management (CSR mandate, 2020). Other CSR initiatives have invested in cold chain infrastructure, training programs, and sustainable fisheries practices to ensure long-term benefits for fishing communities (CSR mandate, 2020). By aligning CSR activities with government policies and cooperative models, reservoir fisheries can be better managed and sustained.

Fig. 6. Prospects of cage culture in reservoirs



7. Conclusion

The adoption and expansion of cage culture in inland open-water systems present a substantial opportunity to boost fish production further. Cage culture has shown considerable economic potential compared with traditional pond culture, with significantly higher gross and net output values. The potential economic surplus from cage culture is significant, indicating its ability to transform the aquaculture sector. Targeted policy interventions are essential to realize this potential. Investment in infrastructure and auxiliary segments, such as subsidies and low-interest loans for cage construction, can mitigate the high initial costs and encourage adoption. Training and capacity-building programs are also necessary to equip fishers with the skills needed to efficiently manage cage culture operations.

By addressing these issues, the expansion of cage culture in inland open-water fisheries can significantly boost India's fish production, enhance economic returns, improve livelihoods, and contribute to sustainable development goals. This strategic focus will solidify the role of inland fisheries in the food security and economic growth of the country.

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CHAPTER-5

The Economics of Asian Seabass (*Lates calcarifer*) Production in India: Status, Impact and Future Prospects

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1. Introduction

Fish and fishery products have gained increasing significance as essential food and protein sources, playing a crucial role in providing highly nutritious dietary options for the expanding global population (Naylor et al., 2021). Aquaculture contributes to more than half of the global fish production (182 million tons), underscoring its importance in the context of stagnating captured fish production (FAO, 2022). In India, aquaculture contributes more than 58% to the national fish production of 16.24 million tons (GoI DoF, 2022). In addition to inland water bodies, India is endowed with approximately 1.7 million ha of coastal and 1.2 million ha of potential inland saline area suitable for aquaculture (Geetha et al., 2019). Brackishwater farming is considered one of the potential sources of fish production, food security, economic opportunities, and foreign exchange earnings. Owing to its high commercial value, Asian seabass (*Lates calcarifer*) is one of the most suitable finfish species for diversification of brackishwater aquaculture, which is currently dominated by the monoculture of *Peneaus vannamei*.

The natural geographic distribution of Asian seabass encompasses the tropical Indo-West Pacific region, including the entirety of Southeast Asia, Taiwan extending to Papua New Guinea, and Northern Australia. The global production of Asian seabass is predominantly in Thailand (36%), Malaysia (26%), Taiwan (12%), Saudi Arabia (11%), and India (4%) (FAO, 2022). Asian seabass is regarded as one of the most versatile candidate species for aquaculture in ponds and cages because of its euryhaline nature and adaptability to freshwater, brackish, and marine ecosystems (FAO, 2019). Furthermore, the omnivorous nature of the species facilitates its cultivation using a range of feed sources, from forage fish to formulated diets (FAO, 2020a).

In India, both brackish water and freshwater pond systems are utilized for the production of Asian seabass, either monoculture or integrated with milkfish, tilapia, Indian Major Carps, and other species at commercial scale (CIBA, 2020 and 2022). In commercial seabass farming systems, fingerlings from the nursery are stocked in pre-grow-out ponds, and subsequently, marketable-sized fish are cultivated in ponds and cages for 8 to 16 months (Table 1). Furthermore, cage farming represents an economically viable model, particularly in the backwaters and marine cages of the southern coastal states, owing to the implementation of higher stocking densities, controlled feeding regimens, regular grading, and monitoring protocols (Thirunavukkarasu et al., 2009).

Although India has the potential to emerge as a significant producer of Asian seabass in the region, numerous technical constraints encountered by farmers limit its production. Recent advancements in the year-round production of uniform-sized hatchery fry (Thirunavukkarasu et al., 2015) and specialized formulated feeds for larval, nursery, and grow-out phases (Ambasankar et al., 2009) have resulted in improved survival rates, growth, and feed conversion, thereby enhancing commercial-scale production. These efforts, driven by research organizations and promotional agencies, are anticipated to significantly augment economically sustainable seabass production. In this context, this study provides a comprehensive overview of the current state of Asian seabass aquaculture in India, including its productivity, technical efficiency, challenges, and prospects.

Table 1. General features of different phases in seabass aquaculture

Description	Nursery	Pre-grow-out	Grow-out
Product	Fingerlings	Advanced fingerlings	Marketable size fish
Activity	Fry (1-2 cm) to fingerling (7.5-10 cm)	Fingerlings (7.5-10 cm) to advanced fingerling/juvenile (12-16 cm, 80-100 g)	Advanced fingerling/ juvenile to marketable size fish (>1 kg)
7Duration	60-75 days	60-90 days	8-16 months
Systems	Hapa, tank, small pond	Larger pond, cages	Large pond, cages
Stocking density	40-50/m^2 in pond 500-1000/m^3 in tank/ RAS	Depends on system	Depends on system
Survival	50-75%	70-90%	70-90%

2. Data and Methods

2.1 Data

To gather data on cost and returns, production parameters, and socioeconomic characteristics, a comprehensive survey was conducted across major seabass-producing states in India from April 2022 to March 2023 using a purposive sampling approach. The survey encompassed Tamil Nadu (TN), Andhra

Pradesh (AP), and West Bengal (WB) on the east coast, and Kerala (KL) and Karnataka (KA) on the west coast. Districts with significant seabass aquaculture activity were also purposively selected within these states. To ensure data diversity, the seabass farming systems were stratified into nursery (n = 60), pre-grow-out (n = 20), grow-out pond (n = 287), and cage (n = 329) systems. Data were collected through a well-structured interview schedule with farm owners and practitioners engaged in seabass farming.

2.2 Performance Indicators

The technical viability of the system was assessed using stocked seed performance in nursery, pre-grow-out, and grow-out ponds and cages in terms of stocking biomass (g m^{-2}), daily weight gain (DWG, g), percentage weight gain (PWG, %), specific growth rate (SGR, % d^{-1}), feed conversion ratio (FCR), survival (%), duration of the crop (in months), total production (kg ha^{-1} yr^{-1}), and ABW at harvest (g and kg) (Kumaran et al., 2021). Furthermore, the economic and financial viability of Asian seabass farming was evaluated through various economic and growth indicators (Parappurathu et al., 2023), which helps decision-makers assess whether the benefits of the action outweigh the costs, considering the time value of money, and using a common metric to make informed choices (Tables 2 and 3).

2.3 Technical Efficiency: Empirical Model Estimation

Technical efficiency reflects the ability of a production system to obtain the maximal output from a given set of inputs and technology. This study assessed technical efficiency using a stochastic production frontier function approach. Unlike traditional production functions, this method separates deviations from the production frontier into two components: statistical noise (random shocks and measurement errors), and inefficiency relative to the stochastic production frontier (Kumaran et al., 2022).

$$LnY_i = \beta_0 + \sum_{j=1}^{n} \beta_j Ln(X_{ij}) + (v_i - u_i) \quad \text{.............. (1)}$$

where the subscript i refers to the i^{th} farm in the sample; Ln represents the natural logarithm; Y is output variable and X_j is input and related variable, β indicates unknown parameters to be estimated; $\boldsymbol{v}$ is an independent / identical distributed random error having normal distribution N $(0, \sigma_v^2)$ and independent of the u_i; u_i is a nonnegative random variable. The maximum likelihood estimation (MLE) of Eq. (1) provides the estimates of β_s and the variable parameters $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\Upsilon = \sigma_u^2 / \sigma^2$.

$$U = \delta_0 + \sum_{j=1}^{n} \delta_j Z_{ij} + W_i \quad \text{............... (2)}$$

where Z's are various operational and farm-specific variables; δ's unknown parameters to be estimated; and W_i's are random variables defined by the truncation of the normal distribution with mean 0 and variance σ_u^2. The technical efficiency score for the i[th] farm in the sample (TE_i), can be defined as

$$TE_i = \exp(-u_i) \quad \text{............ (3)}$$

TE_i scores ranged from 0 to 1. A firm with a score of 1 indicates that it lies on the production frontier and utilizes inputs both technically and efficiently. Lower scores indicate greater inefficiency. The analysis was performed using R Studio version 4.2.3.

Table 2. Performance indices of Asian seabass production

Economic Indicators	
Net operating ratio	$\frac{\text{Operating costs}}{\text{Gross income}} * 100$
Return on Investment (ROI)	$\frac{\text{Gross income} - \text{total cost}}{\text{Total Cost}} * 100$
Benefit Cost Ratio (BCR)	$\frac{\sum_{t-1}^{n} \text{Present value of future benefits}}{\sum_{t=1}^{n} \text{Present value of future costs}}$
Net Present Value (NPV)	$\sum_{t=1}^{n} \left(\frac{CF_t}{(1+r)^t}\right)$ - Initial investment CF_t represents the cash flow at time t r is the internal rate of return t is the time period
Internal Rate of Return (IRR)	$\sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} = 0$
Break-even point	$\frac{\text{Total fixed cost}}{(\text{Sales price per unit} - \text{Variable cost per unit})}$
Break-even price	$\frac{\text{Total fixed cost}}{\text{Total Production}} + \text{Variable cost per unit}$
Growth Indicators	
Daily Weight Gain (DWG)	$\frac{(\text{Mean final weight} - \text{Mean initial weight})}{\text{Duration in days}}$
Weight Gain (PWG)	$\frac{(\text{Mean final weight} - \text{Mean initial weight})}{\text{Mean initial weight}} * 100$
Specific Growth Rate (SGR)	$\frac{(\ln(\text{final weight}) - \ln(\text{initial weight}))}{\text{rearing duration in days}} * 100$

Table 3. Description of performance indices

Indicators	Description
Economic indicators	
Operating Cost Ratio	• The net operating ratio is the proportion of the gross income covering operating expenses • A firm with an OCR below 1 is profitable on an operating basis, while an OCR higher than 1 indicates an operating loss.
Return on Investment (ROI)	• ROI compares how much you paid for an investment to how much you earned to evaluate its efficiency.
Benefit Cost Ratio (BCR)	• The BCR compares the present value of future benefits generated from the farm to the present value of future costs. A BCR greater than 1 signifies that the farm's expected future benefits exceed its costs, indicating it is economically viable.
Net Present Value (NPV)	• The NPV is the main criterion for assessing the suitability of any investment program and according to this financial indicator, the greater is its value, the higher will be the convenience of the investment.
Internal Rate of Return (IRR)	• The IRR is the discount rate at which the discounted benefits are equal to the discounted costs, determining a net present value equal to zero. • It is the annual growth rate that a farm is expected to generate. It is used to understand the profitability and earnings of the farm
Break-even point	• The break-even point is the amount of production volume a farm needs to reach a state where total revenue equals total costs. After reaching the break-even point, revenues above the fixed and variable costs will become profit.
Break-even price	• The break-even price refers to the unit price a product must sell at for total revenue to equal total costs. At the break-even price, no loss or gain is made per unit sold.
Growth Indicators	
Daily Weight Gain (DWG)	• It refers to the average daily increase in body weight of fish over a specific time period. Higher daily gains equate to better feeding efficiency and faster growth to market size.
Weight Gain (PWG)	• It provides a standardized comparison of growth between different culture environments and management methods, independent of differences in initial body size. Higher percent gains over a defined period equate to faster rates of growth.
Specific Growth Rate (SGR)	• It is a measure used to quantify the percentage increase in body weight of cultured fish per day. It allows standardized comparisons of growth performance between groups under different experimental or production conditions over time.

2.4 Time Series Forecasting

To forecast Indian Asian seabass production, different time series models such as naive forecast, simple exponential smoothing, Holt's trend method, and autoregressive integrated moving average (ARIMA) were evaluated using model evaluation metrics, such as the Akaike Information Criterion (AIC), Corrected Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), Mean Percentage Error (MPE), Mean Absolute Percentage Error (MAPE), and Mean Absolute Scaled Error (MASE) (Stergiou, 1991). The ARIMA model (1,1,0) was selected to forecast seabass production. Residual diagnostics such as the Box L-Jung test for serial correlation, one-sample Kolmogorov-Smirnov test, and the Anderson – darling test for normality were conducted.

2.5 Constraint Analysis:

The constraints perceived by respondents in seabass farming were prioritized using the Garrett ranking technique. The orders of merit assigned by respondents were converted into ranks using the following formula:

$$\text{Percent position} = \frac{100(R_{ij} - 0.5)}{N_j}$$

where R_{ij} is the rank given for the i^{th} item by the j^{th} individual and N_j is the number of items ranked by the j^{th} individual. The scores were averaged across respondents to determine the final ranks. This method allowed the quantified prioritization of key technical, economic, and social constraints impacting the sustainability of seabass farming practices. (Garrett and Woodworth, 1969)

2.6. SWOT Analysis

An assessment of strengths, weaknesses, opportunities, and threats (SWOT) was conducted to understand the internal and external factors affecting the sustainability of Asian seabass aquaculture. The analysis was conducted based on primary data collected through key informants and focus group discussions with seabass farmers, experts from the ICAR-CIBA and state fisheries departments, hatchery operators, seed suppliers, feed manufacturers, and other aquaculture value chain participants across the study area.

3. Results and Discussion

3.1. Socio-Economic Dimensions of Seabass Farming

Demographic information, regional differences, and gaps in production systems facilitate the development of appropriate interventions to promote seabass farming. Farmers engaged in nursery rearing were predominantly middle-aged (40%) and educated individuals. The majority (58%) had limited experience (<5 years) and more than half of the family members were reported to be involved in farming activities. Similarly, pre-grow-out culture was predominantly practiced by middle-aged (50%) and highly experienced (65%) farmers. Sustainability of nursery (7.5 years) and pre-grow-out (10 years) activities were observed through permanence in these practices. Most farmers involved in nursery and pre-grow-out operations had undergone formal training and pursued it as a primary occupation, relying predominantly on self-financing (Table 4).

Pond culture of Asian seabass is predominantly practiced in Andhra Pradesh and West Bengal. Farmers from these states possessed higher educational qualifications and experience, demonstrated better capital self-sufficiency, exhibited greater reliance on family labor, and participated more frequently in formal training. Notably, the permanence of activity was higher in these regions. More than half (52%) of the farmers in Andhra Pradesh were engaged in seabass culture as their primary occupation (Table 4).

Similarly, the grow-out cage culture of Asian seabass is predominantly practiced in Tamil Nadu, Kerala, and Karnataka. Farmers in these states reported higher secondary education, high capital self-sufficiency, approximately half of the family labor involvement, and up to 60% had formal training. Nearly half of them considered seabass farming to be their primary activity. In a recent study, the reported self-sufficiency was consistent with that in the present study for the state of Kerala, whereas it was comparatively lower in other cages (Parappurathu et al., 2023). However, approximately half of the farmers in Tamil Nadu and Kerala have extensive experience (> 10 years). The longest duration of activity was observed among Karnataka farmers (eight years) compared to their counterparts in Kerala (seven years) and Tamil Nadu (three years) (Table 4). In a similar study, a longer duration of activity was reported in seabass cage farming in Kerala and Karnataka (five years) and Tamil Nadu (1.7 years) (Parappurathu et al., 2023).

Table 4. Socio-economic dimensions of seabass farming under various production systems

Parameters		Nursery	Pre-grow-out	Grow-out				
				Pond culture		Cage culture		
				Andhra Pradesh	West Bengal	Tamil Nadu	Kerala	Karnataka
Age (%)	Young (upto 30 years)	35.00	25.00	11.00	10.00	11.00	10.00	7.98
	Middle-aged (31-45 years)	40.00	50.00	54.00	39.00	39.00	50.00	57.75
	Old-aged (>45 years)	25.00	25.00	35.00	51.00	50.00	40.00	34.27

Parameters		Nursery	Pre-grow-out	Grow-out				
				Pond culture		Cage culture		
				Andhra Pradesh	West Bengal	Tamil Nadu	Kerala	Karnataka
Education (%)	Primary schooling (<5)	25.00	25.00	25.00	23.00	0.00	0.00	38.97
	Secondary schooling (6-12)	35.00	45.00	71.00	72.00	64.00	73.00	56.34
	University	40.00	30.00	4.00	5.00	36.00	27.00	4.69
Secondary occupation (%)		98.33	100.00	48.36	70.10	57.81	55.61	48.35
Permanence in activity (PA)*		7.58 (4.47)	9.9 (3.68)	14.70 (6.30)	16.84 (10.66)	2.97 (0.83)	6.86 (3.97)	8.14 (3.84)
Experience (%)	Low (<5 years)	58.33	20.00	41.75	20.65	17.19	19.23	31.92
	Medium (5 - 10 years)	11.67	15.00	47.57	13.59	28.13	38.46	33.33
	High (> 10 years)	30.00	65.00	10.68	65.76	54.69	42.31	34.74
Capital self-sufficiency (CS) (%)		81.67	65.00	68.75	78.25	69.55	74.32	61.50
Family labor share (FL) (%)		54.92	44.23	51.00	53.43	41.20	44.05	46.51
Formal training (FT) (%)		45.00	40.00	68.00	63.00	59.00	64.00	55.39

Note: Figures in parentheses indicate standard deviations.

3.2. Economics of Different Fish Farming Systems

Economic analysis of different culture systems provides insights into the viability and profitability of seabass farming. The cost and returns of the nursery, pre-grow-out, and grow-out (pond and cage) farm operations are expressed in Rupees per hectare per year (Rs $ha^{-1}yr^{-1}$), while cage culture in Rupees per cubic meter per year (Rs m^{-3} yr^{-1}). To estimate the fixed costs, depreciation of machinery and interest in capital investment were calculated at 10% and 12%, respectively (Table 5).

3.2.1. Nursery

Seabass nurseries in India are predominantly situated in Krishna district of Andhra Pradesh. These nurseries obtained seeds from both hatcheries and wild collections from adjacent bays and backwaters in Andhra Pradesh (Machilipattinam, Krishna district) and West Bengal (North and South 24 Parganas). Three rearing cycles are typically conducted annually (May-July, September-November, and December-March), primarily using naturally available zooplankton from brackish water creeks as feed. Economic analysis of the fish nurseries revealed substantial profitability (Table 5). Notwithstanding the initial investment and annual operational costs, the nurseries demonstrated robust return on investment, underscoring the viability of fish farming as an appropriate agricultural enterprise, particularly in regions with suitable water resources.

3.2.2. Pre-grow-out

The pre-grow-out farms were located at an average distance of 1.64 km from the farmer's home, with 0.88 acres of a spread area and an average pond size of 0.56 ha. These farms are engaged in fish production throughout the year. Seeds were procured from a considerable distance, weighing 4.6 grams each, and were purchased at ₹19.75 per seed. Forage fish priced at ₹ 27 per kilogram was the primary feed. Harvested fish, weighing an average of 108.6 grams, were sold for ₹ 111.45 per fish. The analysis of pre-grow-out farms demonstrates a profitable venture in the aquaculture industry, achieving a substantial net profit. The high survival rate and multiple (3) crop cycles have contributed to this profitability. However, careful management and risk mitigation strategies are crucial for ensuring long-term sustainability and success in pre-grow-out aquaculture

3.2.3. Grow-out pond system

To understand the economic viability of grow-out pond cultures, this study focused on the major seabass production states in Andhra Pradesh and West Bengal. In Andhra Pradesh, seabass farms were located an average of 5.54 km from farmers' homes, with an average farm area of 2.96 ha and a water spread area of 2.37 ha. Each pond averaged 2.26 acres, and fish were reared throughout the year. The average capital investment in seabass aquaculture in the state was substantial, with major expenditures on leases, farmhouses, machinery, and equipment. Fixed annual costs are largely driven by lease payments and pond construction, whereas operational costs are dominated by feed, accounting for 51.1% of the total cost at ₹ 25 kg-1. Most grow-out farmers use low-value fish such as tilapia, sardines, and minor carps as feed for seabass. This finding is similar to that reported by Young et al. (2020). Labor costs, at ₹14,270 per man-month, accounted for 21.66 man-months per hectare, representing 8.73% of the total cost. Similar to studies in Sri Lanka (Gammanpila and Singappuli, 2014) and Vietnam (Nhan et al., 2022), operational costs (88.20%) dominated the total cost (Fig. 1a). Despite these high costs, the sector remains economically viable, as evidenced by its high profitability (Fig. 1c). Profitability is further supported by the use of affordable feed sources and efficient management of labor costs.

Similarly, seabass farms in West Bengal are typically situated 1.94 km from homes, covering an average of 0.99 hectares with 0.78 hectares of water spread area. Farms contained an average of 2.65 ponds, each measuring approximately 0.42 hectares, and were farmed throughout the year. The average capital investment for seabass culture ponds was ₹59 thousand per ha per year, with significant fixed costs for lease and pond construction. Fingerlings (80.15 g) were procured from wild collection points located 40.33 km away for ₹13.38 per seed. The average stocking biomass was 11.89 g m^{-2}, primarily relying on natural feed. Given the large confined water bodies and abundant live fish availability in West Bengal (Ghosh, 2019), as well as the practice of bait fish feeding (Ghosh et al., 2022), farmers in this region predominantly depend on natural feeding. Farm labor represented the highest operational cost at 46.86% 9 (Fig. 1a), with farms utilizing approximately 24 man-months at an average monthly wage rate of ₹14, 220. Despite these expenses, farms achieve a solid production yield and generate substantial gross and net incomes, demonstrating the economic viability of seabass farming in this region (Fig. 1c).

Seabass aquaculture practices and production performance differed between Andhra Pradesh and West Bengal. Culture operations in Andhra Pradesh demonstrated intensive systems with high input costs, but higher productivity and profitability. Farm production was three times higher in Andhra Pradesh than in West Bengal, which could be attributed to multiple factors, such as stocking of uniform-sized hatchery seeds, higher stocking biomass, greater survival rates, longer crop duration (484 days), and relatively higher daily weight gain (8.01 g), PWG (3259.59 %), ABW at harvest (3.99 kg), and proximity to all three phases. In addition, the superior production outcomes in the Andhra Pradesh ponds were enabled by substantially higher capital investment and operating expenditures. The cost of production in Andhra Pradesh was over 3.5 times that in West Bengal. However, the intensive use of inputs translated into far higher gross income. Overall, the intensive and advanced farming techniques employed in Andhra Pradesh showed significantly higher productivity and profitability, albeit requiring greater capital investments and higher operating expenses. The introduction of commercially available formulated feeding practices and stocking hatchery-produced weaned fry along with training and technical assistance to West Bengal farmers could help in realizing higher production capacities.

3.2.4. Grow-out cage system

Since most cages are situated in Kerala, followed by Karnataka and Tamil Nadu, we studied the economic viability of grow-out cage cultures in these states. Farmers typically own single cage and culture seabass throughout the year in Tamil Nadu, utilizing circular floating cages with an average volume of 113.04 m^3. Acquiring seabass seeds is a constraint because stackable-sized fingerlings/juveniles were sourced at an average distance of 475 km. The average stocking biomass was 438.78 g m^{-3} (51.68 g nos^{-1}), costing approximately ₹40 per seed. The feed was the largest operational cost component, comprising 57.25% of the total (@ ₹32 kg^{-1} of low-value fish), which was in accordance with previous findings in seabass cage farming in the Black Sea in Turkey (Bozoglu and Ceyhan, 2009). Labor costs made for 22.61% of the total cost. Farms utilized 12 man-months of labor per cage, with workers earning an average monthly wage of ₹14,683. Operational costs accounted for 88.73% of the total annual production costs (Fig. 1b). Cages yielded an average of 20 kg m^{-3} (84.89% survival rate), which is comparable to the previously reported 22 kg m^{-3} (Bozoglu and Ceyhan, 2009). Despite operational costs, the net profit indicates the economic viability of cage aquaculture (Table 5, Fig. 1d). These results highlight the potential of cage farming as a sustainable and profitable method of fish production.

Seabass cage farms in Kerala are typically located 2.25 km from the farmers' homes. Each farm operated an average of seven cages, with an individual cage volume of 48 m^3. The annual capital investment averaged ₹4,889 m^{-3} $year^{-1}$, covering cage frames, farmhouses, and equipment costs. Procurement of seeds poses a challenge, as stackable fingerlings/juveniles are sourced at an average distance of 1,072 km. Stocking density averages one Kg m^{-3} (52.55 g nos-1), with each fingerling costing ₹ 40. Procurement of seeds poses a challenge, as stockable-size fingerlings/juveniles are sourced at an average distance of 1,072 km. Despite significant operational costs, particularly feed and labor, farms demonstrate a positive return on investment. The average annual yield of 27 kg m^{-3} coupled with a survival rate of 75.80% indicates the efficiency of the cage culture system. The sale of harvested fish for ₹ 500 kg^{-1} generates substantial gross income, leading to a net profit of ₹ 3,966 m^{-3} (Table 5, Fig. 1d). Although feed constitutes the largest expense, optimizing feeding strategies and exploring alternative feed sources could help reduce costs. Additionally, improving labor efficiency and exploring cost-effective labor practices could further enhance profitability.

The cage farms in Karnataka were typically situated 2.18 km from farmers' homes. Farms operate an average of 1.2 cages per farm with an individual cage volume of 90.72 m^3. The average annual capital investment is ₹ 1,246 m^{-3} $year^{-1,}$ which includes the costs of the cage, farmhouse, and equipment. The resulting fixed operational costs of ₹ 275 m^{-1} $year^{-1}$ were due to depreciation and interest payments. As most hatcheries are in Andhra Pradesh, acquiring seeds was the major constraint adding to the cost of the seed. The stocking biomass averaged 960 g m^{-3} (37.79 g nos^{-1}) costing ₹ 35 per seed representing 25.66% of operational expenses. While feed remains the major cost in seabass farming (Fig. 1b), accounting for over half of the total costs, the operation remains profitable, achieving notable gross income and net profit (Parappurathu et al., 2023) (Table 5, Fig. 1d).

Seabass cage farming has demonstrated commercial viability. In Kerala, the scale is smaller but with higher production levels and good survival rates of 75.8% from a moderate stocking density. This translates into an annual profit of approximately Rs 4,000 m^{-3}, partly aided by the slightly lower feed costs. In comparison, Tamil Nadu farmers run larger floating cages and achieve higher absolute yields. In a controlled experimental study on three-tier cage farming, Kumaran et al. (2021) reported an average productivity of 13.5-15.0 kg m^{-3}. However, larger cages and greater stocking incur higher operational expenses, especially for feed and labor, squeezing annual net profit to around Rs 2,000 m^{-3}. Karnataka represents smaller-scale farming with low fry density and modest productivity with a survival rate of 23%. The fixed costs are low, with annual profits of approximately Rs 2,500 m^{-3}. Across states, feed efficiency, seed availability, and survival impact outcomes, Kerala currently demonstrates superior production performance and economics from its cage models. In a site-specific study, a similar cost of feed was observed in all three stages, whereas the cost of seed was higher (Kumaran et al., 2021).

Across all farming models, feed and seeds were the major recurring costs. However, location-specific factors such as productivity, input costs, and market prices contribute to differences in profitability variations between states. Optimizing feed, improving survival and growth, and adopting an appropriate farm size could positively impact returns. Overall, the results validate seabass aquaculture as a profitable livelihood avenue under optimal management.

Table 5. Cost and returns of seabass farming in India

Parameters	Nursery (Rs ha-1 yr-1)	Pre-grow-out (Rs ha-1 yr-1)	Grow-out				
			Pond culture (Rs ha-1 yr-1)		Cage culture (Rs m-3 yr-1)		
			Andhra Pradesh	West Bengal	Tamil Nadu	Kerala	Karnataka
A. Fixed cost							
Capital investment	2,53,464	1,46,244	9,70,821	59,503	3,994	4,889	1,246
Lease	96,818	85,930	1,90,595	59,503	-	-	-
Pond construction	44,250	33,313	36,595	71,551	-	-	-
Depreciation @ 10%	5,200	2,700	74,363	55,684	399	489	124
Interest on capital cost @12 %	30,416	5,197	1,16,498	82,548	479	587	149
Total fixed cost/crop	1,76,683	1,27,141	4,18,052	2,69,285	878	1,076	275
B. Operational Cost							
Seed	3,12,776	4,80,156	4,30,642	28,973	339	764	744
Feed	0	3,07,370	15,96,613	0	4,003	4,778	1,586
Labor	99,310	1,42,496	3,09,180	3,41,843	1,563	935	152

Parameters	Nursery (Rs ha-1 yr-1)	Pre-grow-out (Rs ha-1 yr-1)	Grow-out				
			Pond culture (Rs ha-1 yr-1)		Cage culture (Rs m-3 yr-1)		
			Andhra Pradesh	West Bengal	Tamil Nadu	Kerala	Karnataka
Pond operation cost	79,729	91,026	85,875	1,53,073	-	-	-
Miscellaneous expenses	81,187	58,697	3,67,565	1,27,489	314	1,084	102
Interest on working capital @ 12%	68,761	1,29,569	3,34,785	78,165	740	907	315
Total operational cost	6,41,764	12,09,315	31,24,659	7,29,542	6,914	8,468	2,899
Total cost (A+B)	8,18,447	13,36,456	35,42,711	9,98,827	7,792	9,543	3,173
Production (kg)	2,566	2,111	13,677	4,263	20	27	14.13
Gross Income	12,61,167	21,67,606	60,22,599	18,73,730	9,980	13,510	5,652
Net income	4,42,719	8,31,151	24,44,498	8,98,605	2,187	3,966	2,479

Fig. 1a. Economics of seabass production in grow-out pond culture

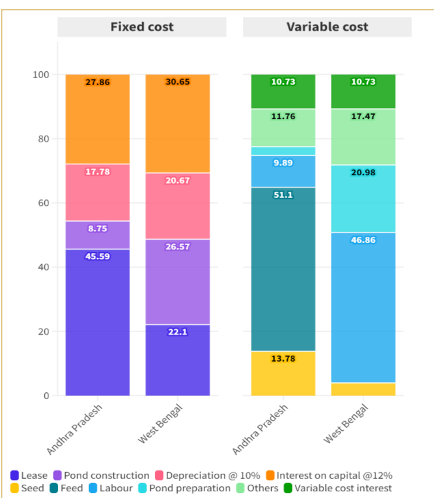


Fig. 1b. Economics of seabass production in grow-out cage culture

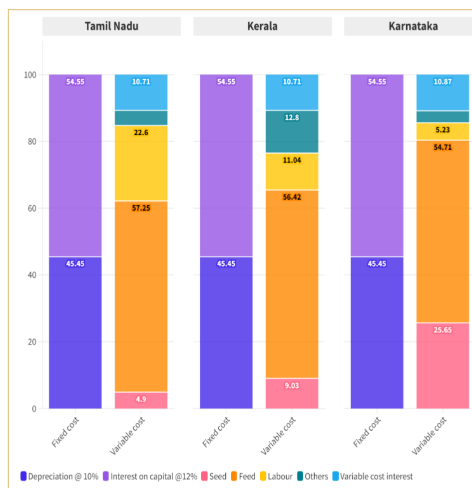


Fig. 1c. Cost and returns of seabass culture in grow-out pond culture

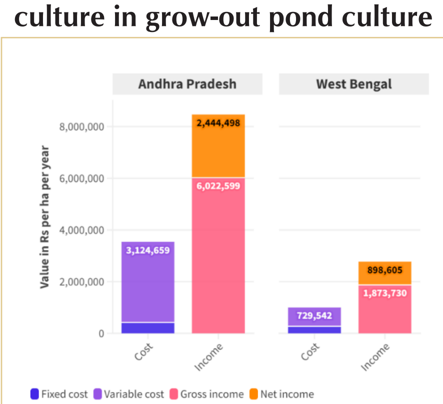
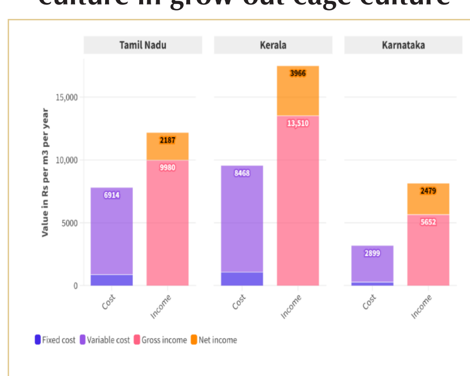


Fig. 1d. Cost and returns of seabass culture in grow-out cage culture



3.1.5. Performance indicators of seabass production

Among the farming systems studied, nurseries had the highest operating cost ratio (78.41%), followed by cage culture (50-70%), pre-growth out, and pond culture. Conversely, pond culture exhibited the highest return on investment (ROI) at 70-88%, followed by pre-grow-out and cage culture. The observed operating cost ratio in the present study was similar to the previously reported ratio of 57-58% in Kerala cage culture (Aswathy and Imelda, 2018). However, grow-out cages in Karnataka demonstrated a significant improvement in ROI (78.14%) compared with the previously reported 31.79% (Ail and Bhatta, 2016). The lower operating cost ratio in pond culture in West Bengal, resulting in a higher ROI, may be attributed to traditional farming practices, stocking wild seeds requiring less input, and lower management costs. In contrast, the higher operating costs in AP farms due to the intensive stocking of nursery-reared fingerlings resulted in a comparatively lower ROI. A similar study in Vietnam by Nhan reported that increased stocking density led to higher total revenues and production costs, but decreased capital efficiency. Nursery farmers achieved break-even at a biomass of 731 kg ha^{-1} (28.80% of the reported production) and a price of ₹ 319 Kg^{-1}, while pre-grow-out systems reached break-even at a biomass of 288.11 Kg ha^{-1} (13.64%) and a price of ₹ 633 Kg^{-1}. In grow-out pond culture, Andhra Pradesh farms reached break-even earlier at 1,545 kg ha^{-1} (11.29% yield) than West Bengal at 1,416 kg ha^{-1} (33.22% yield). Similarly, in cage culture, Karnataka farms achieved break-even earlier at 2.01 Kg m^{-3} (14.22% yield) as compared to Tamil Nadu and Kerala farms (Table 6).

The average crop duration for the seabass nurseries was 2.3 months, stocked at a density of 5.19 g m^{-2} and recorded a production of 61,073 nos ha^{-1} yr^{-1}. Similarly, pre-grow-out farms stocked at 50.38 g m^{-2} achieved a calculated daily weight gain of 1.20 g, and produced 2110.92 Kg ha^{-1} yr^{-1}. With higher stocking biomass (62.73 g m^{-2}), survival rates (87.20%), crop duration (16.14 months), higher daily weight gain (8.01 g), PWG (3259.59 %) and ABW at harvest (3.99 kg), grow-out farmers in Andhra Pradesh produced 13.67 t ha^{-1} yr^{-1} as compared to West Bengal, which reported productivity of 4.26 t ha^{-1} yr^{-1} with 71.57% survival rate. The average biomass harvested in the cages of Tamil Nadu was 19.91 Kg m^{-3} yr^{-1} (ABW at harvest, 2.76 kg) with 84.89% survival rate, FCR of 6.33, daily weight gain (7.51 g), PWG (5247.64%), and SGR (1.11), whereas Kerala with higher stocking biomass (988 g/m^2) achieved a higher productivity of 27.04 Kg m^{-3} yr^{-1}. In a previous study, Kumaran et al. *(2021)* also reported a similar daily weight gain in pre-grow-out (1.21 g d^{-1}) and grow-out cage (4.33 g d^{-1}) cultures. However, in Karnataka, the performance of key technical indicators was low compared to Kerala and Tamil Nadu, although they stocked high biomass, resulting in lower productivity among cages (Table 6).

Table 6. Performance indicators of seabass farming in India

Indicators	Nursery	Pre-grow-out	Grow-out				
			Pond culture		Cage culture		
			Andhra Pradesh	West Bengal	Tamil Nadu	Kerala	Karnataka
Technical indicators							
Stocking biomass (g m-2)	5.19 (0.47)	50.38 (2.85)	62.73 (5.74)	11.89 (1.79)	438.78 (74.49)#	988.04 (198.76)#	963.56 (271.46) #
FCR	-##	5.43 (0.38)	5.80 (0.37)	-##	6.33 (0.32)	6.28 (0.44)	5.39 (0.54)
Survival (%)	81.35 (2.43) 78.00-85.00	84.55 (2.58) 80.00-88.00	87.20 (4.48) 80.00-95.00	71.57 (9.64) 53.00-90.00	84.89 (3.13) 80.00-89.00	75.80 (4.59) 68.00-86.25	72.76 (4.48) 70.00-80.00
Duration (Month)	2.32 (0.20)	2.97 (0.06)	16.14 (1.49)	8.23 (0.46)	12.03 (1.18)	12.23 (1.02)	12.02 (0.04)
ABW at harvest (g)	41.56 (2.11)	108.62 (5.89)	3.99 (0.56)**	1.89 (0.39)**	2.76 (0.23)**	1.87 (0.51)**	1.17 (0.12)**
Production (Kg ha-1 yr-1)	2537.61 (173.13)	2110.92 (112.80)	13676.78 (2198.25)	4262.58 (666.36)	19.91 (2.48)*	27.04 (7.78)*	14.06 (1.46)*
DWG (g)	0.53	1.20	8.01	7.36	7.51	4.97	3.09
PWG (%)	842.53	6687.50	3259.59	2268.825	5247.642	3474.82	2985.927
SGR (% d-1)	3.08 (0.29)	4.80 (0.81)	0.73 (0.07)	1.28 (0.13)	1.11 (0.11)	0.97 (0.09)	0.90 (0.01)
Economic and Financial indicators							
Operating cost ratio %	78.41	55.79	51.88	38.93	69.28	62.68	51.28
Return on Investment %	54.09	62.19	69.99	87.59	28.06	41.55	78.14
Break-even point (Kg)	731.13	288.11	1,545.21	1,416.26	5.70	5.76	2.01
Break-even price (Rs kg-1)	319.15	633.11	200.36	312.61	391.39	352.82	220
BC ratio	1.54	1.62	1.69	1.87	1.28	1.41	1.78
Net Present Value (Rs)	19,58,525	24,56,716	76,13,381	31,02,185	5,986	13,215	2,263
Internal rate of return (%)	51.00	59.86	67.00	89.00	51.81	80.00	81.00

*Note: '**' at 1%; '*' at 5%; # - indicates stocking biomass per m3; ##- indicates live feed; *- indicates production in Kg m-3 yr-1; **- indicates weight per unit in kg. The figures in parentheses indicate the standard deviations.*

A higher IRR, positive NPV, and BCR (>1) were observed for different seabass production systems, which is in line with earlier findings (Ravisankar et al., 2010; Aswathy and Imelda, 2018; Kumaran et al., 2021). The observed higher BCR, NPV, and IRR demonstrate that the pre-grow-out system is financially more viable and profitable than the nursery system. In pond culture, while

West Bengal had higher BCR and IRR, AP farms recorded a higher NPV of Rs 7600 thousand ha^{-1} yr^{-1}. In cage culture, Karnataka farms exhibited higher BCR and IRR than Tamil Nadu, and Kerala and also demonstrated higher NPV and IRR. Overall, pond production models generated better return and profitability metrics than cage models. Among pond production models, WB showed better efficiency in terms of BC ratio, ROI, and operating costs, whereas AP performed best in metrics such as break-even point and NPV. Among the cage models, Karnataka and Kerala performed economically better across most metrics. To compare productivity per unit area (ha), the costs and returns for both pond and cage farming were analyzed. For the calculations, 50 cages of 100 m^{-3} were assumed. The analysis found that cage culture grow-out recorded higher total cost, but also resulted in a higher income and net income per hectare. However, pond culture had a higher profit per ton of production (Table 7)

The production economics of major Asian seabass aquaculture systems provides important insights. Nursery and pre-grow-out ponds perform better financially, with superior profitability metrics, benefiting from lower costs and higher biomass yields. Among grow-out cultures, ponds in Andhra Pradesh demonstrate higher operating costs and lower ROI, whereas West Bengal ponds can achieve higher BCR and return on investment. Cage culture exhibits variability across states, although Karnataka farms can reach break-even more quickly. Additionally, the study highlights diversified cost structures, break-even points, and profitability profiles across multiple farming systems. These dynamics could help farmers to select appropriate models and inform targeted strategies to improve their financial and economic viability. Overall, this analysis provides robust economic insights to support upgraded Asian seabass aquaculture practices and commercial progress. Further investigation of innovative technologies and integrated culture systems may offer additional opportunities for improved production performance and profitability.

Table 7. Comparison of output between pond and cage culture of seabass

Particulars	**Pond**	**Cage (50) (Hypothetical)**	**Pond**	**Cage**
	(Rs thousands ha-1 yr-1)		**(Rs thousands t-1 yr-1)**	
Seed	431	1695	31	19
Feed	1597	20015	117	222
Labor	309	7815	23	87
Others	789	5045	58	56
Total variable cost	3125	34570	228	384
Total fixed cost	418	4390	31	49
Total cost	3543	38960	259	433

Particulars	Pond	Cage (50) (Hypothetical)	Pond	Cage
	(Rs thousands ha-1 yr-1)		(Rs thousands t-1 yr-1)	
Production (t)	1368	9000	-	-
Gross Income	6023	45000	440	500
Net income	2444	6040	179	67

3.2.6 Technical efficiency using stochastic frontier production function

To assess the efficiency of the farms in grow-out production systems, we employed a stochastic frontier production function. The analysis revealed a positive and significant ($P<0.001$) influence of several variables on pond production, including survival rate (0.84), crop duration (0.79), stocking density (0.67), and initial weight (0.76). Improving these variables leads to increased technical efficiency (Table 8a). Similarly, in grow-out cages, survival rate (0.77), crop duration (0.47), stocking density (0.75), and stocking weight (0.72) had a significant ($P<0.001$) positive effect on technical efficiency (Table 8b). Previous studies by Pushpalatha et al. (2021) and Kumaran et al. (2022) have also reported the influence of stocking density and survival on production. Additionally, experience and education positively impacted efficiency in pond and cage culture systems, respectively.

Table 8a. Maximum likelihood estimates of stochastic frontier production function in pond system.

Parameters	Estimate	Std. Error	z value	Pr(>|z|)
Technical Efficiency				
Intercept	-5.193	1.201	-4.324	0.000***
Survival (%)	0.844	0.217	3.893	0.000***
Duration of crop (in months)	0.794	0.068	11.698	0.000***
Feed (Kgs)	-0.037	0.070	-0.527	0.598
Stocking density (Nos m^{-3})	0.670	0.133	5.053	0.000***
Stocking weight (g)	0.761	0.067	11.409	0.000***
ABW at harvest (Kg)	0.077	0.070	1.099	0.272
Inefficiency				
Intercept	-1.610	0.839	-1.918	0.055#
Experience	-0.085	0.040	-2.122	0.034*
Education	0.160	0.072	2.243	0.025*
Age	0.380	0.208	1.823	0.068#
Household size	-0.014	0.074	-0.183	0.855
Sigma Sq	0.091	0.014	6.650	0.000***
Gamma	1.000	0.001	761.725	0.000***
Log-likelihood ratio: 142.605				

*Note: '***' denotes significance at 0.1%; '**' at 1%; '*' at 5%; '#' at 10%.*

Table 8b. Maximum likelihood estimates of stochastic frontier production function in the cage system.

Parameters	Estimate	Std. Error	z value	Pr(>|z|)
Technical Efficiency				
Intercept	-4.895	0.988	-4.957	0.000***
Survival (%)	0.770	0.199	3.871	0.000***
Duration of crop (in months)	0.467	0.086	5.431	0.000***
Feed (Kgs)	0.039	0.052	0.741	0.459
Stocking density (Nos m^{-3})	0.747	0.057	13.197	0.000***
Stocking weight (g)	0.718	0.078	9.163	0.000***
ABW at harvest (Kg)	0.065	0.034	1.876	0.061#
Inefficiency				
Intercept	-0.357	0.980	-0.364	0.716
Experience	0.020	0.804	0.025	0.980
Education	-0.433	0.238	-1.819	0.069#
Age	0.309	0.592	0.523	0.601
Household size	-0.146	0.173	-0.846	0.397
Sigma Sq	0.179	0.022	8.078	0.000***
Gamma	0.999	0.001	713.547	0.000***
Log-likelihood ratio: 38.1712				

*Note: '***' denotes significance at 0.1%; '**' at 1%; '*' at 5%; '#' at 10%*

The grow-out cage and pond cultures exhibited higher mean technical efficiencies (82.08% and 80.93%, respectively), with a larger proportion of farms falling into the very high technical efficiency category (Fig. 2), suggesting expertise among farmers in these systems. However, a significant portion (38%) of pond culture farms operate at medium efficiency and require continued training and technical assistance to optimize production (Fig. 2). In conclusion, key variables such as survival rate, crop duration, stocking density, stocking weight, and socioeconomic factors such as higher education and experience drive higher technical efficiency. Table 9 outlines the factors influencing sustainable aquaculture practices.

Fig. 2. Proportion of farms under various technical efficiency categories per m^3 per year

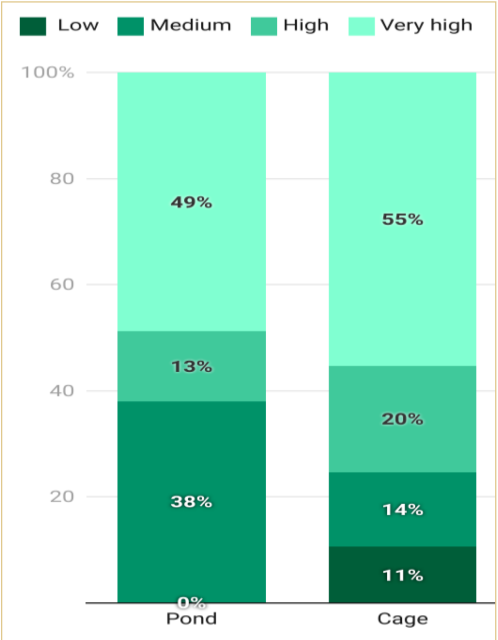


Table 9. Factors influencing sustainable practices in seabass culture

Parameters		Nursery	Pre-grow-out	Grow-out				
				Pond culture		Cage culture		
				Andhra Pradesh	West Bengal	Tamil Nadu	Kerala	Karnataka
Adoption of scientific farming practices (%)	Non-adoption	32.44	15.00	10.05	19.21	9.76	8.75	12.57
	Less than 5 years	27.46	26.45	39.25	48.29	21.34	20.30	26.25
	5-10 years	15.45	10.70	42.45	14.25	22.45	28.46	33.33
	>10 years	24.65	47.85	8.25	18.25	46.45	42.49	27.85
Extension services (%)		84.55	78.95	88.75	73.25	76.35	81.00	83.25
Interaction with Research Institutes (%)		68.75	74.55	82.45	45.55	72.00	76.45	72.45
Farming continuity (%)		95.00	98.45	100.00	89.00	100.0	97.00	95.67

3.2.7 Estimation of seabass production

Based on the primary data collected in this study, the annual production of seabass fry in India was estimated to be 4.98 million, including 1.98 million from six seabass hatcheries. Considering an average body weight at harvest of 2.43 Kg and a survival rate of 78.59%, the total production of Asian seabass in 2022 is estimated to be 7,544 tons. However, the FAO aquaculture report for 2022 listed India's seabass production at 5,700 tons, while MPEDA reported 4,754 tons (MPEDA, 2022). Using national seabass production data from 2010 to 2022 (FAO Fish Database), we forecast future seabass production in India using the ARIMA (1,1,0) model. Residual diagnostics, including the Box-Ljung test, one-sample Kolmogorov-Smirnov test, and the Anderson-Darling test, confirmed a better fit of the model (Table 10). The model predicts that seabass production will reach 11,317 tons in 2025 (Table 11, Fig. 3).

Table 10. Results of residual diagnostics for ARIMA (1,1,0)

Test	Statistic	P-value
Box L-jung	13.773	0.1836
Shapiro-Wilk	0.8388	0.0457
Kolmogorov- smirnov	0.2309	0.4918
Anderson- Darling	0.9401	0.1186

Table 11. Forecast of Seabass production using Auto-Regressive Integrated Moving Average (ARIMA)

Year	Point Forecast	80% CI		95% CI	
		Low	High	Low	High
2023	9,056.84	8,264.61	9,849.07	7,845.22	10,268.46
2024	10,297.99	8,652.53	11,943.45	7,781.47	12,814.51
2025	11,316.25	8,745.28	13,887.21	7,384.30	15,248.19

Note: Low and High indicates the confidence interval limits

3.2.8. Constraints identification through Garrett ranking

The identification of region-specific constraints is essential for developing targeted mitigation strategies to promote aquaculture activities. The constraints identified using the Garrett ranking in pond and cage cultures varied across regions. The availability of quality seeds was the primary technical constraint, in addition to the availability of stockable-size fingerlings, formulated feed, and health and environmental issues. The cost of seed and feed and lack of credit were the major economic constraints, while unstable local market demand and high price spread were also reported by farmers (Table 12). Previous studies have also identified the high cost of feed, poor-quality seeds (Jeeva et al., 2022), and lack of credit and insurance (Aswathy and Imelda, 2020) as the primary constraints in mariculture. Overall, the sector faces poor input supply logistics as a critical administrative constraint, along with a lack of adequate technical supervision and guidance across the culture systems. Therefore, concerted efforts by developmental, promotional, and research organizations to establish more hatcheries would ensure a timely supply of adequate amounts of quality seeds and facilitate the development of low-cost formulated feed, along with expanding domestic and global market opportunities.

Table 12. Garret ranking on perceived constraints in seabass culture.

S no	Constraint Analysis	Pond culture		Cage culture		
		Andhra Pradesh	West Bengal	Kerala	Tamil Nadu	Karnataka
Technical constraints						
1.	Non-availability of quality seed	1	1	2	1	1
2.	Selling of fish	10	7	12	5	2
3.	Non-availability of formulated feed	2	13	6	3	12
4.	Skilled labor shortage	8	9	10	10	14
5.	Electricity	6	12	11	11	15
6.	Mortality	3	3	1	2	13

S no	Constraint Analysis	Pond culture		Cage culture		
		Andhra Pradesh	West Bengal	Kerala	Tamil Nadu	Karnataka
7.	Disease infection	4	4	3	6	8
8.	Lack of knowledge	7	5	13	13	5
9.	Lack of availability of good quality water	11	10	9	9	10
10.	Perishable commodity resulting in losses	13	11	14	14	4
11.	Poaching	5	2	4	4	6
12.	Post-harvest management	12	8	15	15	11
13.	Lack of transportation facilities	9	6	8	12	7
14.	Storage facilities	14	14	5	8	9
Economic constraints						
1	Unstable price of the product	8	7	3	4	1
2	High cost of seed (including transportation)	2	2	4	5	2
3	High cost of feed	1	8	1	1	9
4	Lack of money for constructing pond	6	3	9	9	6
5	Lack of credit	5	1	5	7	5
6	Lack of insurance	10	10	8	10	8
7	Cost of electricity	9	4	10	8	10
8	High labor charge	7	5	7	6	7
9	Exploitation by commission agents	3	6	2	2	3
10	Unstable local demand	4	9	6	3	4
Administrative constraints						
1	Lack of timely & adequate supply of fingerlings	1	3	1	2	1
2	Lack of frequent technical supervision and guidance	3	1	4	4	4
3	Untimely supply of inputs & other materials	2	4	3	1	2
4	Lack of communication regarding the services & other facilities available for fish farming	7	5	7	7	3
5	Location of fish collection centers at distant places	6	7	6	3	7
6	Lack of demonstration and training on recommended practices	4	2	2	5	5
7	Lack of facilities for testing soil, seed and water quality.	5	6	5	6	6

3.3. SWOT Analysis

SWOT analysis of seabass aquaculture indicates the immediate interventions required for the sustainable development of the sector (Ravisankar et al., 2010 FAO, 2020b). The availability of technology for year-round breeding and seed production, in addition to the development of functional feed for various growth stages, such as broodstock, nursery, pre-grow-out, and grow-out feed denotes the major strength. Employing the available qualified young professionals across potential coastal and inland saline water bodies would ensure tapping of domestic and international market opportunities. The cost and availability of quality seed and feed and the long distance of transportation are the major identified weaknesses that need to be addressed through research inputs for the development of policy interventions. Additionally, providing institutional credit and risk mitigation through insurance would help achieve targeted production and ensure the economic sustainability of the sector (Table 13).

The integrated seabass culture system practiced in Indian seabass farming ensures phase-wise growth at different facilities, ensuring year-round production generating employment and revenue for communities, thus transforming seabass into a major aquaculture species supporting livelihoods. The factors identified in the constraint analysis were used to recommend targeted strategies and policy interventions to aid sustainable development of this emerging aquaculture system.

Table 13. SWOT analysis of Indian seabass production

Strength	Weakness
Availability of scientific breeding technology	Inadequate availability of weaned seed
Higher consumer preference	Less awareness among farmers about using formulated feed
Establishment of Hatcheries	High cost of seed and feed (additional transport cost)
Zero conflict water resource	Health and environmental issues
Availability of species-specific feed	Lack of credit and insurance
The commitment of promotional agencies	Exploitation by commission agents
Livelihood improvement	Unstable local demand
	Lack of scientific farming know-how
	Dependence on forage fish
Opportunities	**Threat**
Availability of potential brackish water area	Failure to meet production capacity
Huge seed demand	High price spread
Scope for expansion of hatcheries and feed mill capacity	Unsustainable farming practices
Promotion through Farmers Producers Organizations (FPO)	Increased non-institutional credit

Strength	Weakness
Scope for diversification in brackish water aquaculture	Underutilization of the potential
Large domestic and international market	Live fish feed as disease carriers
Scope for inclusion in national flagship programs	
Increasing employment opportunities	

3.4. Scaling-up Seabass Culture: Future Prospects and Requirements

Given the above strengths, weaknesses, opportunities, and threats, some potential strategies and actions required to scale up seabass culture in India are outlined below:

1. Expansion of Hatchery Infrastructure
   - Increasing the number of fish seed hatcheries to ensure copious seed availability.
   - Promoting private sector hatcheries through financial assistance from the government.
2. Feed Production and Supply Chain
   - Encouraging feed mills to produce exclusive feeds for seabass.
   - Promoting research on alternative crude protein and crude fat sources with cost-effective formulations.
3. Market Development and Value Chain Enhancement
   - Developing domestic marketing strategies for seabass.
   - Strengthening cold chain and transportation infrastructure.
   - Promoting branding and certification for better consumer acceptance.
4. Policy and Financial Support
   - Popularizing government schemes to support seabass farming.
   - Encouraging public-private partnerships for domestic marketing.
   - Facilitating access to credit and insurance for fish farmers.
5. Capacity Building and Technology Transfer
   - Conducting training programs for fish farmers on best management practices.
   - Establishing demonstration farms for knowledge dissemination.
   - Enhancing digital advisory services for real-time technical support.

4. Conclusions

This study provides a comprehensive analysis of the current status, farming systems, production economics, efficiency, challenges, and prospects of Asian seabass aquaculture in India. Advancements in seed production and feeding methodologies can enhance survival rates, growth rates, and yields across nurseries, pre-grow-out ponds, and grow-out culture systems. Overall viability is constrained by recurring expenses, such as seed and feed costs, in addition to inadequate institutional support. Annual seabass production forecasts predict continued output growth in subsequent years. However, targeted strategies are imperative to facilitate large-scale sustainable expansion. Recommendations include upgrading hatchery and feed infrastructure, building capacity among farmers, facilitating access to credit, mitigating risk through insurance, and securing market linkages. The study provides robust insights into the enhancement of evolving cultural practices and the realization of the sector's full potential. This proposed approach allows for extrapolation to other aquaculture systems and geographical regions that face similar opportunities and limitations.

Asian seabass production systems demonstrated that the implementation of efficient, integrated multi-tier production facilitates consistent year-round production. The economic analysis indicates predominantly positive returns, although profitability varies due to location-specific productivity, costs, and prices. Nevertheless, identified constraints in obtaining a timely supply of adequate quantities of quality seed and feed could be addressed through the establishment of additional hatcheries and the development of cost-effective formulated feed, along with the expansion of domestic and global market opportunities. By addressing these key challenges through appropriate technological, policy, and marketing interventions, Asian seabass aquaculture has the potential to significantly enhance production and return, thereby ensuring livelihood security.

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Annexure 1. Time-series forecasting methods for seabass production.

Forecasting method	AIC	AICc	BIC	RMSE	MAE	MPE	MAPE	MASE	Parameter Estimates			
Naïve	-	-	-	599.60	522	24.30	24.30	1.0	-			
Simple Exponential Smoothing	204.60	207.27	206.30	576.12	481.92	-Inf	Inf	0.92	Smoothing parameters: alpha = 0.999		Initial states: l = 0.43	
Holt's method	188.43	197.00	191.25	265.147	221.844	NaN	Inf	0.42	Smoothing parameters: alpha = 1e-04 beta = 1e-04		Initial states: l = -670.1965 b = 554.4798	
ARIMA (0,1,0)	189.57	189.97	190.05	576.08	481.85	24.30	24.30	0.92	Ar1	Ar2	Ma1	Ma2
									-	-	-	-
ARIMA (1,1,0)	183.53	184.87	184.50	401.30	264.88	12.38	14.77	0.50	0.7286 (0.2399)	-	-	-
ARIMA (0,1,1)	187.09	188.42	188.06	471.00	343.49	17.62	17.95	0.65	-	-	0.5489 (0.2616)	-
ARIMA (2,1,0)	183.20	186.23	184.66	357.11	236.19	10.71	14.57	0.45	0.3254 (0.2691)	0.4983 (0.2928)	-	-
ARIMA (2,1,1)	182.72	188.44	184.66	288.08	214.34	8.06	12.25	0.41	0.7783 (0.3366)	0.2216 (0.3368)	-0.9767 (0.1444)	-
ARIMA (2,1,2)	184.73	194.73	187.16	289.21	214.60	8.08	12.28	0.41	0.7282 (1.0196)	0.2717 (1.0195)	-0.9235 (1.0585)	-0.045 (1.027)

Chapter-6

The Impact of Carp Polyculture Technology

Nagesh Kumar Barik

1. Background

Traditionally, inland water bodies, such as rivers, lakes, and reservoirs, have served as the main sources of fish for populations living far from coastal areas. Inland fisheries are a crucial source of protein in regions with a high concentration of water bodies, including coastal plains, floodplains, deltaic areas, and riparian zones. Before India's independence, a significant fish shortage and subsequent price increase (Wright, 1917) led to the culture of fish in small, natural, and artificial water bodies, particularly in the eastern states of Odisha, West Bengal, and Bihar. Other states, including Madras, Bengal, Punjab, Uttar Pradesh, Baroda, Mysore, and Hyderabad, also attempted to introduce fish species from nearby rivers into smaller water bodies. However, due to irregular seed supply and high mortality rates, production remained low. Although a few management practices, such as manuring and removing predatory fish species, were recommended, their implementation was limited (Chopra, 1951).

Fast-growing fish species such as catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhina mrigala*), and calbasu (*Labeo calbasu*), which are naturally found in rivers, were highly sought after but were unable to reproduce in enclosed water bodies. During the monsoon, fishermen gathered spawn from the Ganga and Mahanadi Rivers and their tributaries. Some innovative individuals successfully developed methods to induce these fish to breed in confined spaces by simulating flood conditions, known as 'bundhs.' The eggs collected from these bundhs were then incubated in nearby earthen pits, where high mortality rates were common. Additionally, the transport of spawn from collection or production sites to nearby ponds or markets resulted in significant losses (Bhimachar and Tripathi, 1967). Spawn collection was widespread in most coastal regions, with an estimated 10000–15000 fishermen engaged in this activity in eastern India. However, until the 1970s, no coordinated efforts were made to gather data on the extent of fry collection and distribution across the country.

The gathering of spawns from rivers presented numerous challenges. The collection sites were located in hard-to-reach, isolated regions, and spawn availability was brief and dependent on climatic factors. Moreover, it was not cost-effective to raise mixed-quality river spawns. While bunds produced high-quality spawns, they were scarce, resulting in limited output. With the development of scientific methods and technologies for induced breeding and seed production, the availability of pure seeds became easy and reliable leading to the development of a foundation of scientific fish farming in the country.

Carp polyculture is the mainstay of freshwater aquaculture in the country as more than 80% of the cultured fishes in the country are carps (Indian major carps, exotic carps, and minor carps). The present level of technological progress in carp culture was complemented by achievements of major milestones such as the development of induced breeding technology (1957); composite carp culture (1960s); the introduction of exotic fish and the successful implementation of a series of schemes such as NDP (1965), AICRPs (1971), ORP (1974-75), Lab-to-Land Programme (1979), etc. and has reached to the present day's status of a large scale commercial and intensive farming enterprise (Das & Feroskhan, 2022). At present, the carp production system has been diversified fitting into various ecological and socio-economic conditions, and is the primary source of fish protein in the country.

The present chapter attempts to analyse and evaluate historical trends in the carp culture, diversification of the carp practices, and impact of the carp aquaculture in India. The discussion mainly focuses on recent technological changes and their adoption leading to productivity increase in carp aquaculture. The specialised clusters with unique technological practices and their impacts are also discussed in the chapter.

2. Research Initiatives

The Advisory Board of the Indian Council of Agricultural Research, in its 1944 memorandum, pushed for the development of pond aquaculture and fisheries research. It suggested providing financial support for ad-hoc projects of state governments and universities. This enabled studies on the hydrobiology of specific inland water bodies and the bionomics of key food fish species in the Madras and Bengal states. In 1947, the Government of India established the Central Inland Fisheries Research Station (now the Central Inland Fisheries Research Institute) in Calcutta to conduct scientific studies to thoroughly evaluate the country's inland fisheries resources and create appropriate methods for their preservation, administration, and enhancement (Bhimachar and Tripathi, 1967). The Institute set up its Pond Culture Division in Cuttack (Odisha) to devise scientific techniques for managing culture fisheries which was later developed as the Central Institute of Freshwater Aquaculture at Bhubaneswar.

The research priorities for the culture fisheries were to improve techniques for collecting and rearing major carp fry, investigate carp culture practices to achieve maximum survival rate from spawning to fingerling stage, reduce mortality during transport, eradicate aquatic weeds from fish ponds, and induce spawning of carps by artificial flooding of ponds and by injection of pituitary gland extracts (Bhimachar, 1959). Studies on pituitary gland structure across various species conducted at Indian universities and institutions have enhanced our knowledge of breeding physiology (Das and Khan, 1962; Ramaswami, 1962; Lal, 1964). Induced breeding techniques have been successfully employed to develop fish strains with improved flesh quality and growth rate. Various aquaculture techniques have been tested to enhance productivity. These approaches include managing aquatic plant growth and algal blooms, removing predatory and unwanted fish species, fertilizing ponds, regulating harmful insects, and providing additional feed (Table 1).

Table 1. Evolution of aquaculture research and development in India

Stages	R & D	Extension methods	Output	Outcome	Impact
1920-1940	Survey and exploration	Publication, conferences	Basic understanding of fish and fisheries	Culture-based fisheries as an option	Generated lead to initiate research in specific areas
1940-1960	Basic research-biology, ecology	Experiments, field trials, observations	Understanding of ecology and identification of tools for interventions	Principles and methods of aquaculture	15000-20000 fish seed collectors, inter-regional movement of seeds, stocking of fish in natural water bodies
1961-1980	Technology formulations and demonstrations	Technology demonstrations	Induced breeding, composite fish culture	The evolvement of basic aquaculture technologies	Hatchery bred seeds (30-60%) Aquaculture productivity (600 to 1500 kg/ha)
1981-2000	Technology dissemination and farmers' participation in the development of prototypes and working models	National large-scale Demonstrations	Production systems in Hatcheries, seed production integrated farming, fish farming	Prototypes of production system and models	6 major species, Hatchery bred seeds (80-100%) Aquaculture productivity (1500- 5000 kg/ha)

Stages	R & D	Extension methods	Output	Outcome	Impact
2001-2020	Technology specialisation and intensification	Large scale cluster level adoptions, unique aquaculture models development, Full-scale ecosystem-based efficient and optimized production systems for national markets	Input intensive system, time and space optimisation, long-distance transportation, national input markets Andhra Model, West Bengal Model, Odisha Model, Bihar Model, Northeast model	Large-scale Commercial systems. Efficient production system, price stabilization, and national value chain	20 major species, productivity 7500-12000 kg/ha

3. Evolution of Carp Polyculture Technology

Before 1947, aquaculture was basic and was limited to small backyard ponds. These ponds contained various fish species that were left to grow naturally for one to two years, depending solely on the pond's inherent productivity for nourishment until harvest. This method yielded an average of 600 kg/ha/year. According to available records, the average fish productivity in West Bengal during 1975-76 was 1113 kg/ha/annum (Murshed et al. 1977). In contrast, the current aquaculture productivity reaches as high as 8-10 tons/ha for carp in Andhra Pradesh (Ramakrishna et al., 2013). This significant increase in productivity can be attributed to the scientific management of aquaculture, known as composite fish or carp polyculture. These techniques have been developed over an extended period through scientific research conducted by the ICAR since 1945.

Carp species are highly favored owing to their rapid growth, natural occurrence in Indian waterways, strong consumer demand, and ease of cultivation. Initial technological advancements were primarily centered on carp cultivation techniques. In the past, there was limited regulation of the stocking density or proportions of different carp species, resulting in annual yields ranging from 100 to 1000 kg/ha. Extensive research station experiments have led to five to six-fold increases in production rates. During 1974-75, a remarkable yield of 5,200 kg/ha/annum was achieved by stocking Indian major carp at 7,500/ha, with a ratio of 3.5:3.5:3.0 for catla, rohu, and mrigal, respectively. Polyculture or mixed culture technology for Indian major carp involves eliminating predatory fish from ponds using appropriate ichthyocides, enriching the pond with both organic and inorganic fertilizers, and providing supplementary feed to the stocked fish (Sinha, 1985).

Additionally, the introduction of non-native Chinese carp species, including grass carp, silver carp, and the Bangkok strain of common carp, to India in the late 1950s expanded the range of cultivated carp. These imported species are characterized by their non-predatory nature, rapid growth, and ability to coexist with native species. The Central Inland Fisheries Research Institute (CIFRI) in Cuttack conducted a series of experiments to evaluate the suitability of these three exotic carp species under Indian conditions. Studies have focused on silver carp, grass carp, and common carp, with production levels ranging from approximately 2,896 kg/ha/yr to 3,287 kg/ha/yr. The most favorable outcome was achieved using a stocking ratio of 3:1:2 for silver carp, grass carp, and common carp, respectively, at a density of 5,000/ha (Sinha, 1985) (Table 2).

Research has revealed that these three carp species consistently demonstrated superior production rates when cultivated individually or when Chinese carp were raised separately under identical management and resource conditions. Consequently, a high-yield system incorporating six carp species, referred to as composite fish culture, has been developed. Although composite fish culture is also a form of polyculture, it differs slightly from traditional Indian or Chinese carp farming methods. This distinction lies in the simultaneous stocking of Indian and Chinese carp species within the same system.

Table 2. Salient results of experimentation during development of composite fish culture technology (1971-1985)

Nature of technological interventions	Results (kg/ha)	Average (kg/ha)	References
Carp poly culture	1439- 2975	2207.0	Jhingran, 1975
Natural ponds in six months crop	1300-1800	1550	Chakrabarty et al., 1979c
Natural ponds	1422–1665	1543.5	Jhingran, 1975
Only Fertilizers	1824–2213	2018.5	Jhingran, 1975
Only fertilizer for six months,	2500	2500.0	Chakrabarty et al., 1979a
combined culture of major Indian and exotic carp densities of 4450 to 6250 per hectare	2234, 5041	3637.5	Lakshmanan et al., 1971
4 species culture	2890	2890.0	Lakshmanan et al., 1971
exotic carps alone	2900	2900.0	Lakshmanan et al., 1971
Composite fish culture in six months	3232	3232.0	Sinha, 1975
Fertiliser based aquaculture	3642–3985	3813.5	Sinha et al., 1973
Low-investment fish culture programmes	3352, 4297	3824.5	Saha et al., 1978

Nature of technological interventions	Results (kg/ha)	Average (kg/ha)	References
Only feed	3910–3971	3940.5	Sinha et al., 1973
5 species culture	3991	3991.0	Sinha et al., 1973
Carp poly culture	4000	4000.0	Chakrabarty et al., 1979b
Laterite, red loam and red and yellow soils	3500–4500	4000.0	Chakrabarty et al., 1979b
5000 per hectare density	5175, 5334	5254.5	Chaudhuri et al., 1975
10,000 per hectare stocking density	5734, 7500	5255.0	Chaudhuri et al., 1974
Undrainable ponds	3500–7500	5500.0	Chaudhuri et al., 1978
Gray and brown, alluvial and medium black soils	4200–7300	5750.0	Chaudhuri et al., 1978
While both feed and fertilizer	5498–7172	6335.0	Chaudhuri et al., 1978
6-species	6892	6892.0	Chaudhuri et al., 1978
National Demonstration Scheme at 13320/ha stocking density	7445, 7633	7539.0	Chaudhuri et al., 1978
7500 per hectare stocking density	7503, 8867	8185.0	Chakrabarty et al., 1980
stocking densities of 7719 and 7840 per hectare	8200 – 9389	8794.5	Chaudhuri et al., 1975
Pond with water replenishment	10000	10000.0	Chakrabarty et al., 1980
High-density composite culture (AICRP-Poona Centre)	10678	10678.0	Tripathi, 1982

Composite fish culture relies on several key principles: appropriate size, density, and combination of compatible fish species; effective soil and water management; control of aquatic plants; elimination of undesirable fish; maintenance of fish health; proper feeding practices; and efficient harvest management.

The implementation of composite fish culture involves three main stages: (i) pre-stocking procedures, which include managing harmful aquatic vegetation, eliminating fish predators, applying lime, and fertilizing the water; (ii) stocking operations, focusing on species selection and determining the appropriate stocking density and species ratio; and (iii) post-stocking activities, including supplementary feeding, harvesting, and marketing strategies, pond sanitation measures, and the prevention and treatment of fish diseases.

4. Methods for Impact Assessment

Aquaculture has experienced rapid advancements over a relatively brief period, with fundamental research, technology development, adaptation, and implementation occurring concurrently. The adoption of aquaculture techniques has been diverse, incorporating various integrated farming approaches, such as combining fish cultivation with rice, livestock, ducks, and pigs, all based on foundational carp polyculture systems. In addition, different regions have implemented these technologies in various ways, including different farm sizes, intensity levels (ranging from extensive to intensive), purposes (subsistence or commercial), and market reach (local to national). The diversity of technological applications has expanded to such an extent that tracking adoption patterns has become challenging. To better understand the progression of aquaculture development, researchers have categorized and monitored distinct clusters characterized by unique methodologies and technological sophistication. Technology adoption and performance levels in carp culture were categorized into seven levels, ranging from basic to advanced systems (Table 3). For each level, we identified a specific geographic region where particular technologies were prevalent. Data were then gathered from the farmers within these clusters to evaluate their effectiveness. The specific characteristics of various level of carp polyculture technologies are presented in Table 4.

The impact assessment exercise omitted the two lowest technology levels, 1 and 2, because of their minimal technological interventions and extremely low resource inputs, resulting in poor yields of 1 and 1.5 tons/ha. Technology level 2 was considered the current baseline, reflecting traditional farming methods without the benefit of formal training or technology transfer. Without the development of scientific practices, the farmers are expected to produce fish at this level. These practices are rooted in knowledge passed down through generations within farming communities. For higher levels the aquaculture clusters in Durg (Chhattisgarh) Puri and Khordha (coastal Odisha), Naihati and Kalyani (central West Bengal), Krisha-Godavari region of coastal Andhra Pradesh and Moyna region of West Bengal were considered for data collection. Estimates of national-level adoption were derived from focus group discussions with the experts.

Since 1958, when the technology for scientific farming was first developed, there have been several improvements in farming practices in terms of stocking density, compatible species mix, stocking size, period of culture, manuring, fertilization, feeding, harvesting, etc. There have been continuous improvements in the realm of scientific culture practices and their adoption by farmers across the country. However, the basic technology package developed by the ICAR remains the same and is indispensable for further improvements. In the initial phase, before the development of composite fish culture technologies, the productivity recorded was 600 kg/ha/yr. Considering that a productivity of 1113 kg/ha/year was recorded in 1975-76 by following traditional culture practices, it is expected that a maximum productivity of 1500 kg/ha/yr could be attained through local innovations. Therefore, a productivity level below 1500 kg/ha/year was considered a counterfactual level, and beyond it can be considered an improvement due to technological progress.

This study did not classify traditional fish farming methods as scientific aquaculture methods. These conventional practices involve basic techniques, such as stocking varying amounts of fish seed and using manure, without employing modern inputs such as fertilizers, specialized feed, or improved seed. Although not considered scientific, this production system encompasses extensive areas of water spread. For this study, scientific aquaculture is defined as farming that incorporates modern inputs, judiciously utilizes resources, and applies scientific knowledge in management. This definition aligns with the concept of aquaculture defined by the Food and Agriculture Organization (FAO).

An economic analysis was conducted to assess the aggregate level and distribution of benefits using an economic surplus method. This method relies on the principle of projecting shifts in supply and demand curves based on changes in yield and input costs due to technology adoption. Changes in economic surplus that included producer and consumer surplus were calculated and then discounted (10%) and totalled over 1980-2022 (42 years) to estimate the economic benefits of the technology. The assumption of a "closed economy" was maintained. The basic economic surplus model of research benefits is described by Alston et al., (1995).

Table 3. Various levels of technological progress in aquaculture in India

Technology	Characteristics	Productivity t/ha/yr	Element of carp culture technology
Level 1	8 months crop period high stocking multiple harvesting (Bihar backyard pond model)	1	Stocking
Level 2	10 months crop terminal harvest (Odisha farm pond model)	1.5	Stocking + Fertilization (low)
Level 3	10 month adopted semi-intensive culture (Chhattisgarh Model)	3	Stocking + fertilization + feeding (low)

Level 4	10 months crop scientifically managed (Odisha adopted farmers models/Recommended technology for average farmer)	5	Stocking + fertilization + feeding (Medium)
Level 5	10 months crop (Best farmers West Bengal)	7.5	Stocking + fertilization + feeding + farmers innovation + multiple stocking and harvesting
Level 6	6 months (Andhra Kolleru Model)	9	Stocking large sized seed + fertilization + Intense feeding + farmers innovation
Level 7	5 months (West Bengal Moyna model)	12	Stocking large sized seed + fertilization + intense feeding + farmers innovation + marketing innovation
Total		3.02	

Table 4. Characteristics of various level of carp polyculture technologies

Level	Element of technology	Production orientation (Labour /capital)	Market orientation
1	• SD: 15000-20000 advanced fry /ha • SS: 1-5 g • Manure: Cowdung • Feed: Nil • Owned pond • Productivity: 317 kg/ha/yr • Reference: Barik, 2016 • ST: Community	• Owned land • Use of available water resources • Locally available inputs • One time stocking-multiple harvesting • Own/family labour • Low monetary input	• Local market • Small size fish • Small quantity of fish • Sale at pond site or village
2	• SD: 4000 to 5000 fish/ha • SS: 5-10 g • Prod.: 1000-2000 kg/ha/yr • Manure: 10-12 t/ha • Fert.: Inorganic • Feed: Nil • ST: Community	• Owned land • Use of available water resources • Locally available inputs • One time stocking-multiple harvesting • Own/family labour • Low monetary input	• Local market • Small size fish • Small quantity of fish • Sale at nearby market

Level	Element of technology	Production orientation (Labour /capital)	Market orientation
3	• SD: rohu 2 000 to 3 000 fish/ ha and catla 250 to 300 fish/ha • SS: 10-15 g. • Prod.: rohu (2 000 to 3 000 kg/ha/year), catla (500 to 600 kg/ha/year) • manure: 20 t/year • Fert.: SSP (760 kg/ha/year); urea (440 kg/ha/year); DAP, (380 kg/ha/year); complex fertilizers (200 kg/ha/year); and potash (220 kg/ha/year). • Feed: 4 800 to 7 200 kg/ha/ year • Av. Prod. 3050 kg/ha/year • Ref: Ramakrishna et al, 2013	• Owned/leased land • Specifically developed pond • Use of advanced fingerlings • Recommended species ratio • Adequate fertilisation • Moderate level of investment • Locally available feed ingredients	• Harvesting higher sizes of fish 0.5-0.7 kg • Live fish sale in local market • Multiple harvesting as per local demand
4	• SD: three species @ 5000/ha • SS: fingerlings (10-15 g) • Adequate liming and fertilisation- both organic and inorganic sources • Prod.: 5000 kg/ha/year. • Feed: both mass and floating feed 5000-6000 kg/ha/year	• Higher technological inputs • Use of feed in moderation • Use of best management practices • Moderate level investment	• One/two harvest at the end of year • Local or regional market • Live/dead fresh fish sale
5	• SD: 5000/ha • SS:150-200 gms • Periodic harvest and restocking • Frequent organic fertilization • Feeding mash or sinking pellet:2500 kg/ha • Prod.: 6 600 to 8 400 kg/ha/ year. • Feed: 17 160 to 26 880 kg/ha/ year	• Higher technical inputs in water quality management • Lowering cost of feed by increasing fertilisation • High investment in labour and capital	• Multiple harvest • Live fish for 0.5-0.6 kg of fish to local market • Year-round stocking and harvesting
6	• SD: around 5 000 to 6 000 • SS: rohu (200–300 g) and catla (250–1 000 g) • Six-month crop • Prod.: 8 000 and 10 000 kg/ ha/year • Feeding: 20-32 t/ha Ref: Ramakrishna et al, 2013	• Leased land • Available adequate water • Heavy investment in feed input	• Terminal harvest of higher sizes more than 1 kg rohu and 2 kg catla • Freeze fish to national market
7	• SD: Rohu (5 000 to 6 750 fish/ ha), Catla (550–800 fish/ha) • SS: yearlings (300 to 400 g) • Prod.:12 000 and 14 000 kg/ ha/year • Feeding: 20-30 t/ha • 5-month crop Ref: Primary data collected under the project	• Leased land • Abundant water supply • Heavy investment in feed input • Borrowed capital at high cost	• Higher size fish to regional market (500-700 km) • Live fish supply throughout the year • Higher price advantage

(SD: Stocking density; SS: Stocking size; Prod: Productivity; Fert: Fertilisation)

5. Chronology of Adoption of Carp Polyculture Practices

The chronology of the adoption of polyculture practices with specific details of the programs and their approaches and major achievements in terms of geographical coverage, yield enhancement, etc., are outlined in Table 5. The phase-wise progression of aquaculture technologies, along with their various dimensions, is presented in Table 6.

Table 5. Schemes for transfer of composite fish culture technology in the initial phase of development (1951-1990)

Period	Programmes	Technology transfer approach	Results/achievements
1951-1970	Development of the technology at the Pond Culture Division (Cuttack) of CIFRI	Transfer through training and demonstration to all of India	The carp polyculture was initiated in the available water bodies, ponds, and community water bodies in eastern India
1971-1985	All India Coordinated Research Project on Composite Fish Culture and Fish Seed Production (AICRP)	Testing its feasibility and economic viability at eleven states under	This project, besides testing the feasibility and economic viability of composite fish culture technology under different agroclimatic conditions was also engaged in transfer of technology work in the target area. The training programmes were arranged for the extension workers of the respective State Govts., Officers of Fish Farmers' Development Agencies (FFDA), Bank Officials, entrepreneurs and fish farmers (Tripathi, 1982).
1974–75	Fish Farmers' Development Agencies	The FFDAs are autonomous agencies that function under the Chairmanship of the respective District Collectors. These agencies are expected to provide the much-needed field mechanism to popularise the technology of composite fish culture amongst the farmers and also coordinate the activities of various institutional agencies engaged in inland fisheries development. It is mainly concerned with providing training to selected persons interested in fish culture,	Evaluations made by the National Council of Applied Economic Research reveal that the success stories of the FFDAs had created confidence among those who were hitherto reluctant to adopt the recommended practice of composite fish culture technology. Initially, there were 102 FFDAs in the country under the centrally sponsored scheme and some more were under the State Sector actively engaged in the transfer of technology programme.

Period	Programmes	Technology transfer approach	Results/achievements
		assisting them in securing suitable water resources for the purpose, sponsoring the purposes for grant of loans by banks, arranging necessary technical support, organising the supply of fish seed and other inputs, and finally enabling the farmers in marketing of their catch.	In Balasore (Orissa), an average investment of Rs 4096/ha gave a production of 1932 kg/ha/yr in 1981–82. In the Puri and Ganjam districts of Orissa, the average yield rates during the last 5 years have been of the order of 1520 kg/ha and 1800 kg/ha/yr. In Tamil Nadu, the average production is around 1000 kg/ha in 6–8 months rearing.
1975-1980	Inland Fisheries Project, funded by the International Development Association (IDA) of the World Bank in five selected states viz Uttar Pradesh, Bihar, West Bengal, Orissa and Madhya Pradesh	The Project envisaged the production of carp seed in commercial quantities through the construction of 27 modern fish seed hatcheries of 10 to 25 ha each and improvement of fishponds	The project assisted 58 districts in five states of Uttar Pradesh, Bihar, West Bengal, Orissa, and Madhya Pradesh to develop a hatchery complex for increased seed production and composite fish culture
1980-1985	CIFRI/ IDRC Rural Aquaculture Project	The rural aquaculture project aimed at the demonstration of technologies in the village ponds	Transfer of technology in 41 villages involving 111 farmers and 11 institutions in 6 districts of West Bengal and 32 villages involving 17 farmers and 15 institutions in 5 districts of Orissa by organising result demonstrations on various aspects of fish culture technologies.
1975-1980	National Demonstration ICAR/ State Govt./ Agricultural University Demonstration	The Agricultural universities in Karnataka, Tamil Nadu, Uttar Pradesh (Pant Nagar) and Punjab also took up experimental trials, demonstrations and training.	Demonstrations at Mirhati, Khardah, and Nilganj in West Bengal and Marshaghai in Orissa showed fish productions ranging from 5,142 kg to 7,300 kg/ ha/yr. West Bengal set up 98 demonstration centres in private farmers' ponds, scattered all over the state and obtained average fish production of 4,372 kg/ ha/yr against the earlier production of 600 kg/ha/yr from the same water bodies before the adoption of technology

Period	Programmes	Technology transfer approach	Results/achievements
1965	National Demonstration Project	Demonstration of composite fish culture and production of the order of 2654–4290 kg/ha/yr shown as possible at Krishnagar (West Bengal). Yield rates varying from 5142 and 7300 kg/ ha/ yr were achieved at the National Demonstration Centres in West Bengal and Orissa, respectively	ICAR to demonstrate the potential of new production technologies in the farmers' field. This provided an opportunity for scientists to demonstrate the validity and relevance of their experimental findings in farmers' fields and paved the way for establishing a close linkage between the farmers and scientists from which both have derived immense benefits. High yield rates of 4660–6536 kg/ha/yr were demonstrated by the G.B. Pant University of Agricultural Sciences and Technology in the Terai region of Uttar Pradesh. The use of very small ponds (0.005 ha) was made by the University of Agricultural Sciences, Bangalore, and high yield rates of the order of 2975– 4573 kg/ ha shown possible in just 4½ months.
1977-1990	Krishi Vigyan Kendra (National Science Centre) and Trainers' Training Centre at CIFA, Bhubaneswar	To impart in-service training to the trainers/teachers of various non-degree level institutions dealing with fisheries, such as KVKs, Farmers' Training Centres, FFDAs, agricultural schools, extension training centres, and vocational training schools who are directly involved in developmental activities, especially in Community Development Blocks, Gram Panchayats (Village bodies), tribal belts and extension personnel in the department of fisheries of various state governments	More than 1200 farmers have been trained under these programmes of Kausalyaganga KVK and a number of them have been converted into successful pisciculturists (Sharma and Thakur, 1985).
1979-89	'Lab-to-Land' Programme of Central Inland Fisheries Research Institute	The programme operated in two phases (I phase & II phase). The farmers have undergone training and developed skills and expertise in composite fish culture	With a proper combination of the six species, proper pond preparation, periodic fertilization, and regular feeding farmers have obtained yields varying from 5290–6218 kg/ha/yr among 1000 farmers.

Period	Programmes	Technology transfer approach	Results/achievements
			A total of 600 farm families at six centres in West Bengal and Orissa are being covered under this phase. The results and method demonstrations of composite fish culture are being laid in about 150 ha. water area in the two states during the III phase.
1979-1990	Various rural development programmes	Small Farmers' Development Agency (SFDA), Command Area Development Authority (CADA), Training of Rural Youth in Self Employment (TRYSEM) and Integrated Rural Development Programme (IRDP)	A minimum yield rate of 3000 kg/ha/yr was obtained with little effort and ingenuity.
1970-1975	Voluntary Organisation Demonstrations across the country	Rama Krishna Mission, World Lutheran Service, Don Bosco Society, Tagore Rural Development Society, Kamla Nehru Trust, etc	Extended the technology to the small and marginal farmers across the country
1975-1990	Operational Research Project	Fish culture is one of the components in 102 ORP projects across the country in which an integrated farming approach was undertaken	ORP of Jute Agricultural Research Institute, Barrackpore (West Bengal); Orissa University of Agriculture & Technology, Bhubaneswar (Orissa); Central Plantation Research Institute, Kasaragod, Kerala; Central Rice Research Institute, Cuttack, Orissa; Bihar Agricultural University (Bihar); Soil Salinity Research Institute in Sundarbans etc. are doing commendable work on transfer of technology of composite fish culture in their respective areas (ICAR, 1977). A total of 73 villages, involving 111 farmers and 26 institutions were covered. The project not only made a real impact during its operational phase but has created a class of neo-fish farmers who are well motivated to practice good management, who are learning from one another and providing each other continued social support and positive reinforcement even now when the project has ceased to function (Sinha, 1979).

(Modified from Sharma, 1985)

Table 6. Progression of R & D in freshwater aquaculture in India

Period	1940-1960	1960-1980	1981-2000	2001-2020
Productivity t/ha	0.6-1.0	1-4.5 t/ha	4.5-7.5 t/ha	7.5-12 t/ha
Technology	Extensive system stocking and harvesting	Composite fish culture (Pond management, species combination, water quality management, fertilization, feeding	Carp technology intensification	Breed, feed, medicine, input optimization, capital-intensive inputs, two crops per year
Innovation	Collection of seed, removal of slow growing, predatory fish, weed clearance	New feed ingredients, exclusive aquaculture ponds, farm ponds construction	Feed-based aquaculture, Industrial aquaculture, large ponds, meeting national demands	Institutions for accessing capital, market, value chain
Adoption	Extensive, community-based aquaculture	Experimental stations in 27 places, community ponds, demonstration ponds	Commercial aquaculture in AP, WB, OD, AS, MP, UP, BH	Intensive aquaculture clusters in AP, OD, CH, WB
Research	Exploratory, survey, identification	Basic principles of aquaculture	Commercial aquaculture	Competitive aquaculture
Policies and priorities	Use of available resources for food security	Establishment of aquaculture for nutrition security, farm income, and use of available resources	Higher production and productivity to meet national demand and create a national market	Public capital formation, new business models, improving business environment

Fig. 1. The research and development continuum in aquaculture

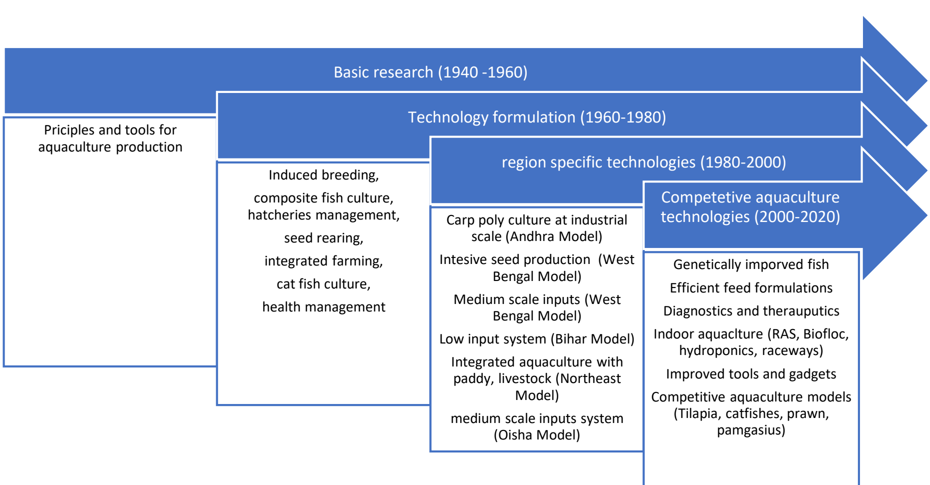
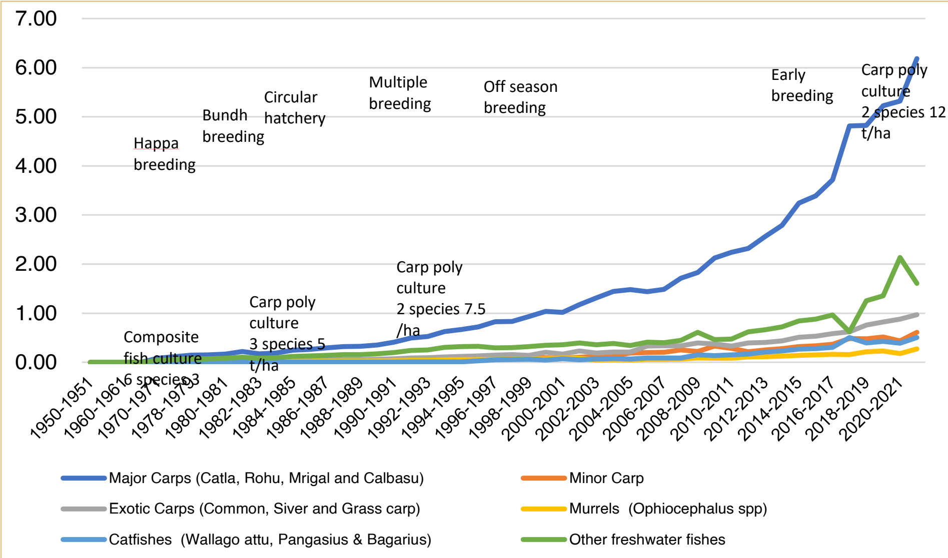


Fig. 2. Progression of the technology and production of carp culture of the freshwater sector in India



The adoption of carp polyculture technologies in India has progressed at varying paces across regions (Fig. 2). The technology transferred through various extension mechanisms primarily occurred at level 3 during 1975-1985 and at level 4 during 1980-1990. The year-wise trends in carp production and area coverage under aquaculture across different levels of technology adoption since 1985 are presented in Annexures 1 to 3. The farmer-developed innovations built over basic technology through interactive learning and utilizing technical and economic opportunities were available to them. Three distinct farmer-driven models with a commercial orientation emerged after 2000 to exploit consumer preferences and market opportunities. These models were developed specifically in three clusters: central West Bengal around Hugli River for level 5, Krishna-Godavari Delta for level 6, and Moyna area of coastal West Bengal for level 7.

6. Economics of Carp Polyculture

Carp culture practices exhibited a wide spectrum, ranging from low-input systems, where fish were allowed to grow over extended periods, to high-input, short-cycle models prioritizing rapid returns. The fish for self-consumption and local markets were at the lower end of investment, whereas the fish targeted at regional and national markets were at a higher level of investment. The farmers at the lower end adopted the low-capital-high-labor system, whereas those at the higher end followed a high-capital-low-labor system. To analyze the dynamics and economics of the carp culture system, the costs A2, B2, C2, and C3, as well as the estimated profit, were calculated and are presented in Tables 7, 8 & 9. The cost of production at C3 has ranged from 0.136 to 0.806 million per ha per crop. Farmers at levels 6 and 7 were able to harvest two crops per year, double the investment in the year. The profit per hectare per year at C3 increased from 0.018 to 0.248 million rupees. The financial efficiency in terms of profit and return on investment was low in the case of level 6 (large-scale Andhra Pradesh farming) due to heavy competition and poor price realization in the market for dead iced fish compared to live fish, which were preferred. Since eastern India was the largest fish market, the Moyna cluster of West Bengal developed aquaculture of more than 20,000 ha in a short period (2018-2022) to supply live fish in the nearby market, selling at a higher price than the level 6 cluster of Andhra Pradesh.

Table 7. Cost of production/ha/crop (Rs)

	level 1	level 2	level 3	level 4	level 5	level 6	level 7
Cost(A2)	98437.5	152800	284375	489200	911250	528625	641875
Cost (B2)	98437.5	158800	294375	519200	951250	538625	686875
Cost (C2)	123712.5	186250	311100	574100	978775	552450	732750
Cost (C3)	136083.75	204875	342210	631510	1076652.5	607695	806025
Production (in kg)	1062.5	1500	3000	5000	7500	4500	6000
Sale Price Rs/kg	145.0	148.0	140.0	145.0	170.0	125.0	155.0
Gross return	154062.5	222000	420000	725000	1275000	562500	930000

Table 8. Profit to the producer per rupees of value of fish sold (Rs)

	level 1	level 2	level 3	level 4	level 5	level 6	level 7
Profit over A2	0.36	0.31	0.32	0.33	0.29	0.06	0.31
Profit over B2	0.36	0.28	0.30	0.28	0.25	0.04	0.26
Profit over C2	0.20	0.16	0.26	0.21	0.23	0.02	0.21
Profit over C3	0.12	0.08	0.19	0.13	0.16	-0.08	0.13

Table 9. Scale of profit/ha/year (Rs in Million)

	level 1	level 2	level 3	level 4	level 5	level 6	level 7
Profit over A2	0.055	0.069	0.136	0.236	0.364	0.068	0.577
Profit over B2	0.056	0.063	0.126	0.206	0.324	0.048	0.487
Profit over C2	0.030	0.036	0.109	0.151	0.296	0.020	0.394
Profit over C3	0.018	0.017	0.078	0.093	0.198	-0.090	0.248

7. Incremental Gain in Key Economic Parameters

The results presented across the seven levels of technology adoption indicated a gradual increase in productivity from one level to the next (Table 10). The costs at C2 and C3 were lower at a moderate level of productivity when farmers used better management practices and recommended input doses. In both the lower and higher levels of input, the cost was found to be higher. Farmers at the lower end have a lower level of investment and target the local market. However, at higher levels of input intensification, producers were more attracted to larger markets operating at higher scales with a commercial orientation. At the middle level of input intensification, which was also aligned with the recommended practices of the research institute, it was found to be economically efficient. However, there was large-scale adoption of the technology at both higher and lower levels of recommended practices suited to local conditions, market orientations, and farmers' priorities.

Table 10. Cost and profit per kg of fish in Rs

	level 1	level 2	level 3	level 4	level 5	level 6	level 7
Cost(A2)	92.6	101.9	94.8	97.8	121.5	117.5	107.0
Cost (B2)	92.6	105.9	98.1	103.8	126.8	119.7	114.5
Cost (C2)	116.4	124.2	103.7	114.8	130.5	122.8	122.1
Cost (C3)	128.1	136.6	114.1	126.3	143.6	135.0	134.3
Selling price/kg	145	148	140	145	170	125	155
Profit over A2	52.4	46.1	45.2	47.2	48.5	7.5	48.0
Profit over B2	52.4	42.1	41.9	41.2	43.2	5.3	40.5
Profit over C2	28.6	23.8	36.3	30.2	39.5	2.2	32.9
Profit over C3	16.9	11.4	25.9	18.7	26.4	-10.0	20.7

Table 11. NPV of various levels of technology at 2021-22 price (million rupees)

Technology level	NPV
Level 3	16286
Level 4	48207
Level 5	103596
Level 6	93876
Level 7	37979

8. Conclusions

India's Blue Revolution has been primarily driven by advancements in seed production, induced breeding, and composite fish cultures of Indian major carp and other key freshwater species. These technological developments have emerged through concurrent research, demonstration, extension, and adaptation processes over the years. Since the 1970s, there has been rapid progress in aquaculture technology, resulting in innovations that have been both accessible and beneficial to farmers. This progress has been achieved through a combination of scientific research and farmer-led practices. As market opportunities expanded, new clusters with innovative technologies based on basic carp culture techniques have emerged. Carp culture technology has become the backbone of the freshwater aquaculture industry in India. Historically, there has been a widespread scarcity of freshwater fish, particularly in urban markets, leading to higher prices due to limited supply. This scarcity has created opportunities for farmers to utilize available water resources such as lakes, ponds, tanks, and other freshwater bodies for fish production. Traditional fish farming areas have operated under extensive and semi-intensive systems, using low inputs to serve local markets. In response to growing demand from large urban and organized markets, specialized clusters have developed using high-input, intensive systems. As a result, the production systems have diversified, employing varying levels of input intensification to adapt to the resources available to farmers and meet market conditions.

The present study identifies and categorizes seven distinct levels of carp culture technology, all based on fundamental polyculture methods. Using traditional aquaculture techniques as a baseline, the study evaluates the impact of various carp culture technologies through historical data spanning from 1985 to 2022. There are varying levels of technical and economic efficiency across different carp farming production systems that fit into the local ecological, social, and market conditions. These long-sustaining systems effectively address the needs of farmers within the constraints of available resources. While scientific research laid the foundation for these advancements, the success of these technologies came from their large-scale adaptation and refinements. Hence, diversified practices in carp farming benefited from the R & D developed over a period of time. This adaptation process enabled farmers to incorporate scientific principles and practices into their farming systems, making aquaculture more efficient and sustainable. Therefore, similar studies on other freshwater technologies will help deepen our understanding of the processes of adaptation, adoption, and the long-term impact of scientific research.

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Annexure A1. Trends in major carp production since 1985 (in million tons)

Year	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Total
1985-1986	0.250	0.038	0.003					0.264
1986-1987	0.260	0.039	0.023					0.291
1987-1988	0.260	0.039	0.042					0.319
1988-1989	0.270	0.039	0.062					0.326
1989-1990	0.270	0.041	0.082					0.350
1990-1991	0.270	0.042	0.101	0.005				0.412
1991-1992	0.270	0.044	0.174	0.010				0.495
1992-1993	0.270	0.044	0.183	0.040				0.525
1993-1994	0.270	0.044	0.180	0.125				0.625
1994-1995	0.270	0.044	0.180	0.135		0.043		0.667
1995-1996	0.270	0.048	0.236	0.150		0.043		0.718
1996-1997	0.270	0.048	0.273	0.160		0.069		0.828
1997-1998	0.270	0.048	0.285	0.175		0.069		0.833
1998-1999	0.270	0.048	0.360	0.190		0.080		0.931
1999-2000	0.270	0.048	0.450	0.200		0.123		1.035
2000-2001	0.270	0.048	0.334	0.210	0.038	0.144		1.015
2001-2002	0.270	0.040	0.366	0.225	0.053	0.258		1.174
2002-2003	0.290	0.050	0.387	0.250	0.075	0.258		1.312
2003-2004	0.350	0.060	0.408	0.300	0.113	0.231		1.443
2004-2005	0.400	0.050	0.429	0.360	0.150	0.194		1.479
2005-2006	0.450	0.051	0.450	0.375	0.188	0.194		1.437
2006-2007	0.450	0.053	0.420	0.385	0.188	0.268		1.488
2007-2008	0.450	0.060	0.570	0.390	0.210	0.032		1.713
2008-2009	0.450	0.060	0.708	0.400	0.225	0.312		1.831
2009-2010	0.450	0.060	0.756	0.410	0.263	0.516		2.121
2010-2011	0.450	0.060	0.804	0.415	0.300	0.439		2.239
2011-2012	0.450	0.060	0.852	0.450	0.338	0.499		2.320
2012-2013	0.450	0.060	0.900	0.475	0.375	0.552		2.563
2013-2014	0.450	0.060	1.020	0.500	0.413	0.610		2.787
2014-2015	0.450	0.075	1.140	0.500	0.503	0.674		3.244
2015-2016	0.450	0.083	1.260	0.600	0.488	0.745		3.388
2016-2017	0.450	0.105	1.380	0.650	0.525	0.823	0.084	3.719
2017-2018	0.700	0.135	1.500	0.800	0.675	0.909	0.108	4.816
2018-2019	0.900	0.180	1.100	0.890	0.675	1.005	0.144	4.822
2019-2020	0.700	0.165	1.725	0.900	0.675	1.110	0.144	5.226
2020-2021	0.700	0.180	1.838	1.100	0.740	1.227	0.168	5.320
2021-2022	0.700	0.195	1.950	1.100	0.740	1.356	0.192	6.184

Annexure A2. Trends in area under aquaculture as a proportion of the total available area

Year	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
1985-1986	0.906	0.091	0.004				
1986-1987	0.886	0.089	0.026				
1987-1988	0.866	0.087	0.047				
1988-1989	0.853	0.082	0.065				
1989-1990	0.833	0.083	0.084				
1990-1991	0.811	0.084	0.102	0.003			
1991-1992	0.752	0.081	0.162	0.006			
1992-1993	0.734	0.079	0.166	0.022			
1993-1994	0.703	0.076	0.156	0.065			
1994-1995	0.689	0.074	0.153	0.069		0.015	
1995-1996	0.649	0.077	0.189	0.072		0.014	
1996-1997	0.622	0.074	0.210	0.074		0.021	
1997-1998	0.612	0.073	0.215	0.079		0.021	
1998-1999	0.574	0.068	0.255	0.081		0.023	
1999-2000	0.531	0.063	0.295	0.079		0.032	
2000-2001	0.563	0.067	0.232	0.088	0.010	0.040	
2001-2002	0.531	0.059	0.240	0.089	0.014	0.068	
2002-2003	0.524	0.072	0.233	0.090	0.018	0.062	
2003-2004	0.554	0.063	0.215	0.095	0.024	0.049	
2004-2005	0.576	0.048	0.206	0.104	0.029	0.037	
2005-2006	0.592	0.045	0.197	0.099	0.033	0.034	
2006-2007	0.590	0.046	0.184	0.101	0.033	0.047	
2007-2008	0.569	0.051	0.240	0.099	0.035	0.005	
2008-2009	0.513	0.046	0.269	0.091	0.034	0.047	
2009-2010	0.485	0.043	0.272	0.088	0.038	0.074	
2010-2011	0.479	0.043	0.285	0.088	0.043	0.062	
2011-2012	0.461	0.041	0.291	0.092	0.046	0.068	
2012-2013	0.446	0.040	0.297	0.094	0.050	0.073	
2013-2014	0.422	0.038	0.319	0.094	0.052	0.076	
2014-2015	0.399	0.044	0.337	0.089	0.059	0.071	
2015-2016	0.378	0.046	0.353	0.101	0.055	0.067	
2016-2017	0.352	0.055	0.360	0.102	0.055	0.070	0.005
2017-2018	0.422	0.054	0.301	0.096	0.054	0.066	0.005
2018-2019	0.434	0.058	0.308	0.089	0.043	0.062	0.006
2019-2020	0.390	0.061	0.320	0.100	0.050	0.072	0.007
2020-2021	0.373	0.064	0.326	0.107	0.051	0.072	0.007
2021-2022	0.339	0.063	0.315	0.136	0.063	0.077	0.008

Annexure A3. Share of production of carps across the level of technology use (%)

Year	Level 1	Level 2	Level 3	Level 4	level 5	level 6	level 7
1985-1986	94.65	14.20	1.14				
1986-1987	89.37	13.41	7.79				
1987-1988	81.50	12.22	13.27				
1988-1989	82.87	11.97	19.03				
1989-1990	77.04	11.56	23.30				
1990-1991	65.58	10.20	24.61	1.21			
1991-1992	54.58	8.79	35.18	2.02			
1992-1993	51.45	8.29	34.87	7.62			
1993-1994	43.23	6.96	28.82	20.01			
1994-1995	40.50	6.53	27.00	20.25		6.40	
1995-1996	37.58	6.68	32.79	20.88		5.94	
1996-1997	32.60	5.79	32.99	19.32		8.34	
1997-1998	32.42	5.76	34.22	21.01		8.29	
1998-1999	29.00	5.16	38.67	20.41		8.55	
1999-2000	26.08	4.64	43.47	19.32		11.92	
2000-2001	26.60	4.73	32.88	20.69	3.69	14.23	
2001-2002	23.00	3.41	31.18	19.17	4.47	21.95	
2002-2003	22.11	3.81	29.50	19.06	5.72	19.64	
2003-2004	24.25	4.16	28.27	20.78	7.79	16.03	
2004-2005	27.05	3.35	29.01	24.34	10.14	13.13	
2005-2006	31.31	3.55	31.31	26.10	13.05	13.51	
2006-2007	30.25	3.53	28.23	25.88	12.60	18.00	
2007-2008	26.27	3.50	33.27	22.77	12.26	1.88	
2008-2009	24.58	3.28	38.68	21.85	12.29	17.06	
2009-2010	21.22	2.83	35.64	19.33	12.38	24.33	
2010-2011	20.09	2.68	35.90	18.53	13.40	19.62	
2011-2012	19.40	2.59	36.73	19.40	14.55	21.53	
2012-2013	17.56	2.34	35.11	18.53	14.63	21.53	
2013-2014	16.15	2.15	36.60	17.94	14.80	21.88	
2014-2015	13.87	2.31	35.14	15.41	15.49	20.77	
2015-2016	13.28	2.44	37.19	17.71	14.39	21.98	
2016-2017	12.10	2.82	37.11	17.48	14.12	22.12	2.26
2017-2018	14.54	2.80	31.15	16.61	14.02	18.88	2.24
2018-2019	18.66	3.73	22.81	18.46	14.00	20.83	2.99
2019-2020	13.39	3.16	33.01	17.22	12.92	21.24	2.76
2020-2021	13.16	3.38	34.54	20.68	13.91	23.06	3.16
2021-2022	11.32	3.15	31.54	17.79	11.97	21.92	3.11

Chapter- 7

Dried Fish Industry: Organization, Impacts and Policies

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1. Introduction

Drying is one of the oldest food preservation methods. Dried fish is a broader term that includes "all the aquatic animals preserved using simple techniques such as sun-drying, salting, fermentation, and smoking that permit storage at ambient temperature for an extended period without specialized packaging" (Belton, 2022). The technologies for dried fish range from conventional sun-drying to sophisticated, computer-controlled industrial procedures (Doe and Olley, 2020). Coastal communities have long incorporated dried fish into their dietary traditions, recognizing it as a vital component of their cuisine. This preserved seafood offers a concentrated supply of protein and other vital nutrients necessary for maintaining good health (Kent, 2019; Siddhnath et al., 2022; Kent 1987, Dey et al., 2005; Jensen 2013). Research suggests that the regular consumption of small dried fish may help address nutritional deficits in young children (Byrd et al., 2021). Improving access to dried fish is viewed as a crucial approach to promoting nutritional security, especially in developing nations. Several global organizations, such as FAO and DANIDA, have promoted the utilization of sun-dried fish powder and related products to tackle food insecurity (Savin, 2018; Skau et al., 2014; Konyole et al., 2012). During periods when fishing is prohibited and fresh fish availability is limited, dried fish serves as a critical food resource.

Fish drying serves not only as a source of nutrition but also as a viable economic opportunity for disadvantaged and underserved communities in South and Southeast Asia (Van Veen, 2012; Hossain et al., 2013; Gupta et al.,2020; Pradhan et al.,2023; Belton and Borgstrom, 2022; Thilsted et al., 2014). This creates job opportunities in value chain activities including fishing, processing, trade, and retail. In India, approximately 80% of fish production comes from small-scale fisheries (SSF). Improving the value chain of dried fish through advancements in technology as well as institutional and policy support can play a crucial role in enhancing livelihoods. Further, the economic issues of dried fish are not widely discussed from a policy perspective (Johnson *et al.,* 2018). In India, the Central Institute of Fisheries Technology (ICAR-CIFT) promotes the use of fish soup and fish powder as a means to address malnutrition. Then, two crucial questions arise: "Who is responsible for fish drying?" and "What economic and social roles do these individuals occupy within the dried fish supply chain?" Further, a review of the literature highlights the necessity of analyzing drying fish industry from a gender lens.

From a technological standpoint, the fish-drying industry can be divided into two primary sectors. The first is an informal sector that relies on conventional methods that utilize natural sunlight to dry fish. The second is a formal sector that employs advanced drying techniques including hot air drying, microwave vacuum drying, freeze drying, sun drying, dry salting, high-pressure processing, pulse light technology, pressure shift freezing, pressure-assisted thawing, photovoltaic systems, and pulsed electric fields. Although these sophisticated methods improve the quality of dried fish products, they require significant capital investment.

The safety and quality of fish are affected by the drying methods, practices, and ingredients added. These challenges include microbial contamination, heavy metal toxicity, and the use of unhealthy chemicals. The quality of fish can be compromised by microorganisms and heavy metals originating from fish. This necessitates robust quality control and monitoring systems to ensure safety and maintain standards. Globally, there is a growing trend towards certification and quality assurance programs that reward adherence to quality standards as an alternative approach. Worldwide, research on dried fish predominantly focuses on "food sciences," with 72% of studies covering areas such as food chemistry, microbiology, safety, and engineering (Belton, 2022). In contrast, policy-related matters have received significantly less attention in the dried fish sector both internationally and within India. The industry is also confronted with challenges stemming from ecological and climatic shifts, inadequate infrastructure, and exploitation of workers.

Given this background, the current research conducts a comprehensive examination of India's dried fish industry, identifies policy shortcomings, and offers recommendations for its enhancement. The remainder of this paper is organized as follows. Section II outlines the data sources and the methodological approach. Section III examines production and its applications, including exports. Section IV assesses the current state of dried fish operations in India using macro-level data. Section V explores the economic structure of dried fish enterprises in the selected Indian states, drawing on primary data from these businesses. Finally, Section VI concludes the paper with a summary of the findings and policy suggestions.

2. Data

This study utilized both primary and secondary sources of information. Data regarding fish production, utilization, and prices were obtained from the

Handbook of Fisheries Statistics, a publication by the Ministry of Fisheries, Animal Husbandry, and Dairying, Government of India. Information on the export of dried fish products was sourced from the Marine Products Export Development Agency (MPEDA), an organization under the Government of India.

The primary data on dried fish were collected from for locations: Visakhapatnam (Andhra Pradesh), Veraval (Gujarat), Cochin (Kerala) and Mumbai (Maharashtra). The firms were selected using snowball sampling. Data were collected from 25 dried fish making firms from each state constituting a total sample size of 100. After scrutinizing the data, information from 96 processors was used for the analysis.

A structured, pretested interview schedule was used to gather the data. This schedule included inquiries about general information, firm size, labor utilization, infrastructure, adherence to good management practices, quality assurance systems, credit and marketing arrangements, and encountered challenges. The survey was conducted in 2023 from January to December. To complement the primary data, information was obtained from secondary sources and insights were derived from a literature review.

The perspective on the Indian dried fish industry was examined from two angles: formal (organized) and informal (unorganized) sectors. Two distinct datasets were used for analysis. To study informal sector enterprises, data from the National Sample Survey Office (NSSO) Unincorporated Non-Agricultural Enterprises Surveys, specifically the 67th (2010-11) and 73rd (2015-16) rounds, which were the most recent surveys on this topic, were used. For formal-sector industries related to dried fish in India, data from the Annual Survey of Industries (ASI) covering the period 2009-10 to 2019-20 were used. Further, a case study of the Jagiroad dried fish market, the major trading hub for dried fish in Northeast India and one of the biggest dried fish markets of Asia, located in the town of Jagiroad in the Morigaon district of Assom is also carried out.

3. Results

3.1. Dried Fish: Production and Export

In 2022-23, India produced 16.2 million tons of fish, consisting of 4.2 million tons of marine fish and 12.0 million tons of inland fish. Approximately 67% of the total fish produced in India is consumed fresh, 16% is utilized for processing and drying, 6% is converted into FM, and 1% is canned (GoI, 2023).

Owing to its highly perishable nature, fish require immediate processing, ideally within two hours of being caught. Swift handling and processing procedures are essential to prevent the degradation of fish quality.

3.1.1. Dried fish production

A broader trend is that dried fish production in India is declining (Table 1). The total dried fish production declined from about 0.6 million tons in 1999-2000 to 0.5 million tons during 2020-21. Thus, the share of dried fish in the total fish production declined from 10.4% to 3.7%. The proportion of fish that is converted into the dried form varies across states, from less than 1% to more than 40%. Gujarat leads dried fish production with 0.36 million tons, accounting for 67% of India's total dried fish production in 2020-21. Kerala ranked second, accounting for 12% of the total production (Table 2). The decline in the share of dried fish indicates a changing trend in fish utilization.

Table 1. State-wise dried fish production in India (in tonnes)

State	1999-2000		2004-05		2009-10		2016-17		2020-21	
	Quantity	%	Quantity	%	Quantity	%	Quantity	%	Quantity	%
Andaman & Nicobar Islands	2930	10.4	238	0.7	1592	4.8	6675	17.2	7000	17.5
Andhra Pradesh			50682	5.9	78325	6.1	466	0.0	9000	0.2
Assam			704	0.4	580	0.3	1080	0.4		
Bihar	1316	0.5	1752	0.7	6917	2.3				
Chhattisgarh			920	0.8	580	0.3	910	0.2	1000	0.2
Daman & Diu	480	3.0	60	0.5						
Goa			8241	0.8						
Gujarat	326794	44.1	333675	52.5	344062	44.6	353069	43.5	356000	41.4
Haryana	5013	16.7	10030	23.9	19500	19.4				
Jammu & Kashmir			604	3.2	658	3.4				
Karnataka	32654	11.2	27240	10.8	58933	14.4			28000	4.4
Kerala			60077	8.9	70867	10.7	62122	10.2	66000	9.7
Lakshadweep	1210	8.9	1358	11.4	1411	11.4	1371	4.6	1000	5.0
Maharashtra	18511	3.5	28805	5.3	29474	5.5	18624	2.8	18000	3.2
Manipur	1950	12.6	50	0.3	142	0.7	2673	8.4		
Nagaland					672	10.6	886	10.3	1000	11.1
Orissa	33831	13.0	17614	5.6	17583	4.7				
Puducherry	9822	22.9	8810	24.0	6925	16.5	656	1.3	1000	2.0
Tamil Nadu	119168	25.1	2675	0.6			206	0.0	36000	4.8
Tripura			710	3.6			2095	2.9		
West Bengal	35689	3.4	7020	0.6	12035	0.8	3546	0.2	4000	0.2
India	**589368**	10.4	**516391**	8.2	**652727**	8.3	**454380**	4.0	**528000**	3.7

Note: *% shows the share of dry fish production to total fish production in that particular state*
Source: *Indiastat.com*

Table 2. Share of dried fish production in major states to total dried fish production in India

States	1999-00	2004-05	2009-10	2016-17	2020-21
Andhra Pradesh	0.0	9.8	12.0	0.1	1.7
Gujarat	55.4	64.6	52.7	77.7	67.4
Karnataka	5.5	5.3	9.0	0.0	5.3
Kerala	0.0	11.6	10.9	13.7	12.5
Maharashtra	3.1	5.6	4.5	4.1	3.4
Tamil Nadu	20.2	0.5	0.0	0.0	6.8
West Bengal	6.1	1.4	1.8	0.8	0.8

Data source: GoI (2023)

3.1.2. Domestic consumption of dried fish

No comprehensive research has been conducted on the consumption patterns of dried fish. The availability of fresh fish significantly affects the consumption of dried fish. When fresh fish is scarce, such as during seasonal marine fishing bans, the use of dried fish increases. The demand for dried fish typically peaks during lean seasons or fishing prohibitions (Das et al., 2013). In certain regions, people prefer dried fish (Sajeev et al. 2020). For example, in Bhubaneswar (Odisha), approximately 40% of consumers reported consuming value-added fish products, including dried fish, once per month (Tanuja et al., 2020). Cultural preferences and regional culinary traditions drive the consumption of dried fish. In numerous coastal communities, dried fish are an integral part of local cuisine. Furthermore, disruptions in the food system, such as those experienced in the fish supply chain during COVID-19, have led to increased demand for dried fish (Anand, 2020).

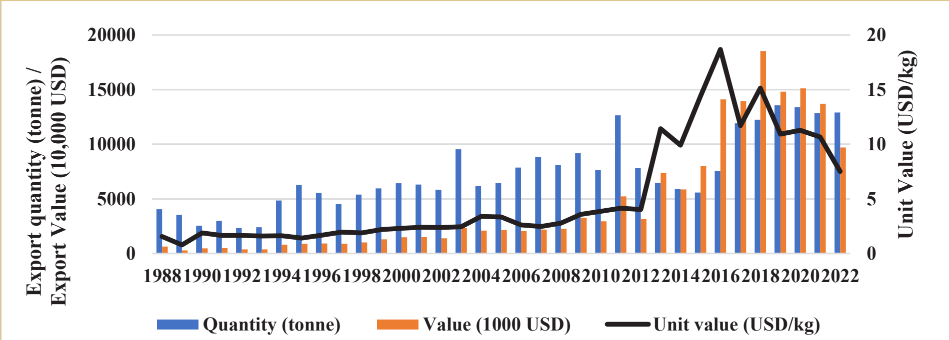
Despite the advantages of dried fish consumption, there has been a noticeable decline in per capita consumption of dried fish. Several factors have been identified as possible reasons for consumers' hesitation towards dried fish. These include the perception that consuming dried fish may lead to health issues, such as hypertension, scepticism about the processing techniques used, and concerns regarding the use of potentially harmful chemicals in the drying and preservation of fish. (Madhavi and Kusuma, 2015; Sajeev et al., 2020).

3.1.3. Exports of dried fish

Dried fish markets are divided into two categories: international and local. The exports of dried fish showed a significant upward trend. Between 1995 and 2022, the quantity of exported dried fish increased significantly from 4056 tonnes to 12908 tonnes. Similarly, the monetary value of these exports saw substantial growth, increasing from US $6.3 million to US $96 million during the same period. (Fig. 1). These changes highlight the economic potential of dried fish.

Sri Lanka, Bangladesh, and China are the primary buyers of dried fish from India. In TE 1992, Sri Lanka was the dominant market, purchasing 68% of India's dried fish exports, representing 45% of its export value. However, by TE 2022, the market landscape had changed significantly. Bangladesh emerged as the leading destination, receiving 61% of the export quantity, although this accounted for only 20% of the export value. This shift indicates that unlike frozen fish products and shrimp exports, Indian dried fish exports are becoming increasingly concentrated in South Asian countries, resulting in lower unit values (Table 3).

Fig. 1. Dried fish exports from India



Data source: Marine Products Export Development Agency, 2023

Table 3. Major export destinations of Indian dried fish

	Bangladesh	Bhutan	China	Hong Kong, China	Sri Lanka	World
Quantity (tons)						
TE 1992				14.5	1749.5	2614.4
				(0.6)	(66.9)	(100.0)
TE 2002	710.3	2.0	404.6	208.1	3328.4	6187.8
	(11.5)	(0.0)	(6.5)	(3.4)	(53.8)	(100.0)
TE 2012	2740.8	10.0	57.8	779.7	4814.2	10233.4
	(26.8)	(0.1)	(0.6)	(7.6)	(47.0)	(100.0)
TE 2022	7941.3	859.9	761.7	200.8	2214.9	13048.4
	(60.9)	(6.6)	(5.8)	(1.5)	(17.0)	(100.0)
Value (1000 USD)						
TE 1992				42.4	1089.3	2246.8
				(1.9)	(48.5)	(100.0)
TE 2002	288.5	3.2	545.0	804.7	2663.5	7285.8

	Bangladesh	Bhutan	China	Hong Kong, China	Sri Lanka	World
	(4.0)	(0.0)	(7.5)	(11.0)	(36.6)	(100.0)
TE 2012	2887.2	81.3	376.5	4480.6	6829.2	18883.5
	(15.3)	(0.4)	(2.0)	(23.7)	(36.2)	(100.0)
TE 2022	12579.7	2747.1	1021.6	36464.3	5695.1	64186.0
	(19.6)	(4.3)	(1.6)	(56.8)	(8.9)	(100.0)
Unit Value (USD/kg)						
TE 1992				2.9	0.6	0.9
TE 2002	0.4	1.6	1.3	3.9	0.8	1.2
TE 2012	1.1	8.1	6.5	5.7	1.4	1.8
TE 2022	1.6	3.2	1.3	181.6	2.6	4.9

Data source: WITS, World Bank

3.2. Dried Fish Industry in India

The national perspective on the dried fish industry is analysed from two angles: formal (organized) and informal (unorganized) sectors using the data on Unincorporated Non-Agricultural Enterprises of NSSO (67th and 73rd rounds) for the former and Annual Survey of Industries (ASI) (2009-10 to 2019-20 period) for the latter. The insights are provided below:

3.2.1. Informal sector enterprises related to dried fish

From 2010-11 to 2015-16, there was a substantial increase in the number of enterprises related to dried fish (Table 4). The sun-drying units experienced a 244% increase during this period. Urban areas experienced a higher growth rate than rural areas (1117% vs. 114%). This disparity can be attributed to the reclassification of certain rural areas as urban. Nonetheless, the sun-drying method in the dried fish industry within the unorganized informal sector grew at an annual rate of 28%. Dried fish segments have become increasingly important. In both years, most sun-drying enterprises were located in rural areas.

Table 4. Estimated number of dried fish-related enterprises in India

	Sun-drying of fish		Artificial dehydration of fish and seafood	
	2010-11	**2015-16**	**2010-11**	**2015-16**
Rural	3540	7576	0	10
Urban	529	6439	9	0
Total	4069	14015	9	10

Source: Estimated from the 73rd (2015-16) round of the Unincorporated Non-agricultural Enterprises (excluding Construction) Survey, NSSO. The GVA and capital were calculated based on the last 30 days of the survey.

Sun drying remains the predominant fish drying method across all states, with a significant increase in the number of enterprises from 2010-11 to 2015-16 (Table 5). States such as Kerala, Tamil Nadu, Odisha, Maharashtra, and West Bengal have shown notable changes in the number of enterprises.

Table 5. Estimated number of dried fish-related enterprises in India, across states

States	Sun-drying of fish		Artificial dehydration of fish and seafood	
	2010-11	2015-16	2010-11	2015-16
Andhra Pradesh & Telangana	0	135	0	0
Bihar	36	0	0	0
Jharkhand	19	0	0	0
Kerala	1284	6659	9	0
Maharashtra	2004	1300	0	0
Odisha	15	1670	0	0
Pondicherry	178	0	0	0
Tamil Nadu	533	4218	0	10
West Bengal	0	33	0	0
Total	**4069**	**14015**	**9**	**10**

Source: Estimated from the 73rd (2015-16) round of the Unincorporated Non-agricultural Enterprises (excluding Construction) survey, NSSO. The GVA and capital were calculated based on the last 30 days of the survey. Some states do not appear in the list, as the dried fish units are not being captured under the sampling framework.

Table 6 presents the average gross value added (GVA), capital, labor, labor productivity (LP), and capital-labor ratio (K/L) for the years 2010-11 and 2015-16. The GVA for sun-drying fish enterprises decreased, whereas that for artificial dehydration enterprises showed a substantial increase. The capital employed decreased for sun-drying fish enterprises and increased for artificial dehydration enterprises.

Table 6. Summary statistics of informal dried fish-related enterprises (mean values, at constant 2010-11 price)

Dried fish		GVA (Rs)	Capital (Rs)	Labor (number)	LP (Rs/ laborer/ month)	K/L (Rs/ laborer)
Sun-drying Fish	2010-11	11305	116260	2.58	3557	44165
	2015-16	6509	75062	2.61	4233	55643
Artificial dehydration of fish and seafood	2010-11	16955	414400	4.0	4239	103600
	2015-16	364874	274933	27.0	13535	10678

Source: Estimated from the 73rd (2015-16) round of the Unincorporated Non-agricultural Enterprises (excluding Construction) survey, NSSO. The GVA and capital were calculated based on the last 30 days of the survey.

The comparison of labor inputs between the two periods indicates a slight growth in the workforce for sun-drying fish operations and a significant expansion in labor requirements for artificial dehydration facilities. Labor Productivity (LP), calculated as gross value-added (GVA) per worker, showed improvement for both types of enterprises during this timeframe, demonstrating the enhanced efficiency of each labor unit over the years. This could potentially signify a greater implementation of advanced technologies. Sun-drying fish enterprises experienced a substantial increase in the capital-labor ratio. Conversely, artificial dehydration enterprises in the informal sector saw a decrease in their capital-labor ratio.

3.2.2. Formal sector industries related to dried-fish

From 2009-10 to 2019-20, India experienced a significant increase in the number of dried fish-related industries in the formal sector from 7 to 22 (Table 7). Specifically, sun-drying fish industries saw an increase from 2 to 14, while artificial dehydration industries expanded from 5 to 8. This indicates a shift towards more structured dried fish operations.

Table 7. Estimated number of formal dried fish-related industries in India

	Sun-drying of fish		Artificial dehydration of fish and seafood	
	2009-10	**2019-20**	**2009-10**	**2019-20**
Rural	0	7	5	3
Urban	2	7	0	5
Total	**2**	**14**	**5**	**8**

Source: Estimated from Annual Survey of Industries (2009-10 and 2019-20).

The state-wise distribution of formal industries shows that in 2009-10, there were formal sun-drying industries in Rajasthan and Assam (Table 8). However, by 2019-20, Rajasthan and Assam did not have any formal sector. Tamil Nadu saw a significant increase. In 2009-10, there were only five artificial dehydration industries in Tamil Nadu. By 2019-20, Goa had five formal industries, and Tamil Nadu saw a decrease in the number of formal industries in artificial dehydration.

Table 8. Estimated number of formal dried fish-related industries across states

State	Sun-drying of fish		Artificial dehydration of fish and seafood	
	2009-10	**2019-20**	**2009-10**	**2019-20**
Andhra Pradesh & Telangana	0	0	0	1
Assam	1	0	0	0

State	Sun-drying of fish		Artificial dehydration of fish and seafood	
	2009-10	**2019-20**	**2009-10**	**2019-20**
Goa	0	0	0	5
Rajasthan	1	0	0	0
Tamil Nadu	0	14	5	2
Total	**2**	**14**	**5**	**8**

Source: Estimated from Annual Survey of Industries (2009-10 and 2019-20).

The summary statistics of the formal industries show a significant improvement in GVA (Table 9). There was a substantial increase in the capital and labor employed in artificial dehydration. The LP improved in both categories, suggesting a more efficient use of labor in the production process. In general, in the formal sector, capital intensity per worker is increasing in the case of artificial dehydration and fish compared to sun-drying.

Table 9. Summary statistics of formal dried fish-related industries

(At constant 2009-10 prices)

Dried fish		GVA (Rs)	Capital (Rs)	Labor	LP (Rs/laborer/ month)	K/L (Rs/ laborer)
Sun-drying Fish	2009-10	-28875949	3241534	146	-171089	17451
	2019-20	36471	524004	4.5	4559	500441
Artificial dehydration of fish and seafood	2009-10	-324	19997	NA	-	-
	2019-20	3999506	5163242	186.13	2498.59	400153

Source: Estimated from the Annual Survey of Industries (200910 and 2019-20).

Note: GVA by definition is total output – total inputs; therefore, the negative value of GVA could be due to high expenses in that year.

India's dried fish industry has undergone a significant transformation, marked by a considerable increase in informal operations. The prevalence of sun-drying enterprises is attributed to the cost-effective nature of fish preservation techniques (Jain and Pathare, 2007). This approach is common in tropical and subtropical areas and leverages abundant solar radiation (Szulmayer, 1971). This is an eco-friendly method for producing dried fish. While some states exhibit a trend toward industry formalization, the informal sector continues to expand. Insights into the industry's evolution and growth can be gleaned from economic performance indicators, workforce and capital dynamics, and shifts in the state-wise distribution. Although overall employment in the formal sector remains relatively low, it is emerging as a significant source of job opportunities. These findings collectively underscore the multifaceted and evolving nature of India's dried fish industry, where informal enterprises predominate; however, the formal sector shows considerable promise.

4. Organization of Dried Fish Processing Units

4.1. Socio-Economic Profile of Respondents

4.1.1. Gendered nature of dried fish units

The dried fish industry is a source of livelihood, income, and employment for millions of individuals, including small-scale and large-scale fishers and processors, wholesalers, and small-scale retailers (Pramanik, 1996; Koralagama et al.,2021; Belton et al.,2022). Men and women play distinct roles in small-scale fisheries. The small-scale fishery sector employs over 90% capture fishers and fish workers worldwide, with women comprising approximately half of this workforce.

Women constitute a substantial portion of the labor force in the dried fish industry (FAO,2015; Berenji et al.,2021). Dried fish production had a clear gender dimension. Men are traditionally engaged in fishing, while women are mostly engaged in postharvest operations, including the drying and selling of fish. However, when it comes to ownership of dried fish enterprises, women's presence is less prominent. Our study revealed that 52% of dried fish units were owned by women (Table 10). Although women are extensively involved in dried fish processing and small-scale trading, men dominate the large-scale marketing of processed fish (De Silva et al.,2012; Koralagama and Bandara, 2018; Koralagama et al., 2021). Female workers in the dried fish industry receive significantly lower wages than their male counterparts. In addition, men occupy more profitable positions within the value chain (Elapata and De Silva, 2018). The level of education among the participants showed significant diversity. Although attempts have been made to introduce modern techniques in dried fish production to foster entrepreneurship, their adoption remains limited. There is a community aspect regarding this. Approximately two-thirds of the respondents were from fishing communities.

Table 10. General information about the dried fish units

Ownership of units, across gender (%)		
a.	Male	48
b.	Female	52
Age (Years)		
a.	20-29	4
b.	30-39	23
c.	40-49	42
d.	50-59	14
e.	>=60	18

Ownership of units, across gender (%)	
Education (%)	
a. Illiterate	10
b. Up to secondary	44
c. Higher Secondary	34
c. Graduation and above	10
Belongingness to the fishing community (%)	67
Share of respondents or their relative with other fishery-related activities (%)	55
Previous experience in dried fish production (%)	41
Average number of years engaged in in dried fish production	22

Size of the processing units

Dried fish production units are generally of a small scale, as indicated in the primary survey. The largest area is approximately 9000 m^2 (Table 11). More than half (54%) of the total dried fish units were pucca (permanent). Ownership has a distinct pattern: about 83% of dried fish firms are of single ownership, and the remaining represent joint ownership. In general, single-ownership units are smaller in size.

The monthly output capacity ranged from as low as one ton to as high as 3000 tons. On average, 71% of the capacity was utilized. Several factors contribute to the underutilization of capacity, including raw material deficits, restricted market demand, and inadequate processing infrastructure.

Table 11. Details of the processing units

Area (Sq. Meter)	
Mean	1112
Maximum	9000
Minimum	37
Median	74
Type of units (%)	
Kutcha	46
Pucca	54
Type of ownership (%)	
Single	83
Joint	17

4.1.2. Labor participation and gender

The dried fish industry engages both permanent and temporary laborers. Table 12 shows the composition of the labor force. Women constituted 48% of the total workforce, deviating from the popular notion that women constitute major workers. Nevertheless, regional differences were observed: women made up 63-64% of the workforce in Veraval and Visakhapatnam, while their representation was 30% in Kochi and 38% in Mumbai. Looking into the composition with respect to contracts, about 53% of laborers are permanent, and the remainder are casual laborers. Temporary workers (as casual laborers) accounted for approximately 47%. In Veraval and Visakhapatnam, most workers are temporary, accounting for 80-85% of the total workforce.

Table 12. Composition of labor force

Item	Percentage
Total male	52
Total female	48
Total	100
Total Permanent	53
Total temporary	47
Total	100
% temporary	47
% female	48

4.2. Processing Aspects

4.2.1 Diversity

A diverse set of fish was used for drying and value addition (Table 13). Fish for drying purposes are generally purchased at lower prices when plenty of fish are available. Fish of all types with high and low values were used for drying. A notable feature of Veraval is the substantial processing of Indian dog sharks and khagi (giant catfish). Kochi distinguishes itself by processing a wider variety of fish, including both marine and freshwater species such as prawns. Dried prawns hold a special place in the market in terms of consumer demand and prices. In Mumbai, the processing of cuttlefish and ribbon fish is dominant. In Visakhapatnam, a wide array of processed fish is available, with sailfish being the most significant contributor. Thus, regional differences depend on the local availability of fish for drying, the local demand for dried fish, and consumer preferences. The requirements of inputs and labor for drying vary according to the type of fish. Normally, 3-4 kg of fresh fish yields a kg of dried fish, but the price of dried fish multiplies several times.

Table 13. The diversity value fish used for value addition

Fish	Share in total purchase quantity (%)	Purchase price (Rs/kg)	Share in total purchase value (%)	Share in value of total dried fish (%)
Veraval				
Eel	14	80	22	9
Croaker	13	48	12	9
Cat Fish	10	48	9	11
Khagi (Giant catfish)	28	30	17	16

Fish	Share in total purchase quantity (%)	Purchase price (Rs/kg)	Share in total purchase value (%)	Share in value of total dried fish (%)
Indian Dog Shark	21	70	29	46
Kochi				
Anchovy	9	57	7	6
Manthal (Cynoglossus)	20	50	14	10
Chemban A (Prawn)	10	110	14	11
Thelli Chemmen (Flower tail prawn)	11	63	10	16
Parava (False Trevally)	21	105	29	29
Mumbai				
Penaeid Shrimp	4	120	8	6
Acetes	4	60	4	6
Ribbon Fish	7	100	14	17
Golden Anchovy	24	30	14	28
Cuttlefish	61	50	59	44
Visakhapatnam				
Croakers	8	50	1	2
Goatfish	13	30	1	2
Ribbon Fish	6	70	2	3
Anchovies	8	82	3	3
Sail Fish	38	600	86	83

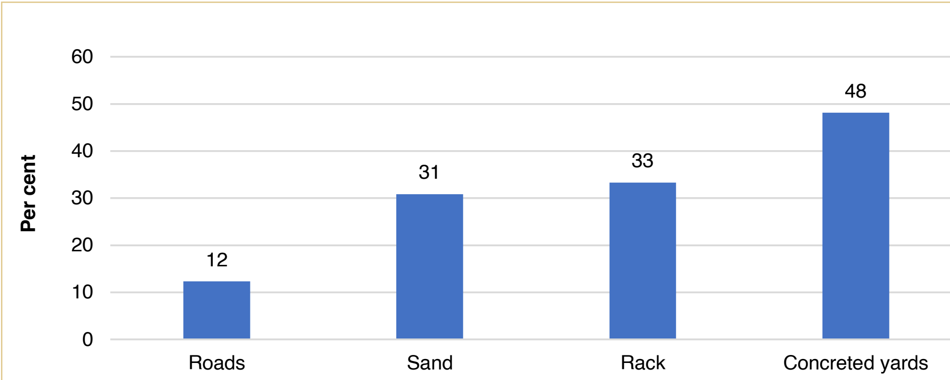
In the domestic market, the demand for dried fish emanates from remote areas where the fresh fish supply chain is constrained due to infrastructure bottlenecks. In other areas, the demand for dried fish is mostly captive, particularly at the species level, as it demands a unique taste. Thus, the prices of dried fish are determined mostly by supply conditions. Owing to limited storage facilities, any surplus fish in the ports must be sold on the same day it arrives. The selection of fish for drying depends largely on the availability of fresh catches at harbors and fluctuations in fresh fish market prices.

4.2.2. Adoption of good management practices

4.2.2.1. Drying methods

Drying methods can be classified into two types: sun-drying and mechanical drying. Sun drying is the most prominent method. Only 4% used solar dryers and another 4% used electrical dryers. Approximately half of the firms used scientifically constructed concrete yards for sun-drying (Fig. 2). The practices of drying on beaches and roadways were adopted by 12% and 31% of the respondents, respectively. This poses risks to quality and safety. This information clearly indicated a shortage of adequate drying facilities.

Fig. 3. Methods of drying fish



Ensuring the quality of dried fish requires adherence to good drying practices (GDP). The use of salt helps prevent spoilage. While 84% of the firms used salt during drying, only about 49% used it for small sized fishes (Table 14). Another recommended technique, immersing small fish in brine solution before drying, is practiced by only approximately 11% of firms. Although finer salt is advised for drying, only 47% of firms use it because of its high cost. For larger fish, 61% of firms employed layer salting. Despite being recommended for drying shrimp, blanching is only used by approximately 6% of the firms. The drying duration also showed significant variation. Soaking in 5% acetic acid is suggested to maintain the quality of dried shrimp, but only about 16% of firms follow this practice. These findings highlight the need for robust extension support to promote scientific fish-drying methods. Currently, fisheries extension services focus primarily on capture and aquaculture, with limited attention given to postharvest operations.

Table 14. Drying practices followed

Salting practice (%)	Values
a. Follow salting while drying the fish	84
b. Follow salting while drying small fishes	49
c. Dip small fishes in brine solution before drying	11
Duration of salting (%)	
a. One day	4
b. Two days	83
c. Three days	13
Kind of salt used (%)	
a. Fine salt	47
b. Coarse salt	53
Blanching for small shrimps (like *Metapenaeus dobsoni*) (%)	6
Duration of drying shrimps (%)	

Salting practice (%)		Values
a.	One day	7
b.	Two days	31
c.	Three days	63
Layer salting for medium and bigger-sized fishes (%)		61
Proportion salt used in layer salting		
a.	Big fish	0.4:1
b.	Small fish	0.2:1
Salting duration for fishes (%)		
a.	One day	39
b.	Two days	41
c.	Three days	21
Washing of salted fish to remove excess salt (%)		
a.	Wash salted fish to remove excess salt using potable water	62
b.	Do not wash the fish	15
Duration of drying of bigger-sized fishes (%)		
a.	one day	3
b.	b. two days	52
c.	c. three days	22
d.	d. four days	23

4.2.2.2. Hygienic handling and pre-processing of fish

Maintaining sanitary practices throughout the process, beginning with the acquisition of raw materials, is essential for guaranteeing the quality of dried fish products. Raw materials were obtained from three primary sources: landing centers (53%), established suppliers (33%), and marketplaces (38%). Approximately 27% of the respondents indicated that they had never received fish of substandard quality. Nevertheless, 35% reported that fish of poor quality were never utilized for drying, whereas 65% stated that such substandard fish were sometimes utilized. The cooling technique is recommended to slow down fish spoilage during transportation. However, its adoption rate is quite low. Vehicles without roofs are widely used, exposing fish to direct sunlight.

The primary factors contributing to the limited use of insulated vehicles are their high expense and the smaller size of firms. Cost reduction is a significant driver of low adoption of icing techniques. Moreover, the additional expenses associated with icing are not offset by higher prices for the products. Lack of awareness was another contributing factor. The market's inability to differentiate quality products hinders the implementation of quality assurance measures.

Table 15. Raw material procurement and transportation

1	**Source of raw material (%)**		
	a.	Directly from landing center	56
	b.	Known supplier	33
	c.	Market	38
2	**Track over the source of the raw material**		20
3	**Transportation of raw material to the firm**		
	a.	Owned vehicle	2
	b.	Rented vehicle	24
	c.	Chaka Rickshaw (make-shift vehicles of local adaptation)	22
	d.	Insulated vehicle	4
	e.	Van	20
	f.	Others	6
4	**Usage of ice during transport**		40

Grading of dried fish, based on certain quality parameters, helps to realize better prices, grading is universally practiced; however, with variations: in Cochin, only about 40% of firms reported grading practices. The criteria were size and quality (88%), color and appearance (88%), cleanliness (12%), and level of drying.

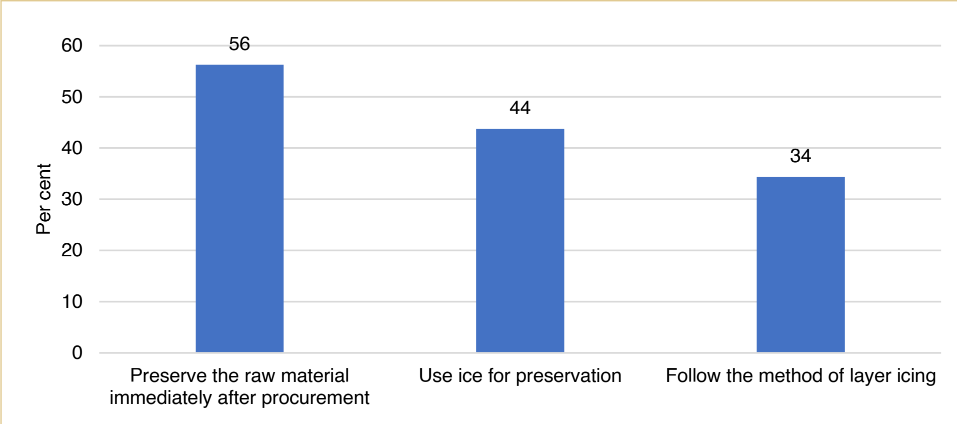
Approximately 63% of the companies reported losses of dehydrated products due to various factors, including rain exposure, humidity, excessive drying, limited storage space, poor handling during processing and storage, and contamination with foreign materials. This highlights the multifaceted challenges that dried fish producers face across different regions, encompassing environmental issues, market dynamics, and operational procedures. These findings emphasize the critical need for sanitary drying methods and appropriate packaging techniques.

Gunny bags were the most common packaging material used in 67% of the cases. Alternative packaging options included waxed corrugated cartons (31%), vacuum packaging (34%), gusseted bags made of HDPE (26%), and deal wood (19%). Each method has its advantages and disadvantages; however, the primary concern is ensuring that the packaging provides adequate protection for the produce without compromising its quality. Currently, quality assessments are conducted through visual inspection rather than scientific testing. These observations underscore the necessity of establishing institutional mechanisms to safeguard produce quality and to prevent spoilage. It is crucial to raise awareness among producers and develop supportive infrastructure to ensure that quality standards are met.

4.2.2.3. Quality assurance/certification

In India, two national organizations, the Food Safety Standard Authority of India (FSSAI) and the Bureau of Indian Standards (BIS), have established certification standards for fish products. However, the FSSAI guidelines are generally preferred for quality evaluation. Market data reveal that fewer than 10% of companies in domestic markets have obtained registrations or certifications for dried fish products.

Fig. 3. Preservation approaches for fish



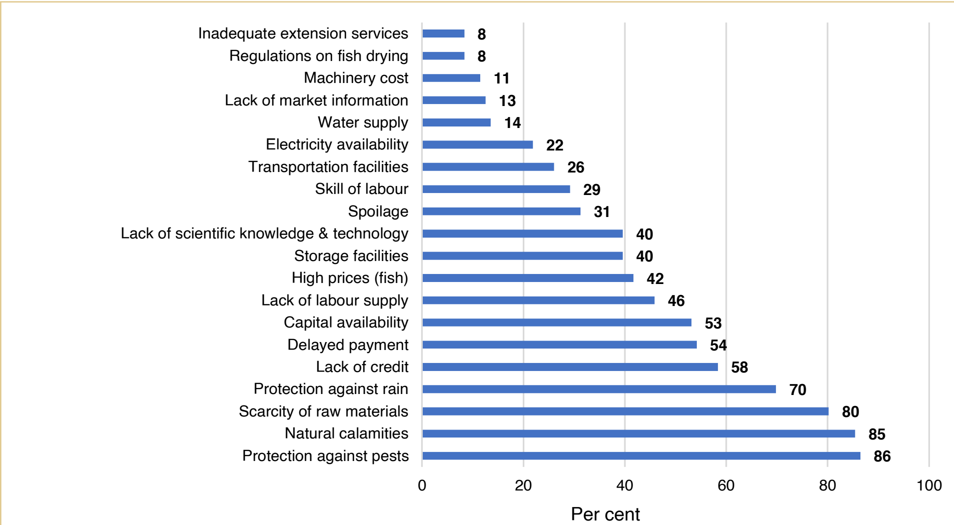
The information revealed differences in preservation techniques, showing the range of methods utilized (Fig. 3). Approximately 56% of companies preserve raw materials at the drying yard immediately after acquisition, whereas 44% utilize ice for preservation. Layer icing, a technique that involves applying ice in layers to establish a uniform and regulated preservation environment, is employed by 34% of the firms. Although ice usage is influenced by factors such as the local climate, infrastructure limitations, and advancements in drying technology, a lack of awareness also hinders its adoption. Nearly 94% of companies use high-quality portable water to clean fish and contact surfaces, and separate waste materials. These results emphasize the importance of promoting hygiene practices throughout all phases of dried fish production, and the necessity of providing processors with modern hygiene equipment.

4.3. Constraints

The dried fish industry encounters various obstacles (Fig. 4), which are categorized as technical and institutional. Primary technical constraints included pest infestations (86%) and environmental disasters, such as floods and cyclones (85%). Although pest problems in dried fish are common, chemical control methods are not recommended. High rainfall and moisture content lead to quality degradation. Pandemics, such as COVID-19, have disrupted the supply chain of dried fish and negatively impacted its market distribution.

Major institutional constraints pertain to access to inputs and services and the inability to adhere to regulatory regimes. The scarcity of raw materials (fish and ice) (80%), lack of credit availability (53%), delayed payment for products, inadequate transportation facilities, poor storage facilities, lack of price information, and inadequate markets and extension services have also been reported. Labor-related challenges include a lack of labor supply and poor skill of laborers in fish drying. Fish dryers are costly. Furthermore, service facilities for dryers are not well developed. Regulatory constraints pertain to weak regimes of inspection and quality checking by state authorities. The market is not well developed to distinguish quality differences in terms of price. One is the lack of certification. Infrastructure-related issues pertain to electricity-, water-, and transportation-constrained dried fish.

Fig. 4. Constraints faced by dried fish processors



4.4. Marketing and Supply Chain

The traditional dried fish industry operates through long-established relationships. Typically, small-scale producers sell their products to wholesalers, who then distribute fish to various regions through retail agents. The lack of proper certification for dried fish products discourages adherence to quality standards. Jagiroad dried fish market located in the Morigaon district of Assom state is a leading dried fish market in Asia. A case study of the market is provided in the box below.

Dried fish trade at Jagiroad market, Marigaon, Assom: A case study

The Jagiroad dried fish market is a major trading hub for dried fish in Northeast India, located in the town of Jagiroad in the Morigaon district of Assom. The Jagiroad dried fish market is a vital part of the fish trade network in Northeast India, providing a source of affordable protein and supporting the livelihoods of many people involved in the trade, processing, and transportation. Dried fish is a staple food in the Northeastern states of India, and the Jagiroad market plays a crucial role in ensuring its availability, thus contributing to the preservation of local food cultures.

The Jagiroad fish market plays a vital role in the local economy, providing livelihoods for numerous individuals involved in the of dried fish. Dried fish include both marine and freshwater species. Popular marine fish include ribbon fish, Bombay duck, silver bellies, and others. Freshwater prawns and smaller ornamental fish are also traded. Salted Hilsa is a high-demand, though expensive, item.

Located in Jagiroad, approximately 50 km from Guwahati, the dried fish market spans about 1.5 hectares and involves numerous traders. Only about 60-70% of traders are permanent members of the Jagiroad Dried Fish Market Cooperative Society. Established in 1967-68, this market is reportedly the third largest in Asia. Some of the dried fish gets exported to Singapore, Bhutan, Malaysia and other Southeast Asian countries. This market, primarily active three days a week (Thursdays, Fridays, and Saturdays), hosts approximately 200 dried fish shops run by wholesalers. Over 4,000 people depend on this bustling trade, either directly or indirectly. Fish prices fluctuate based on size and quality. Remarkably, trade is conducted on a trust-based credit system. Traders have to pay 80% of their previous balance before making new purchases, a practice also followed by wholesalers. All accounts are settled before the Holi festival.

The Jagiroad Dried Fish Traders Association, a registered society, plays the primary role in facilitating trade within the market. Market shops and land are either privately owned or rented from their owners. Retailers travel to the Jagiroad market from across Northeast India, with a significant portion, approximately 40%, coming from Meghalaya, and notably, many of these are women. Other retailers come from Manipur (15%), Arunachal Pradesh (15%), and a combined 30% from Tripura, Nagaland, and Karbi Anglong. The dried fish itself is sourced from various locations across India, including Gujarat (Porbander, Bheradal, Okha), Mumbai, Tamil Nadu (Villupuram), Uttar Pradesh (Gorakhpur, Lucknow), Kolkata, and Andhra Pradesh (Vijayawada, Kakinada). The local sources are mostly from Nagoan, Marigaon, Harpeta, and Lakhimpur in Assam.

More than 50% of the traded dried fish goes through the marketing channel given by dried fish producer-assembler, Commission agentwholesaler-retailer-consumer. Dried fish from outside Assam are primarily transported by train, while local varieties arrive by bus and truck. Imported fish is typically packaged in gunny bags (25-40 kg each) or bamboo baskets (15-20 kg each). Traders generally receive two consignments per month, as the fish spoils if stored for more than ten days. Low-quality fish is then sold cheaply, around ₹ 10, for poultry feed or fishmeal. Retailers also hire trucks to transport their purchases from Jagiroad to their respective markets. A state sales tax applies to dried fish. While more expensive, salted Hilsa is the most sought-after variety in the Jagiroad market. The market handles both salted and unsalted dried fish, with a clear preference for the unsalted variety. The dried fish trade includes both marine and freshwater species, but marine species dominate the market. Low-value fishes occupy a major chunk of the traded dried fish.

Species such as Channa punctatus, Aorichthys seenghala, Puntius siphore, Amblypharyngodon mola, Notopterus chitala, Wallago attu, Labeo rohita are imported from several States. Among the marine dried fish sold at Jagiroad, ribbon fish, Bombay duck, silver bellies, and other smaller fish are traded in the largest volumes. More expensive options like dried sharks, shrimp, and pomfret make up a smaller portion of the trade. Freshwater prawns sold primarily consist of Macrobrachium malcolmsonii and other smaller, locally sourced varieties. Also traded are small, inexpensive ornamental fish from freshwater sources, popular due to their low prices.

The price is arrived based on the demand and negotiations, and not through auctions. The credit facility is practiced among the suppliers of the dried fish, the traders of the Jagiroad market, and the buyers based on mutual trust. Institutionalised trade practices are uncommon. The trading community of the Jagiroad comprises a mix of traders from various states and the local people from a small percentage.

Dried fish is consumed as it is and also converted to other forms like fermented fish known locally as 'Shidal'. Consumers in Nagaland prefer smoked and dried fish. This market for dried fish sees its highest demand from October to February, attracting the most retailers, the reason being the winter season. However, it nearly shuts down during the coastal states' trawl fishing ban, which disrupts the dried fish supply. The market faces challenges related to hygiene, storage, and potential public health concerns primarily due to the nature of the product, scale of operations, and poor infrastructure and quality enforcement system. Insufficient marketing facilities with limited parking and inadequate space for loading and unloading are among the major constraints.

5. Policy Gaps and Intervention Points

In India, the dried fish industry is more than just an economic activity and nutritional resource; it is intricately woven into the social, ecological, and cultural landscapes. To enhance the industry's role in providing nutrition and economic opportunities, it is necessary to restructure the value chain by addressing consumer and producer concerns, implementing modern quality standards, and introducing institutional change. However, this process requires policy support.

5.1. Technology Penetration

Traditional fish drying technology is cost-effective and environmentally friendly, but is labor- and space-intensive, and falls short of ensuring quality and safety. Advanced fish drying technologies are available, including electric and solar dryers, but they are beyond the scope of small-scale producers. Future perspectives for the dried fish industry lie in cutting-edge fish drying and food engineering technology, and the application of omics in dried fish assessment. Technologies that focus on producing high-quality dried fish with minimal changes by non-thermal means could be developed to enhance the safety and quality of dried fish and for value addition (Fitri *et al.*, 2022). The scale economy needs to be fully leveraged to utilize this potential. The dried fish processing technologies can be popularised by policy nudges to adopt improved machineries like electric and solar dryers. One step is to provide soft loans. Another step is to incentives establishment of quality assurance system and traceability in the entire value chain. This could potentially increase the price of the product, but the consumers are sensitive to quality assurance system. Dried fish producers–individuals or groups- need to be financially supported to adopt advanced technology. Ongoing fishery schemes should incorporate these dimensions.

5.2. Promotion of Producer Collectives

A serious concern in dried fish production is that producers are scattered, have low bargaining power, and have a poor capital base. Organizing dried fish producers into collectives can help address weaknesses and leverage economies of scale.

5.3. Regulatory Framework

The lack of a comprehensive and specific regulatory framework for the dried fish sector has led to difficulties in monitoring and enforcing standards. The FSSAI and BIS set standards for dried fish, but there are some areas of regulatory overlap and contradictions. This lack of convergence among standard-setting agencies must be addressed. Furthermore, the regulations for ensuring the quality, hygiene, and labelling requirements for dried fish products are limited and inadequate. The weakest link is inspection and enforcement, which comes under the purview of the states.

5.4. Hygiene and Quality in Dried Fish Processing Units through GMP

The drying process for fish involves a series of steps to ensure product safety and quality, and the need to follow Good Manufacturing Practices (GMP) and Good Hygienic Practices (GHP). To achieve this, identifying the critical control points (CCP) and following scientific packing and labelling is essential. Plant design, construction, layout, machinery design, and construction must facilitate unidirectional movement, ensuring compliance with the GMP criteria. Personnel hygiene is paramount and involves medical fitness checks, clean uniforms, and proper sanitation. Cleaning practices are governed by standard sanitation procedures (SSOP). Risk/hazard monitoring facilities and robust laboratories are essential for effective GMP/GHP implementation. Traceability and recall procedures, along with employee training in personal hygiene, GHP, and HACCP systems, further contribute to a comprehensive approach to ensuring the safety and quality of dried fish products. By following GMP standards, the industry can not only meet regulatory requirements but also enhance market competitiveness, instilling consumer confidence in the safety and quality of dried fish products, both domestically and internationally. Establishing a labelling and traceability system for the dried fish could turn out to be a key component of enhancing consumer acceptance in domestic and export markets.

5.5. Extension, Training and Capacity Building

Most dried fish producers lack knowledge of modern technology that adheres to quality standards. The extension of fisheries, which focuses on capacity building, is essential. Fisheries extension is mostly limited to culture and harvest operations and is not venturing into higher levels of activities, such as value addition, including dried fish making. This calls for skill development programs. To upscale the training and increase the number of trained personnel, advanced research institutes need to act as institutes for training trainers. For this purpose, different stakeholders, including line departments, NGOs, and organizations working in rural areas, are to be roped in. Furthermore, programs for promoting awareness about dried fish production, including quality maintenance at all levels, are to be enhanced. Conducting targeted training workshops, on-site training, and establishing demonstration processing units adhering to GMP standards allows processors to witness best practices first-hand.

5.6. Social Protection for Fish Workers

Workers in the dried fish industry are generally marginalized groups that are vulnerable to various forms of exploitation and occupational health hazards.

Sanitation and other infrastructure in production centers are often poor. Even though the government has introduced a minimum wage in India, it is not widely practiced in unorganized sectors. Therefore, improving amenities in the workplace and social protection for workers must be ensured. The major social protection measures can be enacting welfare funds, accessibility to medical facilities, and pensions for those working in the sector for a certain minimum period. This requires the registration of firms, as per the regulations, and a statistical system for arriving at the annual potential cost. Women, being a major contributor to the dried fish value chain, enhancing their social welfare through a gender-sensitive approach would have a greater relevance.

5.7. Lack of Physical and Digital Infrastructure

Inadequate infrastructure facilities and poor incentive systems (market and public) for adopting modern and efficient technologies hamper a sector's competitiveness and productivity. Essential infrastructure, such as cold storage, reliable transportation, modern drying methods, such as solar drying, and improved processing techniques are expected to improve efficiency and product quality. Another serious lacuna is poor market infrastructure for fresh and dried fish. Therefore, strengthening post-harvest infrastructure, such as chilled storage facilities, ice plants, cold chains, freezing/processing units, roads, transportation, modern wholesale and retail fish market outlets, and effective marketing networks, are key requirements for developing this sector. Technology also plays a crucial role in market connectivity and supply chain management. Investments and financial support (mainly subsidies) are needed to address these challenges, as one of the major barriers to entry is the high cost of technology and infrastructure development. This can be an integral part of developmental schemes.

5.8. Market Linkages

Limited initiatives to establish strong market linkages for dried fish producers hinder access to domestic and international markets. The lack of marketing support and promotion strategies for dried fish products restricts the growth potential of the sector. Effective market linkages provide producers with access to diverse marketplaces, affect sales promotions, and create a wider customer base. Market linkages also facilitate technology transfer and innovation, and encourage advanced drying, packaging, and storage practices. Niche markets for dried fish are to be identified and promoted. Labelling fish can create value and promote the adoption of GMPs.

5.9. Institutional Support for Entrepreneurship Development

Entrepreneurs in the dried fish industry face numerous challenges including skill gaps, outdated technology, and market price instability. The

Government of India has implemented various initiatives to address the challenges faced by entrepreneurs. These programs cover a wide spectrum of support, including strategies for financial inclusion, skill training, fostering entrepreneurship, and creating opportunities for professional networking. Several schemes have been launched, such as Pradhan Mantri Mudra Yojana (PMMY), Stand-Up India Scheme, Deen Dayal Upadhyaya Grameen Kaushaliya Joana (DDU-GKY), Entrepreneurship-cum-Skill Development Program (E-SDP), Entrepreneurship Awareness Programs (EAPs), Assistance to Training Institutions (ATI), Credit Linked Capital Subsidy and Technology Upgradation Scheme (CLCS-TUS), MSME Competitive (LEAN) scheme, and MSME-Innovative (incubation, IPR, Design and Digital MSME) scheme. These programs are designed to enhance access to financial resources, improve skill development and job placement, and expand entrepreneurship opportunities.

Dried fish constitute not only a significant dietary component contributing to the food and nutritional security of the coastal population in India but also provide employment and foreign exchange. The dried fish value chain has to imbibe modern technologies including quality standards to enhance consumer acceptability and to penetrate external markets. By focused intervention through technology, institutions, and policy, the dried fish economy could be turned into a more vibrant sector in the post-harvest domain of fisheries.

5.10. Promotion of Dried Fish Consumption

In view of the potential of fish to address undernutrition in rural areas, consumption of dried fish is to be promoted by policies and incentives. First, improve the consumer confidence on safety and quality of the dried fish. Implementation of effective quality assurance system in the entire value chain of dried fish is to be promoted, with proper packaging and labeling. Second, strengthen the regulatory regime for quality assurance with increased inspections and enforcement of the regulations. Third, diversification of dried fish products could be another strategy to promote the consumption. This includes developing value-added products from dried fish and promoting establishment of elaborate supply chain. Four, the dried fish is produced mostly in the unorganized sectors, and reputed brands are very scarce. Brand building in case of dried fish products needs to be promoted by incentives. Five, the dried fish can be included as a component in the food supply schemes for targeted population, as in the case of school children, pregnant and lactating women and for special areas.

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Impact of Technologies and Policies on Marine and Inland Fish Culture Systems in India

Edited by: Shinoj Parappurathu, Suresh A, Nagesh Kumar Barik, Geetha R, Anjana Ekka, Rajni Jain

This book is intended to serve as a valuable resource for researchers, academicians, policymakers, students, professional practitioners, and the industrialists. It is organized into seven chapters, each dealing with innovations in a particular sub-sector of the marine/inland aquaculture economy with detailed analysis and findings regarding the economic and social impacts of selected technologies. Furthermore, the chapters also discuss policy implications associated with the shifting regimes of technology and future investment and governance requirements towards further development of the sector. ICAR-NIAP is proud to take the initiative to commission the studies that led to the compilation of this book under a National Network Project funded by the ICAR and hopes that this work will inspire further research and innovation in the field of aquaculture and allied sectors toward a more inclusive and sustainable fisheries community.

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ISBN : 978-93-342-3364-3

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