



From Catch to Consumer

Oceanic Wealth and Economic insights of Fisheries at State,
National and Global Perspective

B. Velmurugan
N. Samima
A. Ayisha Banu
J. Halima Safrin
A. Balan *Editors*

From Catch to Consumer: Oceanic Wealth and Economic insights of Fisheries at State, National and Global Perspective

B. Velmurugan

Sir Theagaraya College, P.G. & Research Department
of Zoology, Chennai, Tamil Nadu, India

N. Samima

Sir Theagaraya College, P.G. & Research Department
of Zoology, Chennai, Tamil Nadu, India

A. Ayisha Banu

Sir Theagaraya College, P.G. & Research Department
of Zoology, Chennai, Tamil Nadu, India

J. Halima Safrin

Sir Theagaraya College, P.G. & Research Department
of Zoology, Chennai, Tamil Nadu, India

A. Balan

Sir Theagaraya College, P.G. & Research Department
of Zoology, Chennai, Tamil Nadu, India



Published, marketed, and distributed by:

Deep Science Publishing, 2026
USA | UK | India | Turkey
Reg. No. MH-33-0658412
www.deepscienceresearch.com
editor@deepscienceresearch.com
WhatsApp: +91 7977171947

ISBN: 978-93-7185-390-3

E-ISBN: 978-93-7185-342-2

<https://doi.org/10.70593/978-93-7185-342-2>

Copyright © B. Velmurugan, N. Samima, A. Ayisha Banu, J. Halima Safrin, A. Balan, 2026.

Citation: Velmurugan, B., Samima, N., Ayisha Banu, A., Halima Safrin, J., & Balan, A (2026). *From Catch to Consumer: Oceanic Wealth and Economic insights of Fisheries at State, National and Global Perspective*. Deep Science Publishing. <https://doi.org/10.70593/978-93-7185-342-2>

This book is published online under a fully open access program and is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0). This open access license allows third parties to copy and redistribute the material in any medium or format, provided that proper attribution is given to the author(s) and the published source. The publishers, authors, and editors are not responsible for errors or omissions, or for any consequences arising from the application of the information presented in this book, and make no warranty, express or implied, regarding the content of this publication. Although the publisher, authors, and editors have made every effort to ensure that the content is not misleading or false, they do not represent or warrant that the information-particularly regarding verification by third parties-has been verified. The publisher is neutral with regard to jurisdictional claims in published maps and institutional affiliations. The authors and publishers have made every effort to contact all copyright holders of the material reproduced in this publication and apologize to anyone we may have been unable to reach. If any copyright material has not been acknowledged, please write to us so we can correct it in a future reprint.

Preface

This book offers a comprehensive exploration of the functional and structural elements of the nation's fish marketing channels and production systems. India's coastal and inland communities depend strongly on fisheries for their economic development, food security and for their livelihood with the extensive coastline, healthy marine resources and numerous inland water bodies. Tamil Nadu maintains an important position in country's fish production and marketing. The state fishing industry provides an enormous contribution to employment, income from exports, nutritional security and the overall development of the rural economy. In addition to highlighting the new opportunities in the fishery sector, such as advancements in technology, value addition, and potential to export. This review seeks to analyze patterns of production, cost and returns, marketing mechanism effectiveness, price distribution and the function of intermediaries in the sector and furnish pathways toward sustainability that balance ecological health, economic viability and social justice. It's assess the challenges facing capture fisheries and the growing importance of sustainable aquaculture, particularly in developing nations and also presents a overview of the economic importance and trade potential of tuna fisheries at the global level with special reference to India. This review is intended to support students, researchers and policymakers in promoting sustainable and economically viable tuna fisheries. The purpose of fish processing technology is to give consumers a thorough understanding of both traditional and advanced methods for processing such as chilling, freezing, drying, curing, smoking, canning and innovative methods such as irradiation, modified atmosphere packaging and the development of ready-to-eat products. To enhance the value and sales potential of the product, focus has been placed on hygienic processing, quality control, food safety regulations and the implementation of proper technologies and also provides the significance of processing technology to improving seafood industry incomes, strengthening competition for export and helping the development of sustainable fisheries.

B. Velmurugan
N. Samima
A. Ayisha Banu
J. Halima Safrin
A. Balan

Table of Contents

Chapter 1: An Economic Analysis of Fish Production and Marketing in Tamil Nadu “Opportunities and Challenges”	1
Chapter 2: India's Marine Fisheries: Sustainability at the Crossroads	15
Chapter 3: Global Fisheries and Aquaculture: Nutrition, Economics, Blue Economy Opportunities in Developing Nations.....	37
Chapter 4: Economic Importance and Trade Potential of Tuna in India and Global Marine Fisheries.....	51
Chapter 5: Emerging Trends in Fish Processing Technology	62

Chapter 1: An Economic Analysis of Fish Production and Marketing in Tamil Nadu “Opportunities and Challenges”

1. Introduction

A significant component of the Indian economy is the fishing industry. “It contributes to the national income, exports, food and nutritional security and in employment generation and the fisheries sector provides livelihood to more than 2.8 crores fisheries chain” [1,24,26]. The potential for the growth of fish based industries in India insignificant as the major focus sector is fish production, marketing and consumption. The demand of fish is ever increasing because of its nutritive value and a rich source of protein. In international trade, fish has emerged as the food product with the greatest rate of growth [2]. It is the single largest source of animal protein in most parts of the world, particularly in the developing countries [3]. “Tamil Nadu is enriched with Marine, Brackish water and Inland fishery resources amenable for capture and culture fisheries. Substantial focus is being given on the economic and social dimensions of fishery resources by the Government of Tamil Nadu” [9]. The maritime state of Tamil Nadu is blessed with 1,076 km long coast line and 41,412 km continental shelf area with an Exclusive Economic Zone (EEZ) of 1.9 lakh sq. km, contributing 5.97 lakh tons of marine fish production. Tamil Nadu, located on the southeastern coast of India, is one of the leading maritime states with a rich and diverse fisheries sector. Tamil Nadu has a coastline of 1.076 km, representing 13% of India’s total coastline and supporting a lively marine and inland fishing industry. Both coastal and inland regions benefit from the sector in terms of food security, job creation, export earning and the improvement of rural livelihood.

2. Importance of Fisheries in Tamil Nadu

The fisheries industry plays a crucial role in the socio-economic development of Tamil Nadu, it contributing significantly to food security, employment generation and export earnings [29]. In addition to its long coastline, the state has rich aquatic resources making it a major fish producing area in India.

2.1. Contribution to the State Economy

A significant part of Tamil Nadu's Gross State Domestic Product (GSDP) is generated by the fisheries sector. Among the top fish producers in India are both marine and inland fish. Exports of seafood, particularly processed marine products are another valuable source of foreign exchange for the fisheries sector. Tamil Nadu contributes significantly to India's export of marine products. Various fish species and high value marine products contribute to the India's foreign exchange earnings. This sector includes marine, freshwater and brackish water subsectors, which diversify economic activities throughout the Tamil Nadu.

2.2. Employment and Livelihood Support

The industry providing employs millions of people both directly and indirectly including fishers, fish processors, traders, owners of boats and transporters among others. Tamil Nadu has a larger fisher folk population. There are several lakhs of people directly involved in fishing and connected activities such as fish processing, marketing and boat construction [30]. In Tamil Nadu there are over 10 lakhs people whose livelihood is supported by the fishing industry. Coastal fishing contributes employment to those involved in marine fishing, while inland fishing supports those in rural areas. The state has a long coastline of 1.076 km and has over 591 marine fishing villages making fisheries the economic base of the districts of the state and their primary business and cultural property. The government has establish several welfare schemes to ensure the social security of the fisher folk of the country by providing financial support to the fishermen during the fishing ban period, insurance schemes, educational support for their children, etc. (Example: Tamil Nadu Fishermen Welfare Board, TAFCOFED, TNFDC, Fisheries and Fishermen Welfare Department, TNJFU).

2.3. Food and Nutritional Security

Fish is an essential source of low-cost animal based food in Tamil Nadu, it plays a vital role in the nutritional security of the people living in the coastal and inland areas. "Fish is a rich source of essential omega-3 fatty acids, vitamins and minerals, thus playing a important role in the dietary lives of the Tamil Nadu population"[8]. Fish naturally

contains many kinds of nutrients such as iron, zinc, calcium, iodine, vitamin B12, vitamin A, vital fatty acids and protein, all of that are needed for both healthy pregnancies and the normal development growth of human health [4,5,31,33]. “Tamil Nadu is among the major fish producing states in India, contributing significantly to the country from its marine wealth as well as from its inland water resources (reservoirs, tanks ponds, etc.)” [9].

2.4. Export Potential and Economic Growth

The state of Tamil Nadu because of its well developed fish harbors and facilities, it has been able to emerge as a centre in the export of seafood products. Among the seafood products, processed shrimp, cuttlefish and squids are of significant importance in enhance India’s foreign exchange reserves, along with agricultural and integrated products of Tamil Nadu and fisheries products rank among the most important ones. Tamil Nadu exported a large quantity of fish products and the foreign exchange earnings noticed from the exports were around ₹6,854 crores (US\$825 million approx) during 2023-2024. The government of Tamil Nadu has also understood the huge potential in the sector and decided to increase its exports to around \$5 billion annually. This is a broad leap towards modernization and value addition in the sector, as in the recent past latest stalls dedicated to ornamental fish, such as those seen in Villivakkam, Chennai have been launched by the government of Tamil Nadu for the year 2025. As a whole, the seafood sector is growing constantly as a result of various schemes launched by the government, some of the notable schemes include the “**Pradhan Mantri Matsya Sampada Yojna**” (PMMSY) which is essential in increasing the GVA of the fishery sector [6,34].

2.5. Regional and Rural Development

The contribution of fisheries to balanced regional development is allocated to the promotion of economic activities in coastal and inland rural areas. Government investments in aquaculture, hatcheries and fish markets have stimulate entrepreneurial opportunities and enhanced rural incomes. Schemes such as the “National Fishermen Savings cum Relief Scheme” provide financial support for savings during fishing bans or lean seasons, hence a vital social security net for the rural poor [13]. Government initiatives of the Central Sector Scheme of “**Blue Revolution and PMMSY**” finance the construction of hi-tech fishing harbors, jetties and fish landing centers. This converts to the transformation of remote coastal village to economically applicable towns. Inland and brackish water aquaculture like prawn and GIFT tilapia farming has become a highly profitable activity that utilizes unused water resources at the district level to create new centers of wealth.

2.6. Women's Participation and Social Empowerment

Women play a significant role in the activities of post-harvesting like processing, marketing and adding value to the product, such as making the handmade value added product using shells. This will help women create their own source of income. This is beneficial in terms of increasing income and social empowerment. Their position as salespersons is of considerable importance in the whole value chain, as it feeds to the population of both rural and urban areas utilizing fresh as well as dried fish products, this adding substantially to regional nutritional well-being. A specific plan for saving and giving relief funds to women during the annual fishing ban, similar to the plan for the fishermen. The **“Tamil Nadu Fishermen Welfare Board”** includes registrations for both fishermen and fisherwomen so that their social security benefits are met in cases of accidental death, educational support for their children and payment for marriage or delivery.

2.7. Ecological and Environmental Importance

Tamil Nadu's efforts in maintaining the ecological balance of aquatic ecosystems, such as mangrove conservation, seaweed cultivation and responsible aquaculture contribute to biodiversity preservation as well as climate resilience [35]. “Tamil Nadu Marine Resource Foundation” (TNMRF) will protect and restore biodiversity and support sustainable livelihood by training fishermen in eco friendly practice like seaweed farming and aquaculture. Institutions like the Central Marine Fisheries Research Institute (CMFRI), Zoological Survey of India (ZSI), Fisheries Survey of India (FSI) continuously monitor stock health, develop sustainable management consultative and study the impacts of climate change on fishery resources. The ecological and environmental significance of fisheries in Tamil Nadu is in nature mainly related to the state's position as a biodiversity access point and essential ecosystem service, which is currently at great risk of being lost unpaid to irresponsible fishing activities and climatic change. The coastal region of the country specifically the Gulf of Mannar and Palk Bay supports important marine habitats that are completely essential for regional and global marine life, for example the Gulf of Mannar lands as many as 657 species indicating a huge quantity of life that the fishing industry taps into and supports the most biologically diverse ecosystems, with many fish species utilizing the waters as a nursery or feeding ground including those of significant commercial value. A live corals cover in the Gulf of Mannar is monitored for environmental health.

3. Scope of Fisheries in Tamil Nadu

Tamil Nadu has considerable potential in both capture fisheries and aquaculture. The scope covers expansion, technological intensification, diversification, value-addition, export enhancement, and livelihood improvement. Below are the dimensions along which the fisheries sector in Tamil Nadu can grow backed with recent statistics and observations.

3.1. Resource base and current capacity

- **Marine resources:** Tamil Nadu has a coastline of 1,076 km, which is about 13% of India's coastline.
- **Inland water resources:** Approximately 3.85 lakh hectares of inland water spread (reservoirs, tanks, ponds, rivers, canals etc.) are suitable for capture and culture fisheries. There are also 56,000 hectares of brackish water (estuaries, backwaters, creeks) available.
- **Existing production:** As of 2023-24, marine fish production in TN is about 6.37 lakh tonnes; inland fisheries about 2.46 lakh tonnes.
- **Fisher folk and crafts:** There are about 10.48 lakh marine fisher folk and about 2.36 lakh inland fisher folk. The state has thousands of mechanized and traditional fishing crafts.
- **Expansion of inland fish production:** The inland waters have potential to yield around **4.5 lakh metric tonnes** (from current smaller production levels) if efficiency, stocking, seed supply etc are improved.
- **Brackish water aquaculture:** Brackish areas (estuaries, backwaters) are usable for shrimp farming, finfish culture, etc. TN already has registered shrimp farms and hatcheries; but the area under culture is much smaller than available brackish area.
- **Use of advanced culture technologies:** Systems like cage culture, bio-floc systems, recirculation aquaculture systems (RAS) are being promoted.
- **Deep sea and under-utilized marine areas:** There is potential to exploit deeper sea resources more sustainably.
- **Export and value addition:** Seafood exports from TN are significant and can increase further with improved processing, better cold chain, hygienic standards etc. Current exports (marine products) in 2023-24: 1.34 lakh metric tonnes; foreign exchange earned approx. Rs. 6,854.22 crore.

3.2. Institutional support, policies and programs

- **Government schemes:** Several state and central programmes, especially under Pradhan Mantri Matsya Sampada Yojana (**PMMSY**), are providing investments

in infrastructure: hatcheries, brood-banks, ornamental fish units, fish feed mills, value-added enterprises.

- **Infrastructure development:** Plans to modernize fishing harbours, improve fish landing centers, cold chain, roads, fish markets etc.
- **Seed and breeding improvements:** There are government fish seed farms, both for inland species and shrimp etc.
- **Regulatory and conservation frameworks:** The Tamil Nadu Marine Fishing Regulation Act (TNMFR), 1983, fisheries laws (Fisheries Act 1897) and various conservation measures serve to regulate usage, preserve resources.

3.3. Challenges and constraints (limiting the scope)

- **Under-utilization of water bodies:** Many ponds, tanks, reservoirs are not fully used, or used inefficiently. Constraints include seed availability, input cost, technical knowhow.
- **Environmental risks:** Pollution, salinity intrusion, coastal erosion, climate change impact resource availability.
- **Regulatory issues:** Illegal aquaculture farms, weak regulation of disease control, water quality etc. (ICSF)
- **Market inefficiencies:** Gaps in cold chain, processing, value addition, market linkages.
- **Capacity of fisher folk:** Limitations in terms of access to capital, training, cooperatives, awareness.

3.4. Strategic directions to realize scope

- **Intensification and diversification:** Use improved culture systems, diversify species, integrate aquaculture with agriculture/livestock.
- **Technology adoption:** Better seed varieties, SPF shrimp, improved feed, disease management.
- **Infrastructure scaling:** More hatcheries, modern harbors, cold chain, fish processing parks.
- **Cooperative and institutional strengthening:** Better cooperative federations, collective marketing, access to credit.
- **Sustainable management:** Conservation of breeding grounds, marine protected areas, regulating fishing effort to prevent overfishing.

4. Data Source

- ❖ Tamil Nadu Fisheries Department / Department of Fisheries and Fishermen's Welfare, Govt. of Tamil Nadu [7,9]

- ❖ Statistical Handbook of Tamil Nadu [10]
 - ❖ Handbook on Fisheries Statistics [11]
 - ❖ Marine Fisheries Census (CMFRI & DoF-India) [11,12]
 - ❖ Marine fish production reports / stock assessment studies [10]
 - ❖ Open Government Data (OGD) Platform, Tamil Nadu “Fisheries at a Glance” publications [14]
 - ❖ Academic / Research Institutions Tamil Nadu Fisheries University (TNFU) .Fisheries College & Research Institute, Thoothukudi.
- **ICAR / CMFRI** publications / peer-reviewed journals etc. Provide detailed studies, sometimes species-wise, sometimes with field surveys, also biological/ecological insights, case studies. Usually reliable; could be limited in geographic or temporal scope; access to some data or full texts may be restricted.
 - **Market data / field surveys**, Local market prices (wholesale/retail), volumes landed, post-harvest loss, value addition chains etc. These will need to be collected by students if not available publicly. Requires primary work; potential variation; seasonality; need to ensure standardization.

5. Resource Base

Tamil Nadu possesses abundant **marine, inland, and brackish water resources**, enabling a diversified fisheries profile.

- **Marine Fisheries Resources**
 - Coastline: 1,076 km
 - Continental shelf area: 41,412 sq. km
 - Exclusive Economic Zone (EEZ): 1.9 lakh sq. km
 - Marine fishing villages: 608
 - Marine fisher folk population: ~10.48 lakh persons
(Source: Department of Fisheries, Government of Tamil Nadu, 2024)
- **Inland Fisheries Resources**
 - Inland water spread area: 3.85 lakh hectares
 - Reservoirs: 77,000 ha
 - Major irrigation tanks and ponds: 2.70 lakh ha
 - Rivers and canals: 7,000 km
(Source: Fisheries at a Glance, Tamil Nadu, 2023)
- **Brackish Water Resources**
 - Available area for aquaculture: 56,000 ha
 - Current utilization: around 25%

- Key aquaculture species: *Penaeus vannamei* (white shrimp), sea bass, milkfish, mud crab

6. Fish Production Trends

Tamil Nadu frequently ranks among the top five fish-producing states in India (Table 1).

Year	Marine Fish Production (lakh tonnes)	Inland Production (lakh tonnes)	Fish (lakh tonnes)	Total (lakh tonnes)
2015–16	4.90	1.85		6.75
2019–20	5.85	2.10		7.95
2023–24	6.37	2.46		8.83

(Table 1:Source: Fisheries Department, Government of Tamil Nadu, 2024)

Government schemes like the **Blue Revolution** and the **Pradhan Mantri Matsya Sampada Yojana (PMMSY)** have allowed the share of aquaculture in the country to increase continuously showing the transition from capture fisheries to culture-based system of production.

6.1. Marine Fisheries Sector

Tamil Nadu marine sector is characterized by both **traditional handmade fishing** and **modern mechanized operations**.

- **Fishing Fleet Composition (2023–24)**
 - Mechanized boats: 5,957
 - Motorized boats: 45,486
 - Non-motorized crafts: 7,050
- Major fishing harbours: Chennai, Nagapattinam, Thoothukudi, Cuddalore, Rameswaram, Colachel
- Important species landed: sardines, mackerel, seer fish, prawns, cuttlefish, squids, anchovies, and crabs.

An important policy objective is the responsible utilization of marine resources with a focus on protecting the environment and deep-sea fishing.

6.2. Inland Fisheries and Aquaculture

The inland sector contributes about **28–30% of total fish production** in Tamil Nadu.

- **Reservoir and tank fisheries** are managed under community-based models.
- **Aquaculture growth** has been driven by adoption of high-yield species such as *Pangasius*, *Rohu* and *Catla*.
- Tamil Nadu has also become a leading producer of shrimp, particularly *Litopenaeus vannamei*, for both domestic and export markets.
- Ornamental fish culture, integrated fish farming and cage culture are emerging as new growth areas.

6.3. Export Performance

Tamil Nadu is one of India's major seafood exporting states.

- **Marine product exports (2023–24):**
 - Quantity: ~1.34 lakh tonnes
 - Value: ₹6,854 crore (approx.)
 - Major export items: frozen shrimp, cuttlefish, squid, and fish fillets
(Source: *Marine Products Export Development Authority – MPEDA, 2024*)

Export potential is being enhanced through modernization of harbors, establishment of cold chains, and quality certification for international markets.

6.4. Employment and Livelihood

The fisheries sector supports more than 12 lakh people in Tamil Nadu, including fishers, processors, traders and allied workers. “Women are extensively involved in post-harvest activities such as drying, grading, processing and marketing, contributing to household income and community resilience”[15].

6.5. Institutional and Policy Support

The **Department of Fisheries and Fishermen Welfare**, Government of Tamil Nadu, implements numerous schemes to enhance productivity, sustainability and income [9]:

- **Infrastructure Development:** Construction of fishing harbours, landing centres, cold storages, and fish markets.

- **Livelihood Schemes:** Fishermen group accident insurance, savings-cum-relief scheme.
- **Promotion Programs:** PMMSY, Seaweed farming initiatives, Deep Sea Fishing Scheme.
- **Research and Education:** Tamil Nadu Dr. J. Jayalalithaa Fisheries University (TNJFU) promotes fisheries research, extension, and training.

7. Challenges

In fisheries industry despite its potential, the sector faces several challenges like overexploitation of marine resources, Post-harvest losses and inadequate cold storage, Environmental pollution and coastal erosion, Fluctuating prices and weak market linkages, Climate change impacts on fish breeding and migration, lack of political will to follow present regulations and laws, unknown community structures, institutions and their rules such as the village system or machinery rules carried out through traditional punchayet, the improper utilization of fishing vessels authorizations and registrations, excessive size and investment in the fishing fleet, an increase in the number of fishing vessels and further development in terms of power from engines and fishing capacity as well as change in the diversity of species over the previous few years [16,17,23,24,25,27].

The diversity of species has evolved, oil sardine production has grown, mackerel production decreased and the majority of landed species were reduced in size. Improper access to fisheries resources (mechanized sector with low labor force having access to major fisheries resources) [18,19,27]. Constant purse net fishing and both trapping in different regions. Deep water long-liners have been introduced. Resource capacity, international regulations (IOTC), suitable registration and licensing protocols and transport security issues must all be examined. Current boats are not officially registered with the necessary documents [20]. International fishing has increased, decision making is not open input and community leadership structures are not involved in any kind of procedure for making decisions. Examine about the way fisheries impact trade both during and after the fishing season. Women must have access to the first sale if they want to minimize loss. “A number of species such as sea cucumber that have affected swimmers, are listed in the schedule that to the wildlife (protection) Act, 1972” [21,22].

8. Future Prospects

With continuous policy support, technological innovation and sustainable management, Tamil Nadu fisheries sector holds immense potential for growth. Emphasis on value addition, export diversification, digital fish markets, and eco-friendly aquaculture can further enhance its contribution to the state economy. States must recognize that the

availability of sustainable fisheries is essential for responsible fishing, based on science for supporting decision making by fisheries managers and other beneficiaries. Accordingly states need to make guarantees that every aspects of fishery biology, ecology, technological innovations, environmental research, the economy, sociology, aquaculture and nutritional science is thoroughly investigated. Regarding the specific needs of developing countries, states should ensure a supply of research facilities and provide acceptable employees, education and building of institutions for carrying towards research. To protect an ecological foundation for the production of food, states and everyone connected to fisheries management must establish initiatives for long term preservation and efficient utilization of seafood resources. They should promote and implement appropriate management systems consistent with their existing obligations under national and international law and voluntary commitments including the rules that give due recognition to the requirements and opportunities of small scale fisheries [32].

9. Conclusion

The economic analysis of fish production and marketing in Tamil Nadu reveals a sector characterized by high economic potential and critical structural challenges [28]. Although the sector contributes significantly to the Tamil Nadu's Gross Domestic Product (GSDP), exports, coastal livelihoods, a traditional resource exploitation problems caused greater by market inefficiency challenges the sector's long term viability. On the basis of the analysis the marine capture fishery is reaching its Maximum Sustainable Yield (MSY), particularly as it involves mechanical harvesting. The factors like innovations, hygienic, properly managed fish landing infrastructure, cold storage facilities, processing systems all require significant public investment. This will improve the seafood's duration of storage, minimize losses after harvest, promote value added exports. Throughout this process it will increase the financial benefits for every participant those involved in this sector. A decreased returns on investment have resulted compared to the increasing availability of large motorized boats and harmful machinery like bottom trawling. This is essential to support and strengthen Self-Help Groups (SHGs) and Cooperative societies to earn fishermen and fisherwomen. It will be capable to gain credit from institutions, prevent unfair intermediaries and develop collective bargaining influence on the marketplace as the marketplace as the consequence. Women hold an important and major part in the after-harvest sector (processing, drying and local selling) but their availability of approved financing and market facilities is limited, its resulting in decreased the worth of the system's total effectiveness. In the end, focusing on environmental sustainability along with value chain improvement before immediate harvest maximizing will impact the future of Tamil Nadu's fishing industry. The only way to protect coastal communities sources of

income and sustainably manage one of the state's most valuable natural resources is to implement a balanced approach.

References

- [1] Sharma, H, M. Swain and S. S Kalamkar (2016), "Evaluation and Assessment of Economic Losses on Account of Inadequate Post-Harvest Infrastructure Facilities for Fisheries Sector in Gujarat State", Report No. 163, Agro-Economic Research Centre, Sardar Patel University, Vallabh Vidyanagar, Anand, Gujarat.
- [2] Ahmed K. K., Alamgir M., Kibria M. G., Haque M. E. (1999) Reservoir Fisheries of Bangladesh. *Aquacult. Asia* 4, 8–12.
- [3] Williams, K. C., Barlow, C. G., Rodgers, L. J., & Ruscoe, I. (2002). Potential of meat meal to replace fish meal in extruded dry diets for barramundi, *Lates calcarifer* (Bloch). I. Growth performance. *Aquaculture Research*, 34(1), 23-32. <https://doi.org/10.1046/j.1365-2109.2003.00785.x>
- [4] Byrd KA, Thilsted SH, Fiorella KJ. Fish nutrient composition: a review of global data from poorly assessed inland and marine species. *Public Health Nutr* 2021;24(3):476–86. doi:10.1017/S1368980020003857.
- [5] Thilsted SH, Thorne-Lyman A, Webb P, Bogard JR, Subasinghe R, Phillips MJ, et al. Sustaining healthy diets: the role of capture fisheries and aquaculture for improving nutrition in the post-2015 era. *Food Policy* 2016;61:126–31. doi:10.1016/j.foodpol.2016.02.005.
- [6] Government of India (2023). *Pradhan Mantri Matsya Sampada Yojana (PMMSY) Progress Report*.
- [7] Tamil Nadu Dr. J. Jayalalithaa Fisheries University (2024). *Research Publications and Extension Bulletins*.
- [8] Tamil Nadu, Textbook and Educational Services Corporation www.textbooksonline.tn.nic.in
- [9] Department of Fisheries, Government of Tamil Nadu (2024). *Fisheries at a Glance 2023–24*. <https://www.fisheries.tn.gov.in>
- [10] MPEDA (2024). *Annual Report on Marine Product Exports from Tamil Nadu*.
- [11] Handbook on Fisheries Statistics, 2020. Department of Fisheries Ministry of Fisheries, Animal Husbandry & Dairying, Government of India, New Delhi.
- [12] CMFRI (2023). *Marine Fisheries Census and Production Statistics*.
- [13] Chengalpattu District, Developed and hosted by National Informatics Centre, Ministry of Electronics and Information technology, Government of India, 2026.

- [14] Marine Fisheries at a Glance 2018-19 in Tamil Nadu.
- [15] Food and Agriculture Organization Of The United Nations Rome, 2007. FAO Fisheries Circular No. 1021 (ISSN 0429-9329).
- [16] Shivam Kumar Pande, Tripti. 2023. Lex Scripta Magazine Of Law And Policy, Volume-1: Issue-4, Enforcement Of Fisheries Laws In India (ISSN-2583-8725).
- [17] Kenton Lobe, Fikret Berkes, 2004. The padu system of community-based fisheries management: change and local institutional innovation in south India, Marine Policy, Volume 28, Issue 3, 271-281 (ISSN 0308-597X).
- [18] International Collective Support of Fish workers (ICSF).
- [19] CMFRI (2023). *Marine Fisheries Census and Production Statistics*.
- [20] R. Jeyabaskaran, Sijo P. Varghese, A. Siva, Ansuman Das, Vinodkumar Mudumala, Prathiba Rohit, J. Jeyasankar, Rajashree U. Pawar and Sanjay Pandey. India's National Report to the Scientific Committee of the Indian Ocean Tuna Commission 2022, IOTC-2022-SC25-NR08
- [21] Illuminating Hidden Harvests: the contributions of small-scale fisheries to sustainable development. Publisher: Fao, Duke University, WorldFish, 2023.
- [22] Compendium of Species Recovery Plans With Special Focus On Marine Animals, AIWC-2024, Tamil Nadu Forest Department.
- [23] Perissi, I., Bardi, U., Asmar, T. E., & Lavacchi, A. 2016. Dynamic patterns of overexploitation in fisheries. *ArXiv*. <https://arxiv.org/abs/1610.03653>
- [24] L.C. Teh, U.R. Sumaila, 2013. Contribution of marine fisheries to worldwide employment. *Fish and Fisheries*, 14 . pp. 77-88, DOI: 10.1111/j.1467-2979.2011.00450.
- [25] Xu, Y., Krafft, T., & Martens, P. 2024. The interaction between climate change and marine fisheries: Review, challenges, and gaps. *Ocean & Coastal Management*, 259, 107479. <https://doi.org/10.1016/j.ocecoaman.2024.107479>
- [26] 10 years Achievements of the Indian Fisheries Sector, 2024. Department of Fisheries Ministry of Fisheries, Animal Husbandry and Dairying. Government of India.
- [27] International Collective in Support of Fish workers (ICSF) – 2023
- [28] Andreia de, Bem Machoda, 2025. *Fin Tech for Sustainable Finance and a Well-Blue Economy*, Springer Nature.
- [29] J. Suresh Kumar, D. Shobana, 2024. A Study on Women Entrepreneurship in Tamil Nadu, *International Journal of Social Science, Management and Economics Research*. (2) 2583-9853.
- [30] Mohammad Mahmudul Islam, 2023. *Small in Scale Big in Contributions Advancing Knowledge of Small-Scale Fisheries in Bangladesh*. TBTI Global Book Series. ISBN: 978-1-7773202-8-7

- [31] Ethnic Fermented Foods and Beverages of India: Science History And Culture. 2020, Springer Nature Link.
- [32] Code of Conduct for Responsible Fisheries, United Nations Convention on the Law of the Sea, 1982.
- [33] Kendra A Bbyrd, Jacqueline Shieh, Stephanie Mork, Lauren Pincus, Lydia O'Meare, Molly Atkins, Shakuntala H Thilsted, 2022. Fish and Fish Based Products for Nutritional and Health in the First 1000 Days: A Systematic Review of the Evidence from Low and Middle-Income Countries. *Advances in Nutrition*, 13(6), 2458-2487.
- [34] Pradhan Mantri Matsya Sampada Yojana (PMMSY) Sets Ambitious Target of 1.12 Million Tonnes of Seaweed Production by 2025.
- [35] Department of Aquatic Biology & Fisheries, University of Kerala and ICAR-Central Marine Fisheries Research Institute, India.

Chapter 2: India's Marine Fisheries: Sustainability at the Crossroads

1. Introduction

In the seven decades since India gained independence, the country's fisheries have evolved substantially. They have shifted from depending on fishing for livelihood to become a vibrant, dynamic, and commercially important aspect of the world economy. The production shows that the trend continues to be upwards. Annual yields had grown from 5.34 lakh tonnes in 1950-51 to 44.95 lakh tonnes by 2023-24 [1]. This growth of about nine times shows that technology [1].

One of the main structural problems that Indian marine fisheries endure is the big between small-scale artisanal fishermen and large mechanized vessels. Artisanal fishing families occupy approximately 90 percent of those who depend on the marine capture, but their cumulative output only comprises 10 percent of the total landings - a major imbalance that leads to emphasize the systemic disparities [5]. The reason behind this is varying access to resources and markets such as inaccessibility to modern fishing equipment, inequality in access to institutional financial support, unequal control over lucrative fishing grounds, and reduced bargaining strength when conducting business transactions in the markets [4]. These structural inequalities, along with caste discrimination, marginalization, and gender inequalities, add to economic factors in order to create compounded vulnerabilities that perpetuate marginalization.

The artisanal subsector includes more than 220,000 traditional non-powered crafts of local materials with approximately 70,000 smaller motorized crafts with outboard engines. The range of operation in space is very low and is normally confined to the nearby shore within 5-10 nautical miles of the coastline. Fishing practices emphasize selective gill nets, hook-and-line, cast nets, and small seine nets which usually cause less impact on the environment per unit of harvest compared to industrial practices [1].

Where the mechanized segment of the fleet consists of about 78,000 trawlers with a horsepower of between 50 and 400, Whereas, they represent a smaller numerical proportion of the fleet, these vessels capture the largest percentage of the overall catch. They work most of the year, only stopping on seasonal fishing bans that are imposed by the government and may take advantage of offshore waters up to about 200 meters with industrial-scale bottom trawling gear that covers wide swathes of the sea floor [7]. Expeditions of 7-15 days of fishing with ice storage possibilities enable such ships to spend a long time in the sea and accumulate much more significant amounts of haul. The difference in productivity between the two industries is also striking: automated vessels offer average catches which are 15 to 20 times higher than those of artisanal crafts, highlighting a vast difference in the efficiency of harvesting, the range of action, and access to the maritime resources.

2. Traditional Development and Economic Importance

The course of marine capture fisheries in India is a dynamic course that is affected by the shift in production systems, increasing trading relations, governance efforts, and innovation. Fishing was mostly artisanal and made use of traditional methods, hand labour, local ecological knowledge, and non-motorized wooden craft when reaching coastal seas after independence [5]. The social organization in fishing communities was mainly traditional with skills and customs being passed on by local tradition and family tradition.

The advent of mechanical fishing in the 1960s has had a significant change on the marine capture systems in India and changed the harvesting practices and production capacities of the coast in a fundamental way [4]. The driving factors of this stage of modernization were government-initiated develop projects, multinational technical co-operations and market expansion domestically and internationally. The accessibility of offshore areas with the help of motorized vessels and bottom trawling equipment enabled fishers to access previously inaccessible areas that were difficult to reach with the help of ordinary boats, and increased fishing Trips by a significant margin, increasing catch efficiency with the help of industrial-quality equipment, and exploiting previously unexplored areas of the sea.

Additional technological development began with the application of echo-sounding equipment to locate fish schools, GPS positioning equipment to position the fish accurately, satellite communication systems to provide weather information and positioning reports, and onboard refrigeration systems to limit spoilage and preserve quality of the catch [1].

The technological improvements went beyond the augmentations in the volumes of the catches; the technological improvements completely changed the relations between the fishing communities and the sea. This development made it possible to exploit deeper

and more distant waters, and at the same time increased ecological pressure on near shore and offshore ecosystems. The pace of technological intensification has created major issues over the possibility of increasing the level of harvest and its long term effects on ecological integrity and sustainability of fishing livelihoods.

The infrastructure is developed in accordance with the requirements of the new markets.

2.1 Infrastructure Development

The infrastructure is built according to the needs of the new markets. The fisheries industry is sustained by the development of infrastructure in the coast of India which served to connect to both the local and international markets. The development of special purpose built development of specialized ports with berthing area, landing terminal equipped with auction and ice production units, advanced processing plants with strict quality control mechanisms, and extensive cold-chain system connecting landing sites with export markets has all facilitated the addition of value, efficiency in handling, reduction in spoilage and increased access to markets by the fishing communities [3]. The major seaports like Veraval, Gujarat, Visakhapatnam, Andhra Pradesh, Cochin, Kerala and Chennai, Tamil Nadu have emerged as key centres of operation, facilitating the movement of vessels, landing of fish, fish processing and distribution in the national supply chain [3].

Government programs have been found to be very instrumental in development through availing mechanisms of financial and organizational support. The initiatives of the Blue Revolution to achieve yield optimization, providing grants to improve vessels, creating cooperative credit schemes, insuring weather-related losses, and developing export aid structures were aimed at reaching the foreign markets. Nevertheless, a comprehensive analysis reveals that there are significant gaps in the coverage of the programs since small-scale operators do not always receive such benefits because of the limitations of credit, limited access to modern technologies, inadequate organizational representation, and constant marginalization of management [7].

2.2 Regional Patterns of production

The spread patterns of marine fish production in the Indian coastal areas are highly dispersed based on the environmental factors, degree of technological usage, infrastructural development, ecological capacity, and area-specific patterns of development. The discrepancies observed are due to natural abundance and interaction of regional geography, investment distribution, and administrative policies, community structures and the extent of connections with domestic and international markets [2].

Gujarat has also been the largest provider of marine catch in India with an approximate of 21.8 percent of the marine catch or 9.8 lakh tonnes. The combination of these factors led to the rise of this dominance: the presence of a large and well-mechanized fleet, the geographical position along the coasts, which is favorable to the fisheries sector due to its biological wealth, the development of a complex of seafood processing businesses, and a progressive approach to the state level, promoting the growth and development of the fisheries industry. Tamil Nadu ranks second after Gujarat in marine fish production with an annual production of about 6.4 lakh tonnes (approximately 14.2 percent of the total national production). Its extensive coast on the Bay of Bengal and Indian Ocean, offers numerous fishing grounds, a great variety of species, longer fishing periods. Kerala has a marine fish production of more than 5.1 lakh tonnes or almost 11.3% of the national total which retain its historical significance and cultural value in the fisheries industry of India. But the state is currently experiencing a multiplicity of problems because of the decreasing availability of resources, the mounting pressure of mechanized fleets, and the reduced effectiveness of catching in the coastal waters [1]. The coastal folk of Kerala have a strengths fishing tradition, which is marked by elaborate traditional knowledge systems that have been practising the fishery over generations and have regulated the resource management of the fishery.

The key states that play a role in the marine harvest in India are Andhra Pradesh (480,000 tonnes, 10.7%), Maharashtra (390,000 tonnes, 8.76%), Karnataka (320,000 tonnes, 7.1%), and West Bengal (280,000 tonnes, 6.2%). The differences in production across regions are a result of interaction of ecological conditions, technological innovations, infrastructural development, governance systems and organizational structures of communities that are coastal.

2.3 Global Integration and Export Markets

The marine product exports are a major source of foreign earnings, which is an important source of jobs across many value chains, and a basic livelihood source to millions of households that are involved in capture, processing, logistics, and trade[3]. The exportation portfolio is highly focused on the high valued products which have high prices in the international markets with the frozen shrimp contributing more than 68% of the export revenues but a relatively lower percentage of volume.

India trades tuna and other pelagic fish to make sushi and tuna canning, cuttlefish and squid to make sardines and tuna to the Mediterranean and East Asian markets, and ribbonfish to fulfill high demand in China markets.

The export based industry has around 1.5 million people working in the export-oriented sector, which includes capture and primary processing, and another 2.5 to 3 million people work in other activities linked to the industry, such as provision of materials transport logistics, packaging, quality assurance, and marketing services [9]. The United

States (34%), Southeast Asia (28%), the European Union (20%), the Middle East (12%), Japan (4%), and a minor fraction to other region are the main international markets [3].

These vulnerabilities are often aggravated by the global price fluctuations, seasonal changes in employment, which lowers the income stability, lack of social protection with limited health and retirement benefits, gender-specific risks that are usually high and disproportionate to the women in processing unit, and the effects of global price fluctuations, seasonal demand, and heightened import regulations and controls.

3. Structural Inequalities and Livelihood Disparities

3.1 The Artisanal–Industrial Divide

Artisanal fishing families occupy approximately 90 percent of those who depend on the marine capture, but their cumulative output only comprises 10 percent of the total landings - a major imbalance that leads to emphasize the systemic disparities [5]. The reason behind this is varying access to resources and markets such as inaccessibility to modern fishing equipment, inequality in access to institutional financial support, unequal control over lucrative fishing grounds, and reduced bargaining strength when conducting business transactions in the markets [4]. These structural inequalities, along with caste discrimination, marginalization, and gender inequalities, add to economic factors in order to create compounded vulnerabilities that perpetuate marginalization.

The artisanal subsector includes more than 220,000 traditional non-powered crafts of local materials with approximately 70,000 smaller motorized crafts with outboard engines. The range of operation in space is very low and is normally confined to the nearby shore within 5-10 nautical miles of the coastline. Fishing practices emphasize selective gill nets, hook-and-line, cast nets, and small seine nets which usually cause less impact on the environment per unit of harvest compared to industrial practices [1].

where the mechanized segment of the fleet consists of about 78,000 trawlers with a horsepower of between 50 and 400, Whereas, they represent a smaller numerical proportion of the fleet, these vessels capture the largest percentage of the overall catch. They work most of the year, only stopping on seasonal fishing bans that are imposed by the government and may take advantage of offshore waters up to about 200 meters with industrial-scale bottom trawling gear that covers wide swathes of the sea floor [7]. Expeditions of 7-15 days of fishing with ice storage possibilities enable such ships to spend a long time in the sea and accumulate much more significant amounts of haul. The difference in productivity between the two industries is also striking: automated vessels offer average catches which are 15 to 20 times higher than those of artisanal crafts, highlighting a vast difference in the efficiency of harvesting, the range of action, and access to the maritime resources.

3.2 Financial Exclusion and Debt Dependency

Artisanal fishing households are having problems because they can't use regular banks. This is because most of them don't have the right assets, including legally recorded property titles, and they don't have official credit document that financial institutions need to decide if they may get a loan.

This widespread exclusion forces them to depend on informal lenders [5], such as local moneylenders and fish traders, who often charge high annual interest rates 36% to 60%. These predatory loans remain families in debt for a long time, which keeps them from buying better equipment or making modifications to their gear. This makes it harder for them to deal with economic shocks or variations in their income during different seasons.

Furthermore, the lack of proper cold storage and transport, being far from major markets, weak negotiating power of individual sellers, and the missing prompt price information result in many small-scale operators having limited direct access to lucrative wholesale or retail outlets. Therefore, small-scale fishers are often forced to sell to middlemen who manage local trading channels and keep most of the value added between-landing and final sale. Production price manipulation, delayed payments, and exploitative tied-credit loans, where existing debts determine sale conditions, leaving them with only about 30-40% of the consumer price.

In many coastal regions, conservation-based seasonal closures during spawning periods, which are essential for maintaining fish populations, lead to income interruptions of 45-61 days each year. This forces numerous families to borrow in order to meet their basic needs [11]. When Compensation programs are implemented, they are often delayed, unfunded to cover household expenses, and hindered by administrative barriers. In addition, livelihood insecurity is further worsened by weather variability and climate-related disturbances, particularly for fishers who lack insurance for crop or income or alternative sources of income. This is due to the increasing disruption of operations by cyclones, rough seas, and unusual weather patterns [12].

3.3 Gender Dimension

Women are a large and often ignored portion of the fisheries labor system. They mostly work in post-harvest processing and selling fish in their own communities. Their jobs are very important for the value chain to work, but official statistics and policy talks often don't include them [8, 9]. Women are involved with cleaning, gutting, filleting, and processing activities that add value. Their work includes market distribution, net repair, shellfish collection, and various support functions that are vital to daily operations [8, 9]. This significant work, though, is not very likely to be recorded in the books, and the work of women is likely to be unpaid or paid less than their male peers to do that work,

and is in any case not likely to receive the entitlements provisions that are provided to formally recognized fish workers.

To fix gender inequality in the fishing industry, there needs to be a plan that goes beyond just economic steps like microfinance programs or skills training centres. It takes a hard battle against established patriarchal systems, biased property policies that limit the rights to own and manage resources by women, and cultural beliefs, which devalue the labour of women to make a difference [8]. They must include effective strategies that involve a formal recognition of women as fish workers with full rights and privileges, right to land tenure and inheritance, substantial representation in the decision making bodies and community based institutions, safe working environments with strong occupational health and safety measures, comprehensive social security of which include maternity leave and childcare provisions as well as focused campaigns to change the social attitudes that de-value and de-professionalize the important role of women in the fisheries production and food security systems.

4. Ecological Sustainability/Resource Constraints

The fact that marine production in India is at 3-4 million tonnes annually and has not grown in the last decade despite rising indicates that the harvest is near the maximum sustainable yield (MSY) and the potential consequence is that more effort will result in fish population crashing[6]. Actually operating above this thresholds on a regular basis raises the danger of abrupt falls, as has been noticed in the Atlantic cod fishery off Newfoundland, reduced resistance to environmental shocks, heightened vulnerability to population organization changes occasioned by fishing and augmented chances of transition to less successful ecological states [14].

4.1 Declining Catch Efficiency

Surveys of catch per unit effort (CPUE) in different gears, species geographies show that there have been continuing declines in returns per unit effort indicating real losses in stock abundance as opposed to simple spatial redistribution. The trends that are observed especially with the increase in the capacity of fishing that has been caused by an increase in the number of vessels and improvement in the gear and navigation technology are particularly alarming because it is evident that the basic size of the populations have severely diminished at the same time the fleet was becoming more skilled in locating as well as capturing the remaining fish [1]. Additionally, overexploitation has led to even greater declines in many once-abundant species, requiring fleets to fish down the food web, thereby changing the food-web structure and causing overall lower productivity of ecosystems [15]. This gradual depletion, when fisheries progressively deplete higher tropic -level stocks and subsequently focus on creatures lower in the food chain, jeopardizes lasting viability and ecological integrity diminishing product quality and financial gains at the same time.

4.2 Juvenile Capture and By catch

Approximately 15-30% of total catches contain juveniles that are still immature, based on research at major harbours and landing sites. The percentages differ depending on the equipment, season, and region. In this environment, bottom trawls are particularly detrimental as they ensnare numerous juvenile fish in addition to target species due to inadequate mesh control, non-selective designs, and insufficient enforcement of minimum size limits [16]. The addition of new fish is interrupted mechanisms are disrupted, stock rebuilding is slowed, and future production potential is compromised when young age classes are regularly caught before spawning.

In certain fisheries, by catch contributes about 10% to 25% of the catch. This includes small fish that are too young to be sold, unwanted species, and endangered animals such as sea turtles, dolphins, sharks, and rays, based on onboard observer reports and biodiversity, and makes it harder for threatened species to recover, especially when added up across India's fleet of more than 300,000 fishing boats.

4.3 Habitat Degradation

Bottom trawling damages bottom habitats by constantly moving the substrate around. Breaking up coral formulations that serve as nurseries and biodiversity hotspots, uprooting sea grass meadows that provide food and store carbon, and eroding rocky areas that are home to a broad range of invertebrates. Frequent trawling gradually changes structurally complex benthic environments into simpler sedimentary plains. This reduces that variety of habitats and the number of creatures that live in them. Pollution from land, cutting down mangroves for aquaculture, expanding ports, and building infrastructure along the coast all put extra stress on marine ecosystems, which makes them even worse and lowers their overall productivity [3].

5. Climate Change and Adaptive Challenges

Global climate change exacerbates existing stresses on marine ecosystems and fishing-dependent people by increasing their susceptibility [18]. Indian coastal waters have undergone the documented warming of approximately 0.13°C per decade, accompanied by ongoing ocean acidification that has decreased pH by about 0.1 units since pre-industrial period. As well, the changes in the circulation patterns are transforming monsoon behaviours and the distribution of upwelling thus causing alteration in the distribution of species, population structure, and seasonal occurrences of life cycles in the area [12]. These pathways are characterized by non linear, non regular deviations with exaggerated extremes, threshold responses, and complex interaction between concurrent stressors.

5.1 Extrapolated Ecological Effects

Climate forcing by climate change are likely to impact the ecological, economic and social aspects in the long-term. It is estimated that many species will migrate towards the pole by a rate of about 40-50 km/10 years in search of favorable temperatures, thereby shifting the distribution of resources and causing changes in current fisheries patterns. Changes in the time of spawning because of altered thermal signals can lead to mismatches between reproductive events and optimum survival of larvae and change patterns of predator-prey interactions as species respond differently and in different ways to warming. The effects of higher temperatures on disease risks include the fact that this condition contributes to accelerated pathogen growth, whereas numerous coral bleaching episodes associated with thermal stress can endanger the livelihood of reef systems, sustaining a plethora of productive fisheries [18].

5.2 Differentiated Vulnerability

Such complicated climate-induced alterations strike small-scale fishing communities more, since due to their weak movements they cannot keep up with fish which migrate towards remote regions [19]. They are also limited in terms of adaptation ability owing to a lack of financial resources, access to information on a timely basis and susceptibility to storms and rough seas, since they depend on small ships, which are working close to the shore. The greater mechanized fleets with modern navigation systems and extended operational range are able to travel with the changing of the fish species to enable them to sustain or possibly expand their capture given the different circumstances.

Thus, climate effects contribute to the aggravation of already existing societal and economic disparities by moving access to sea resources out of hands of poor, small-scale actors to technologically advanced, capital-intensive fleets that better adapt to changing conditions [12].

6. Biodiversity, Portfolio Effects and Ecosystem Services

The theory of bio-diversity creating a portfolio effect, similar to financial diversification, is a good basis to understand the current economic importance of species richness in directing fishing livelihoods, and the ecological importance of biodiversity in terms of conservation [20, 21]. Equally, to the diversification of investments in different assets with different risk features to lower the total volatility, the development of an array of different species with dissimilar existence histories, local association, environmental tolerance and climate reaction constitute a peculiar kind of natural insurance against fall of one solitary stock. This biological diversification stabilizes income over time, lowers reliance on stock-specific disturbances, and strengthens resistance to environmental changes.

Research on Alaska's salmon fisheries, California's groundfish sector and other extensively studied multispecies systems shows that catch ranges containing 5 – 10 species correlate with 20 – 35% lower income variability when compared to highly specialized processes focusing on a single or a few species [21]. This stabilizing impact is especially essential for small-scale operators who operate at or near subsistence levels because they have low financial reserves, little or no access to formal insurance, and few alternative livelihood alternatives during poor fishing seasons. Diversification benefits are not limited to individual boats; they also include the stability of community employment, the maintenance of a diverse array of processing and marketing activities and the preservation of regional economic stability, even if specific stocks perform unfavourably in an assumed year.

6.1 Ecosystem Functioning and Services

Despite the fact that biodiversity is the basis of critical biological processes and services that underpin fisheries production, it is rarely explicitly recognized in economic systems, except from the observable benefits represented in markets [22, 23]. Since species are linked with complex food-webs, perturbations in one population can propagate via predator prey interactions, competition, habitat-shift, and other indirect mechanisms, and have unanticipated impacts, threshold reactions and regime shifts. By removing the best predators, the trophic cascades may result in reorganizing the ecosystem structure, reshaping the community composition to the benefit of diverse functional groups, reducing overall production and predisposing to the biological invasion [22].

Cross-ecological experiments in different marine ecosystems have shown that decline in biodiversity invariably leads to lower potential yields, higher changes in interannual catches and susceptibility to perturbations, e.g. storms, heat waves and pollution events. Areas that have gone through considerable cumulative species losses in recent decades experience far more severe cuts on commercial landings as well as a more pronounced boom bust cycles, exposing the stability of communities that depend on fishing and those economies [22].

6.2 Governance Challenges

The essential challenge is to render this voluminous knowledge of the ecology into significant governance solutions to alter the fishing patterns, protect biodiversity, and preserve ecosystem services [24]. Rules and regulations currently in place in India and elsewhere tend to focus on individual stocks individually and not on how food chains or succession affect each other or what happens to other factors of the non-target ecosystem as a result of actions on any given fleet or gear. Transitioning to Ecosystem Based Management (EBM) that reflects these interdependencies requires stronger monitoring systems, increased capacity for multispecies and ecosystem modeling, improved

coordination among fragmented institutions, firm political commitment to precautionary policies and sustained enactment beyond short electoral cycles [25].

7. Aquaculture Development and Blue Economy Vision

India has emphasized aquaculture as a supplementary production option to overcome the sustainability limits of capture fisheries while also meeting the increased demand for aquatic goods caused by population expansion and dietary changes [26]. Between 2013 - 14 and 2024 – 25, national fish production grew by roughly 9.6 million tones to 19.5 million tons [26]. Between 2013-14 and 2024-25, national fish output grew by roughly 9.6 million tonnes to 19.5 million tons [26]. The majority of this gain was due to agricultural operations, which now account for around three quarters of overall production. This remarkable rise has placed India among the leading aquaculture producing nations, yet output remains concentrated in a limited number of locations and species categories.

7.1 Drivers of Aquaculture Growth

A combination of various interrelated factors have catalyzed this growth and these factors include; breeding techniques, better disease management, improved feed formulations and mechanization of farms all of which have enhanced efficiency and reduced mortality [10]. Parallel progress in hatcheries and nurseries has enhanced supply of high-quality seedlings and post-larvae, which enables production of more stable output. Cold chains, processing transportation networks and infrastructure have been supported to preserve quality across the pond to the market and further increase the access to high value domestic and export markets. The shift towards a less reliant monoculture of carps to a more diversified type of planted species has generated novel economic possibilities and reduced the systemic risks connected with monoculture [26].

Andhra Pradesh contributes nearly 40 percent of the India aquaculture with an overwhelming domination in shrimp farming that covers over 160,000 hectares. This importance is attributed to the good agro- climatic conditions, good availability of brackish water, closeness to major ports, and export logistics are easy to carry out, and the wide application of the Best Management Practices with the help of extension services and regulation activities promoting the involvement of the private sector. The leading state in the inland agriculture is the West Bengal in which innovative polyculture systems that house different carp species improve efficiency of resources, generate greater profits than monoculture systems and absorb about one million individuals [26].

7.2 Environmental and Social Concerns

Although aquaculture is a beneficial technique, it is also associated with considerable ecological and social issues, which have to be managed to make it sustainable. The pond discharge with extreme content of nutrients, organic loads and various pollutants may

contaminate the surrounding water bodies, and adversely affect the local population [10]. Transmission of pathogens between farms and between domesticated and wild species has the potential to impact the sustainability of agricultural production as well as the natural ecosystem, and the use of wild-caught fish in fishmeal has led to questions about the sustainability of capture fisheries and the availability of feed on a whole [27]. The destruction of ecosystems that are essential biological processes has been hastened by the conversion of mangroves and wetlands into ponds especially in sensitive coastal lands.

Sustainable development of the agricultural sector requires ecosystem -oriented government that balances the goals of production and environmental conservation and social justice [24]. Operational standards of responsible production such as Aquaculture Stewardship Council (ASC) and Best Aquaculture Practices (BAP) are voluntary certification programs including standards associated with ecological performance, labor standards, communal implication and food security.

7.3 Blue Economy Framework

The strategy of the Blue Economy of India has a comprehensive vision of the management of the marine and coastal resources, where the same aims at conservation, economic development and social welfare simultaneously. It recognizes that the cumulative ocean-based activities contribute over 4 percent of the national GDP and support livelihoods of millions of individuals especially in coastal regions. Development is affected by the notion that the exploitation and utilization of ocean resources should not exceed ecological constraints to deliver long-term benefits, and, at the same time, increase the living standards and maintain healthy marine environments [28]. This opinion underlines the inherent relationship between environmental integrity and human well-being and not the trade-off.

8. Employment, Livelihoods and Nutritional Security

About 2830 million individuals depend completely or partly on fisheries and related industries that comprise the full gamut of activities along the aquatic food web [7]. The number of individuals employed either on full time or part time in marine and inland capture is approximately 9 million [7] in trawlers powered by huge engines and other non-motorized traditional boats. The activities of post -harvest utilize an additional 4-5 million workers at the processing plant and cold storage structures to undertake different tasks such as production of ice, and different kinds of value addition to be exported to external markets. Another 3 -4 millions of citizens are employed in marketing and trade and these are retail, wholesale and export industries that interrelate the producers and customers both locally and internationally. Moreover, 10 -12 million people work in the support services, such as, boat building, net-making engine repair, ice production, and other associated supporting jobs [7].

8.1 Cultural and Social Dimensions

It is not only that marine fishing is a source of livelihood to many households but rather it is closely linked to religious or spiritual world perceptions, social systems, and a sense of collective identity [5]. Passage of knowledge, skills and traditional practices received through the culture across generations helps to strengthen the unity of the community and to maintain ancient traditions of the sea trade [25].

8.2 Nutritional Contributions

Food cultures and consumption are strongly based in the local food cultures within the coastal regions with fish and other aquatic things playing a vital role in quality of food intake and food security [29]. According to national research, there are great regional differences: the average coastal dweller eats 2530 kg of fish man each year, which is supported by the convenient access to fresh harvest and rich cuisines. The national average consumption, on the other hand, stands at only about 9-10 kilograms per year which is restricted due to lack of cold-chain and distribution networks in inland areas. In some of the coastal areas, fish contributes over one -fifth of the total protein intake, versus about 6 -7 percent at the national level [30]. Aquatic food is rich in protein and contains essential micronutrients like vitamins A and D, Omega -3 fatty acids and trace minerals including iodine, zinc and selenium [29]. Small pelagic species that are economical and available to the disadvantaged households play vital roles in correcting the micronutrient deficiencies and reducing the under-nutrition of the endangered groups [31].

9. Management Reforms and Policy Interventions

The fisheries of India are regulated in a intricate administrative structure and are necessitating liaison between the Union government and the concerned states. The key legal and policy tools include the Marine Fishing Regulation Acts (MFRAs) that are in place by all maritime states, the Coastal Regulation Zone (CRZ) Notification, the National Marine Fisheries Policy (2017), and the Pradhan Mantri Matsya Sampada Yojana (PMMSY) as the key development program. Nevertheless, with this elaborate arrangement, there are still great gaps in implementation, which weaken managerial performance [32].

9.1 Implementation Gaps

The strictness in different states is hugely different. Although there are quite good surveillance and compliance mechanisms in some of them, others have a relatively low level of patrolling ability, which opens opportunities of breaking rules. There is a low likelihood of surveillance and minimum fines deprive offenders of the real threat when

committing illegal acts. Border wars among local states and various fisheries organizations increase uncertainty about jurisdiction and diminish regulatory transparency. Further, little has been invested in stock evaluation and scientific infrastructure hindering data driven, decision making, as numerous critical resources are yet to be researched. Top-down, centralized policy making processes that deprive fishing communities can produce cynicism, opposition and disobedience [13].

9.2 Management Tools

Sustainable utilization of fish stocks requires a set of synergizing management tools [33, 34]. Quantitative stock-based harvest quotas and maximum sustainable yield (MSY) standards are essential in averting overexploitation, but sound quota systems must rely on effective monitoring systems, including vessel monitoring, dockside monitoring, and reliable catch reporting, which in many jurisdictions are ineffective [11, 33]. The regulation of capture size brings about the attainment of sexual maturity in the individual before they can capture, whereby each group has the potential of having at least one chance of reproduction and has the ability to sustain recruitment [35]. Nonetheless, the problem of gear inspection and regulation of landing sites is often inefficient, with a high percentage of using undersized mesh and little use of penalties [35].

Timed seasonal closures in line with the spawning periods protect the breeders in large numbers and provide the much needed recovery time by the underrepresented populations. As of now, state-based restrictions tend to range 45-61 days a year; research indicates that longer, species-specific shutdowns may have a substantial positive impact on population recovery, but only when adequate and prompt compensation is given to those who suffered as a result of the shutdowns [11].

Non-take reserves and habitat protection zones are spatial techniques that help to preserve biodiversity and provide a spillover in case of recovering stocks that spread into other fishery areas [23]. Despite India developing several coastal Marine Protected Areas, they are de facto ineffective because of poor staffing, infrastructure, and local participation, which cut their effectiveness by a significant factor. Good Marine Protected Areas would require proper enforcement funds and high participation of fishermen and other stakeholders to keep them on board and safeguard livelihoods [28].

Digital tools could be extremely useful in terms of supervision and adaptive management. Vessel Monitoring Systems (VMS) enable the real-time tracking of the movement of the fleet and the possibility to identify the trespassing into the limited range as well as to certify compliance with time conditions. Satellite monitoring is capable of tracking illegal operations in distant offshore areas whereas mobile apps are able to simultaneously deliver weather and safety reports to individuals and elaborate information on catches and fishing activity to be used in management systems [11].

10. Deep-Sea Fisheries: Opportunities and Challenge

The EEZ in India is expected to maintain a long-term production of approximately 4.4 million tonnes of which only 70-75% is utilized. Most of the latent potential is found in deeper off shore areas which lie beyond the effective radius of most of the existing fleets. This offers not only some new opportunities, but also massive threats of future growth. The resources that are not exploited by the Indian operators in a significant manner include billfishes, Oceanic tunas, large oceanic squids, deep water sharks and the various mesopelagic organisms. Different resources are found in these deeper waters.

10.1 Infrastructure and Capacity Requirement

In order to leverage on these opportunities successfully, a lot of financial spending and strategic planning is necessary [37]. It needs special ships that are safe to operate in the deep, rough waters which cost several crores of money and involve sophisticated maintenance arrangements. The differences between these ships and the coastal trawlers are manifold as these ships possess reinforced hulls, better navigation and communication systems, equipment designed specifically to fish in very deep waters and better crew safety equipment.

It also requires human beings to work onshore including the technicians to maintain the vessels and gear, quality assurance people to process and handle it, analysts that understand the global seafood market, and fisheries scientists. To satisfy these requirements will require coordinated programs that will include maritime academies, vocational institutes and research organizations.

10.2 Environmental Precautions

Because deep-sea habitats are not well-known and are highly sensitive to interference, any move towards massive use of such resource is subject to careful evaluation of environmental impact first [16]. The ocean ecosystems are often characterized by slow biological turnover, low general productivity, high endemism and extreme vulnerability to biological and physiological disruptions caused by the fishing activities.

There is a need to take a cautious stance and the initial catch limits should be set at a level below the theoretical levels until holistic scientific knowledge is gained. The observation of not only developments of target species needs to be conducted but also of comprehensive ecosystem indicators, including bycatch composition, seabed habitat condition, and predator-prey dynamics changes. Adaptive management approaches that change effort and permissible catches depending on emerging information are the key to avoiding long-term and potentially permanent damage of the deep-sea ecosystems.

11. Fisheries Management, Ecosystem Based

Ecosystem -Based Fisheries Management (EBFM) is a new school of thought in management thought which integrates narrow, stock-oriented management methods with the management of complete ecosystems and ecosystem processes [23, 24]. The aim shifts to maximizing the productivity of single species towards ensuring overall ecosystem well-being because it is acknowledged that the sustained productivity of fisheries relies on the well-being of food webs, habitats and biological processes. This approach entails the focused analysis of trophic relationships in which it is realized that variations in the population of a single group can propagate cascade impacts by predator-prey and competitive interactions, altering the dynamics of the system.

EBFM recommends that critical habitat should be preserved so as to support population such as spawning, feeding areas and nurseries where juveniles develop are important to the whole marine biodiversity [16]. Furthermore, it recommends the need to integrate long-term and traditional ecological experiences, held by fishing communities with formal scientific information thereby, developing ecologically- sound management strategies, which are socially and culturally grounded [12].

12. Co-Management and Community-Based Management

Local management practices put an emphasis on rich and complex ecological knowledge of fishermen who have accumulated such knowledge through centuries of personal interaction with the environment. This body of traditional ecological knowledge includes information about, use of habitat, seasonal information, behavior of species and environmental signs, it can greatly enhance official assessments since they will be based on regional experience [25]. In the past, traditionally a number of communities along the coastline were in favor of customary tenure systems that governed the access of some of the fishing areas, apportioned chances to the users, blocked any attempts during breeding seasons and fined violators. These measures by the natives generally guaranteed long term availability of resources until they were washed away by the process of state-initiated modernization, introduction of the mechanized fleets and erosion of customary powers [5, 28].

13. Possible Future and Suggestions

The attainment of long-term sustainability in the Indian marine fisheries will need a significant transformation in ecological, economic, and social levels. This was a call to a change towards ecosystem management that preserves biodiversity, protects important habitats and also that the extraction of resources is not performed beyond the levels of biologically sustainability. By developing an integrated and well-managed system of Marine protected Areas that cover a minimum of 10 percent of the coastal waters, marine organisms would be provided with a refuge, spillover effect of replenished

population into the adjacent fishing grounds, and ecosystem resilience to climate changes.

13.1 Economic Diversification

Economically, reducing the vulnerability and pressure of the wild species require the diversification of livelihoods, value chain strength, as well as the creation of incentive systems to promote responsible behavior. Specific skill-building, better post-harvest management, and equitable allocation of gains along supply chains can improve livelihood and equity. Responsibly sourced seafood with environmental accreditation can give incentive in the market and access to higher-value markets, and new opportunities in the ecotourism, farming of high-value marine species, and marine biotechnology can help lead to a gradual switch to fully exploited or overexploited capture fisheries [10].

13.2 Social Equity and Inclusion

Historically marginalized fishing communities need to be better represented and safeguarded in order to bring social justice and inclusion to them. The introduction of secure, legally established tenure or territorial use rights in close offshore areas could enable small scale fishermen to carry out a stewardship practice whilst ensuring that they are not displaced by large industrial scale fleets. Fair leadership involves inclusive institutions where fishermen are included to take part in decision making and acknowledging the role of women throughout the value chain. Social protection, including health insurance, old -age security and disaster-response benefits, can be an effective tool in reducing risk and enhancing long-term planning.

13.3 Climate Adaptation

In order to be more resistant to climate change, vulnerable populations need to rebuild their ecosystems and enhancing their adaptive capacity. Massive mangrove planting will prevent storms and rising sea level as well as give nursery grounds to numerous fish and crustacean species [18]. The recovery reef strategies including coral gardening, transplanting and the construction of artificial reef structures can be used to restore the three dimensional ecosystems in regions that have been damaged either through bleaching or destructive fishing practices.

Innovative climate risk management policies are also needed such as, reliable early alerts on cyclones and extreme oceanic environments, which are spread across mobile networks and coastal communication systems, would help curb the loss of life and property [12]. The seasonal forecasting and coastal prediction could be used to help in

deciding on the best fishing seasons and areas which will be safer and easier to plan. Finally, transitions to other forms of income or alternative activities such as livelihood diversification methods that predict future loss or reduced profitability of some traditional fishing grounds can be used to address the long term vulnerability posed by climate changes.

In Chicago, training is conducted for scientists to gain expertise in new developments within the community technical field. <|human|>13.4 Scientific Capacity Building: Both in Chicago, scientists are trained in new developments in the community technical field.

To increase national scientific capacity on ecosystem supervision, inventory examination and climate impact measurements, genuine evidence based fisheries administration is necessary [6]. More funding on research infrastructure like survey vessels, hi-tech laboratories and advanced methods of analysis would help in a more thorough assessment of the health and the state of the resources and ecosystems. The co - production of knowledge, and trust and mutual problem solving can be achieved through joint research projects that create relationships between universities and research institutions and fishing communities and industry members. The identification of trends, the evaluation of the effectiveness of policies, and a more dynamic management process require long-term observation systems which monitor various ecological and socio-economic variables across space and time. Standardized field techniques, standard transparency, and independent scrutiny would all make it much easier to analyze data if they were all available and could be combined.

14. Conclusions

India's marine fisheries are at an essential stage currently. They are able to look at whether the project is financially possible. They need to find a balance between promoting social equity and making money. The country has already become an important an active player in the global fisheries by virtue of decades of rapid growth. But this path has led to abundance of environmental damage and socioeconomic inequality. Which is now putting the sector' long-term viability at risk.

The stabilization of the marine landings on approximated sustainable levels implies that no more extensive development in the form of increased fishing activities can be done. The sustainable marine resources have been compromised and over riddled with constant overexploitation, habitat degradation, and climate change, a serious threat to the marine resources which sustain livelihoods and food to millions of people. Cumulatively, these pressures pose a threat of forcing the ecosystems into the stage of degradation which may become hard to correct hence growth built on increment of fishing pressures is no longer sustainable.

The ongoing pressures of over exploitation, habitat destruction and concentration of incomes among the capital intensive fleets are gradually being felt on the marine resource base on which millions of people depend on to sustain their livelihoods and food security, and the marginalization of many small-scale fishers continues to reflect the unwanted inequities in the distribution of resources, and the urgent necessity of comprehensive reforms to enhance the situation of vulnerable groups.

Because the increase of temperatures in the sea, changes in currents, changes in the distribution of species are only going to increase the existing threats and cause more hazards. Resilience can be promoted by also restoring ecosystems and adopting sustainable harvesting methods as well as increasing the capacity of the most susceptible groups especially those that are small-scale artisanal fishermen who contribute least to the environmental degradation but bear the biggest losses.

The way ahead will be to go beyond sectoral thinking and fully recognize both the complexity of social-ecological systems, be proactive amidst incomplete information, and have meaningful participation in policymaking processes by historically marginalized groups especially women throughout the fisheries value chain. The choices taken in the coming ten years will either mean that marine fisheries will keep on delivering livelihoods, food, and national revenue or that the extraction in the short term will destabilize the ecological basis as well as the health of the community. The opportunity of the change requires the determination to question the status quo, and the ability to integrate the ecological base and the wellbeing of the community.

References

- [1] Srinath, M., Kuriakose, S., and Mini, K.G. (2005). Methodology for the estimation of marine fish landings in India. *Indian Journal of Fisheries*, 52(2), 145-154.
- [2] Kripa, V., Mohamed, K.S., Koya, K.P.S., Jeyabaskaran, R., Prema, D., Padua, S., et al. (2018). Overfishing and climate drives changes in biology and recruitment of the Indian oil sardine *Sardinella longiceps* in southeastern Arabian Sea. *Frontiers in Marine Science*, 5, 443.
- [3] Madhupratap, M., Nair, K.K.C., Gopalakrishnan, T.C., Haridas, P., Nair, K.N.V., Venugopal, P., et al. (2001). Arabian Sea oceanography and fisheries of the west coast of India. *Current Science*, 81(4), 355-361.
- [4] Bavinck, M., Jentoft, S., and Scholtens, J. (2018). Fisheries as social struggle: A reinvigorated social science research agenda. *Marine Policy*, 94, 46-52.
- [5] Kurien, J. (1998). *The Blessing of the Commons: Small-Scale Fisheries, Community Property Rights, and Coastal Natural Assets*. Trivandrum: Centre for Development Studies.

- [6] Mohamed, K.S., Sathianandan, T.V., Zacharia, P.U., Asokan, P.K., Krishnakumar, P.K., Abdurahiman, K.P., et al. (2014). Depleting Indian marine fishery resources: Status and management options. *Indian Journal of Fisheries*, 61(4), 1-11.
- [7] Allison, E.H., and Ellis, F. (2001). The livelihoods approach and management of small-scale fisheries. *Marine Policy*, 25(5), 377-388.
- [8] Harper, S., Zeller, D., Hauzer, M., Pauly, D., and Sumaila, U.R. (2013). Women and fisheries: Contribution to food security and local economies. *Marine Policy*, 39, 56-63.
- [9] Kleiber, D., Harris, L.M., and Vincent, A.C.J. (2015). Gender and small-scale fisheries: A case for counting women and beyond. *Fish and Fisheries*, 16(4), 547-562.
- [10] Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C., Clay, J., et al. (2000). Effect of aquaculture on world fish supplies. *Nature*, 405(6790), 1017-1024.
- [11] Cochrane, K.L., and Garcia, S.M. (2009). *A Fishery Manager's Guidebook*. 2nd ed. Rome: FAO.
- [12] Vivekanandan, E., Hermes, R., and O'Brien, C. (2021). Climate change effects on fish resources of India: An outlook. *Indian Journal of Fisheries*, 68(Special Issue), 109-121.
- [13] Jentoft, S. (2007). Limits of governability: Institutional implications for fisheries and coastal governance. *Marine Policy*, 31(4), 360-370.
- [14] Anticamara, J.A., Watson, R., Gelchu, A., and Pauly, D. (2011). Global fishing effort (1950-2010): Trends, gaps, and implications. *Fisheries Research*, 107(1-3), 131-136.
- [15] Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., and Torres, F. Jr. (1998). Fishing down marine food webs. *Science*, 279(5352), 860-863.
- [16] Thrush, S.F., and Dayton, P.K. (2002). Disturbance to marine benthic habitats by trawling and dredging: Implications for marine biodiversity. *Annual Review of Ecology and Systematics*, 33, 449-473.
- [17] Lewison, R.L., Crowder, L.B., Wallace, B.P., Moore, J.E., Cox, T., Zydalis, R., et al. (2014). Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. *Proceedings of the National Academy of Sciences USA*, 111(14), 5271-5276.

- [18] Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney, K., Watson, R., and Pauly, D. (2009). Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries*, 10(3), 235-251.
- [19] Allison, E.H., Perry, A.L., Badjeck, M.C., Adger, W.N., Brown, K., Conway, D., et al. (2009). Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries*, 10(2), 173-196.
- [20] Kasperski, S., and Holland, D.S. (2013). Income diversification and risk for fishermen. *Proceedings of the National Academy of Sciences USA*, 110(6), 2076-2081.
- [21] Schindler, D.E., Hilborn, R., Chasco, B., Boatright, C.P., Quinn, T.P., Rogers, L.A., et al. (2010). Population diversity and the portfolio effect in an exploited species. *Nature*, 465(7298), 609-612.
- [22] Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., et al. (2006). Impacts of biodiversity loss on ocean ecosystem services. *Science*, 314(5800), 787-790.
- [23] Piktich, E.K., Santora, C., Babcock, E.A., Bakun, A., Bonfil, R., Conover, D.O., et al. (2004). Ecosystem-based fishery management. *Science*, 305(5682), 346-347.
- [24] Garcia, S.M., Zerbi, A., Aliaume, C., Do Chi, T., and Lasserre, G. (2003). *The Ecosystem Approach to Fisheries: Issues, Terminology, Principles, Institutional Foundations, Implementation and Outlook*. FAO Fisheries Technical Paper No. 443. Rome: FAO.
- [25] Berkes, F., Colding, J., and Folke, C. (2003). *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge: Cambridge University Press.
- [26] Edwards, P., Zhang, W., Belton, B., and Little, D.C. (2019). Misunderstandings, myths and mantras in aquaculture: Its contribution to world food supplies has been systematically over reported. *Marine Policy*, 106, 103547.
- [27] Tacon, A.G.J., and Metian, M. (2008). Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture*, 258(1-4), 146-158.
- [28] Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge: Cambridge University Press.
- [29] Thilsted, S.H., Thorne-Lyman, A., Webb, Bogard, J.R., Subasinghe, R., Phillips, M.J., et al. (2016). Sustaining healthy diets: The role of capture fisheries and aquaculture for improving nutrition in the post-2015 era. *Food Policy*, 61, 126-131.

- [30] Srinivasan, U.T., Cheung, W.W.L., Watson, R., and Susmaila, U.R. (2010). Food security implications of global marine catch losses due to overfishing. *Journal of Bioeconomics*, 12(3), 183-200.
- [31] Béné, C., Barange, M., Subasinghe, R., Pinstrup-Andersen, P., Merino, G., Hemre, G.I., et al. (2015). Feeding 9 billion by 2050: Putting fish back on the menu. *Food Security*, 7(2), 261-274.
- [32] Pomeroy, R., Parks, J., Mrakovcich, K.L., and LaMonica, C. (2016). Drivers and impacts of fisheries scarcity, competition, and conflict on maritime security, *Marine Policy*, 67, 94-104.
- [33] Hilborn, R., Amoroso, R.O., Anderson, C.M., Barun, J.K., Branch, T.A., Costello, C., et al. (2020). Effective fisheries management instrumental in improving fish stock status. *Proceedings of the National Academy of Sciences USA*, 117(4), 2218-2224.
- [34] Costello, C., Ovando, D., Clendenning, G., Strauss, C.K., Hilborn, R., Melnychuk, M.C., et al. (2016). Global fishery prospects under contrasting management regimes. *Proceedings of the National Academy of Sciences USA*, 113(18), 5125-5129.
- [35] Hilborn, R., Fulton, E.A., Green, B.S., Hartman, K., Tracey, S.R., and Watson, R.A. (2015). When is a fishery sustainable? *Canadian Journal of Fisheries and Aquatic Sciences*, 72(9), 1433-1441.
- [36] Froese, R., and Pauly, D. (2023). FishBase. World Wide Web electronic publication. www.fishbase.org
- [37] World Bank. (2017). *The Sunken Billions Revisited: Progress and Challenges in Global Marine Fisheries*. Washington DC: World Bank.

Chapter 3: Global Fisheries and Aquaculture: Nutrition, Economics, Blue Economy Opportunities in Developing Nations

1. Introduction

“Fisheries and aquaculture occupy a unique position at the intersection of food security, economic livelihoods, and environmental stewardship” [2, 4, 9]. “Across many regions of the world, particularly in developing coastal and island nations, aquatic food system serve not only as a primary source of nourishment but also as a backbone of employment, income generation, and cultural identity” [15, 18, 21].

“Blue foods including fish, shellfish, and aquatic plants provide nutrient-dense dietary options that are often more accessible and environmentally efficient than land-based animal foods” [2, 6, 7]. “At a national scale, India’s marine sector contributes substantially to economic output, directly employing millions of fishers while indirectly supporting many more through processing, transportation, and export-related services” [4, 5, 18].

“Despite its major contributions to livelihoods and exports, the sustainability of marine fishery resources confront rising problems” [1, 3, 8]. “Responsible fishing, the defense of small-scale fishermen’s rights, science-based catch limits, marine protected areas, and changes to harmful subsidies are all being supported more and more by national and international policy” [1, 4, 15]. The blue economy framework, which is in line with India’s objectives for food security, climate resilience, and long-term economic growth in the marine sector, emerges as a crucial route to integrate sustainable aquaculture, ecosystem restoration, and inclusive governance in this dynamic policy environment [2, 4, 15, 18, 20, 22].

2. Role of Seafood in worldwide Nutritional security

“Seafood are affordable animal protein, especially to low-income and coastal areas, fisheries play a major role in India’s nutrition and food security” [4, 9, 21]. “Compared to land-based animal protein sources, seafood from marine habitats like the Arabian Sea and Bay of Bengal generally has less of an impact on the environment and supports traditional diets” [2, 7, 18, 22]. “Regular consumption of seafood is associated with decreased risks of cardiovascular disease, stroke, and death from all causes [7, 9].

Growth, tissue repair, and immunological function all depend on the high-quality, complete, and easily accessible protein found in seafood [7, 9]. Sea foods have contain natural source of omega-3 (EPA and DHA), which are key for brain growth, fighting inflammation, and heart health [6, 7, 9]. Sea foods contain vitamin B12, which is essential for producing red blood cells, supporting neurological function, and synthesizing DNA [6, 9]. Salmon and fatty fish provide vitamin D, which helps the body absorb calcium for stronger bones [6, 7]. Iodine helps the body make thyroid hormones, that play important role in metabolism [6, 9, 14].

3. Economic and Social Foundations of the Seafood Sector

- Seafood is one of the most commonly traded food items around the world [4, 5].
- The global fish market makes around \$400 to \$500 billion every year, and the money from exporting fish is about \$195 billion [4, 5, 16, 18, 20].
- The sector has big effects that spread out, meaning that activities like processing, storing, shipping, and selling [18, 20].
- The fish create about \$2.50 to \$4.00 for every \$1 earned from primary fish production [18, 19, 20].
- While emerging nations accounting majority of the global seafood trade value, fisheries and aquaculture are important sources of foreign exchange earnings for nations like China, Norway, and India [5, 12, 16].
- “While fisheries contribute 1-5% of the GDP in many coastal and island nations, aquaculture accounts for more than half of the world’s sea food exports” [15, 18, 20].
- Value-added processing greatly boosts economic returns; in India, shrimp processing raises product value by 30-50% [12, 14].
- “Around 59 million people work directly in fishing and aquaculture, while the whole sector including processing, families, and dependents, supports roughly 600 million livelihoods worldwide” [4, 18, 21].

- About 3.2 billion people worldwide receive inexpensive nourishment from seafood, which accounts for 17% of the world’s animal-derived protein and over half in some regions of Asia and Africa [2, 6, 7, 9].
- Traditional fishing techniques contribute to the preservation of indigenous Knowledge and cultural legacy that has been passed down through the generations [1, 8, 15, 18].

4. Economic contribution and opportunities of Artisanal fisheries

- “Small scale fisheries which use traditional methods, small crafts, cheap capital, and family labour for jobs, food security, and rural lives”. They promote fair income distribution, provide reasonably priced fresh fish to regional markets, and employ millions of people both directly (fishermen)and indirectly (processing, marketing, net-making) [3, 4, 18, 21].
- The primary source of income for the impoverished in rural and coastal areas; low entry barriers support weaker groups; women support homes through post-harvest labor (cleaning, drying, selling) [4, 9, 18, 21].
- Broader economy promotes inclusive growth, poverty alleviation, and local trade in resource-dependent regions [15, 18, 20, 22].
- Fishermen are often disadvantaged by the presence of middlemen because they lack easy access to loans, inadequate infrastructure like cold storage and proper landing spots, and weak market connections [4, 10, 18, 20,].
- In addition, their incomes are further reduced by competition from large mechanized boats, declining fish stocks, seasonal fishing bans, climate variability, and rising costs for fuel and gear [3, 4, 8, 18, 20].

5. Climate Resilience in Fisheries

Climate change is an impact on fisheries through ocean warming, deoxygenation , acidification, and altering the food chains, migration and mass production, endangering fish stocks, ecosystems, and human livelihood. These implications are especially significant in countries like India, where fisheries provide livelihoods for millions of people in coastal areas [4, 6, 7, 9, 20].

5.1 Viable Aquaculture as a Climate Solutions

Sustainable aquaculture eases the pressure on overfished stocks, it supports climate goals by working with blue carbon ecosystems. Blue carbon ecosystems include mangroves, salt marshes, and seagrasses. These ecosystems absorb carbon from atmosphere, they protect coastlines to prevent erosions and storms. They also

provide major economic benefits like fisheries support and tourism [2, 4, 7, 14, 18, 19].

5.2 Restoring Ecosystem and Natural Capital Development

Restoring ecosystem helps achieve global climate targets [18, 20]. Healthy ecosystems stay productive and resilient to climate changes [8]. Restoring ecosystems improves natural resources and natural communities resilience [15, 18]. Sustainable aquaculture benefits from protecting fish stocks and habitats like mangrove [4, 19].

5.3 Policy Innovation and International Cooperation

Policy Innovation and Cooperation Sustainable aquaculture relies on strong regulations and global teamwork [3, 15]. Using less fishmeal and fish oil improves sustainability, while incentives encourage green tech and discourage harmful practices. Investments in ocean sustainability can deliver five times the economic and social returns [18, 19, 20].

6. Pathways to Prosperity: Five Strategic Opportunities for Coastal Developing Nations

Developing nations refer to the economic, social, and technological prospects created by expanding sustainable seafood production, processing, and trade particularly through aquaculture and value chains that drive poverty reduction, rural industrialization, and integration into global markets for low and middle income coastal nations [2, 4, 5, 15, 18, 20]. These opportunities leverage natural advantages like biodiversity, labour, and coastal access, while addressing challenges like infrastructure gaps through policy, investment, and innovation [15, 18, 19, 20]. The opportunities are

- ❖ Aquaculture Expansion as Growth Engine
- ❖ Export Market Access and Diversification
- ❖ Value Added Processing and Industrialization
- ❖ Blue Economy Integration and Policy Support
- ❖ Social Inclusion and Resilience Building

6.1 Aquaculture Expansion as Growth Engine

Aquaculture Expansion as Growth Engine refers to the fish farming whether in ponds, cages, especially in developing countries [4, 14, 21]. Outpacing wild catches since 2022 and is on track to meet 60% of global demand by 2030 [4, 5].

Capitalizing local resources, labour, and tech, it creates export opportunities and takes pressure off depleted wild stocks [1, 4, 7].

6.1.1 Production Systems and Tech for Scaling Up

Pond and cage Farming: mainly in Asia (91% of global output), yields 10 to 30 tonnes per hectare in a year for shrimp and tilapia, way above the 1 to 2 tonnes from wild capture [4, 5, 14]. Recirculating Aquaculture Systems (RAS) use zero waste tech to farm premium fish like seabass at high densities (50 to 100 kg/m³) [7, 14]. Integrated Multi Trophic Aquaculture (IMTA) combines fish, shellfish, algae to recycle nutrients, cutting waste 30 to 50% like Vietnam’s shrimp and seaweed farms [2, 8]. Bio floc and Zero water exchange systems use minimal water and double tilapia yields in India and Bangladesh compared to traditional ponds [14, 21].

6.1.2 Targeting High-Growth Export Species

S. No	References	Species	Major Producers	Production Yield	Export Value / Market Reach	Growth Trend / Impact
1.	(FAO, 2022; MPEDA, 2023; OECD, 2023)	Shrimp (<i>Litopenaeus vannamei</i>)	India, Vietnam, Ecuador	10–20 tonnes per hectare	USD 5–10 per kg in international markets	Annual export growth exceeding 15–25%, driven by strong demand in the US, EU, and East Asia.
2.	(FAO, 2021; WorldFish, 2022)	Tilapia	China, Indonesia, Egypt	20–50 tonnes per hectare	USD 2–5 per kg globally	Sustained global growth of over 10%, supported by affordability and wide consumer acceptance
3.	(FAO, 2022; UNCTAD, 2023)	Pangasius	Vietnam	300–500 tonnes per hectare	Export value of approximately USD 11.5 billion	Holds more than a 9% share of the global whitefish market, with steady export expansion.
4.	(FAO, 2020;	Milkfish	Indonesia, Philippines	5–10 tonnes per hectare	Mixed local	Stable demand with a balanced focus on

	ASEAN Secretariat, 2021)				consumption and regional exports	domestic food security and niche export markets.
5.	(FAO, 2021; World Bank, 2022)	Carp and Catfish	Bangladesh, India	15–25 tonnes per hectare	Primarily domestic markets and MENA region exports	Moderate growth driven by regional trade and strong domestic consumption patterns.

6.1.3 Economic and Employment effects

- Quick returns on aquaculture: invest 4 to 8 lakh per hectare, break even in 1 to 2 years, and earn 20 to 50 % returns annually, much higher than the crops (10 to 15%) [14, 21].
- Seafood processing has huge job potential: for every tone processed, 4 to 5 jobs are created [4, 18]. Vietnam’s seafood industry employs 4.5 million workers, while India’s PMMSY (Pradhan Mantri Masthya Sampada Yojana) initiative supports 14 million livelihoods [10, 17, 21].
- Foreign Exchange: Aquaculture drives 60 to 90% of seafood exports in top countries; developing Asia earns over 100B USD [5, 16, 20].

6.1.4 Policy and Investment

- Government Schemes: India’s PMMSY (Pradhan Mantri Masthya Sampada Yojana) 2.5B USD subsidies, insurance and Vietnam’s VASEP (Vietnam Association of Seafood Exporters and Producers) export hubs drive growth [10, 17].
- Feed Innovation: Plants and insects are a protein-rich meal to replace fishmeal, cost 50% algae adds value [14].
- Certification: ASC standards add prices by 20%, block chain tracks every catch [5, 16].

6.1.5 Real-World Success stories

- India: 8% of global aquaculture, with shrimp exports worth 4 billion USD, making up 65% of its total exports, driven by 2 million ponds and a remarkable 23% year-on-year growth [10, 12].

- Bangladesh: Earns 2 billion USD from shrimp exports, supporting 4 million livelihoods with salinity-tolerant strains helping farmers combat the impacts of climate change [18, 21].
- Vietnam: Generates 11.5 billion USD from pangasius fish and shrimp exports, creating 4 million jobs in the Mekong Delta and transforming the region from a traditional rice- producing area into a major aquaculture hub, properly shifting from rice bowl to fish bowl [5, 17].
- Indonesia: Milkfish and tilapia industries are profitable with deep-sea cages and Java ponds driving exports worth 3 to 4 billion USD [4, 18].
- Nigeria and Africa: Tilapia farming is emerging as a useful opportunity, with World Fish training 100,000 farmers and targeting a 1 billion USD potential [21].

6.1.6 Talking Sustainability and Challenges

- Wild Pressure: Over 50% of seafood is now farmed, relying on wild stocks, with 64% of it sustainable [4, 5].
- Climate Resilient: Mangrove farms and disease-resistant breeds such as SPF shrimp [1, 14].
- Challenges: Disease, including WSSV in shrimps and pollution are being addressed through the implementation of biosecurity measure and probiotics, which have reduced losses by 50% [8, 21].

6.2 Export Market Access and Assortment

- Developing countries can access major international markets such as the United States, the European Union, China, and Japan by meeting export quality standards and obtaining relevant certifications which is utilized in world export market [5, 16].
- Focusing on high-value products such as shrimp, salmon, and ready to cook fillets, while diversifying export destinations, can generate stable foreign exchange earnings, strengthen supply chains, and support rural economic development which is supportive for the fisherman and their livelihoods [12, 20].

6.2.1 Transporting to High-Value Species

- Commodity Premium Shift: Pelagics fishes are priced at 1 to 2 dollar per Kg but Shrimp and Tilapia valued at 5 to 12 dollar per kg is driving development, represented by India's Vannamei Shrimp exports, which account for 65% of its 4 billion dollar seafood exports [5, 12].

- Aquaculture Advantage: Farmed species constant quality and size, making them excellent for export, as evidenced in Vietnam’s Pangasius fillets, which contribute 70% of country’s export value [5, 12].
- Organic and Sustainable Labels: ASC and MSC certification adds 20 to 30% price premium, appealing to eco-conscious buyers in EU and supporting the regions green deal initiatives [2, 16].

6.2.2 Capturing new markets and Demand

- Demand for shrimp and tuna drives the US market, with Vietnam getting a 25% of the market 2.86 billion dollar and India sending 40% of its exports to the US [12, 17].
- The Europe market, including post-Brexit United Kingdom, demands traceability, with Ecuador exporting 1.5 billion USD worth of shrimp to Spain and France [5, 16].
- China and Asia are driven by a rising middle class: India’s pangasius fish exports are up to 50% and Japan seeks premium tuna and shrimp [5, 16].
- The Middle East and Africa are growing markets for halal-certified products, such as Egypt’s tilapia exports to Gulf [16, 20].
- E-commerce platforms like Alibaba and Amazon enable direct to consumer sales, bypassing middlemen and adding 15% margins [16, 18].

6.2.3 Leveraging Trade Deals and Tariff Cuts

S. No	References	Benefiting Countries	Agreement	Description	Impact
1.	(ASEAN Secretariat, 2020; FAO, 2022; UNCTAD, 2023)	Vietnam, Indonesia	Regional Comprehensive Economic Partnership (RCEP)	A multilateral trade agreement aimed at reducing tariffs and improving market access among Asia-Pacific economies.	Zero tariffs on nearly 90% of seafood products, resulting in more than a 15% increase in exports.
2.	(European Commission, 2021; OECD, 2022)	India, Ecuador	European Union Free Trade Agreements (EU FTAs)	Bilateral trade agreements facilitating reduced customs duties and preferential access to EU seafood markets.	Reduction in duties from 5% to 12%, generating export gains exceeding USD 1 billion.
3.	(CPTPP Commission, 2019; FAO, 2021)	Vietnam	Comprehensive and Progressive Agreement for Trans-Pacific	A high-standard regional trade agreement enabling tariff-free access to	Expanded access to Canada and Australia, leading to a significant

			Partnership (CPTPP)	advanced economies.	pangasius export boom.
4.	(African Union, 2020; World Bank, 2022)	African nations (Nigeria, Kenya)	African Continental Free Trade Area (AfCFTA)	A continent-wide trade framework designed to boost intra-African trade and economic integration.	Intra-African seafood trade increased by over 25%, with an estimated USD 5 billion trade potential.
5	(USTR, 2023; Ministry of Commerce, India, 2023)	India	US–India Trade Talks	Ongoing bilateral negotiations focused on reducing trade barriers in agricultural and seafood exports	Shrimp export quotas lifted, with projected export gains of approximately USD 1 billion.

6.2.4 Certification and Compliance Systems

Food safety certifications like HACCP (Hazard Analysis and Critical Control Points) and BRC (Bank Realisation Certificate) Global standard are mandatory for exporting to the United States and Europe, with India’s 300 plants already Europe-approved [5, 13].

Sustainability certifications, such as ASC (Aquaculture Stewardship Council) for aquaculture and MSC (Mediterranean Shipping Company) for wild-caught fish, can increase prices by 20%, with Vietnam achieving ASC certification for 50% of its pangasius production [2, 5].

Block-chain is like a secure digital ledger that records every step of fish farming and processing, so no one can fake the data and The Internet of Things (IoT) technologies uses to monitor conditions in real- time. Together, they prove seafood is sustainable,helping exporters comply with the EU’s import rules [5, 16]. Anti-Dumping Measures, governed by WTO fixed Ecuador’s case, removing extra taxes and boosting their shrimp trade [16].

6.2.5 Value-Added Product Diversification

- Transformation of raw seafood into value-added products like IQF fillets and breaded shrimp boosts value by 30-50%. This fixes market problems, build stronger supply chains, and uses premium prices to avoid overfishing [4, 5].
- Frozen exports like smoked salmon, sushi packs, and Thailand's canned tuna, worth approximately USD 2 billion increase trade income. They bypass market issues and keep fish catches below safe limits (MSY) [16, 17].
- Fish skin collagen-derived by products, like oil capsules, add 10-15% to revenue. Omega-3-enriched foods grow 12% yearly due to health trends and fix resource market gaps [6, 7].

6.3 Value-Added Processing and Industrialization

By turning whole fish into fillets, IQF products, smoked and canned fish, convenience foods, and products from by-products they can earn much more per kilogram and reach higher-value markets. Processing plants and related services like packaging, cold-chain, quality control, and marketing create many jobs for coastal communities, often employing large numbers of women and youth and building skills in food technology and certification. For developing countries, investing in value-added seafood help them move up global value chains, keep a bigger share of final consumer value, and strengthen export earnings. At the same time, using trimmings, skins, bones, and low-value species for fish meal, oil, collagen and new products reduces waste and post-harvest losses. Over all, value-added processing and industrialization support higher incomes, more jobs, better resource use, and a more sustainable blue economy [4, 5, 18].

6.3.3 Processing Techniques and Product Types

- Primary Processing: Gutting, filleting, skinning; reduces weight loss 20-30%; IQF (Individual Quick Freezing) preserves quality.
- Secondary Processing: Smoking, curing, breading, e.g., fish fingers, shrimp tempura add 50% value.
- Tertiary and Ready-to-Eat: Sauces, burgers, soups; shelf-stable for retail and supermarkets [4, 5].
- Innovative Products: Fish sausages, powders, fortified feeds; Kenya samosas and balls extend market reach [6, 7].
-

6.3.4 Infrastructure and Cluster Development

- India’s seafood processing handles 1.2 million tons yearly at just 50% capacity [12, 18]. Over 300 plants thrive in spots like Kochi and Veraval [12,18].
- Cold chains (blast freezers, reefer trucks, special ports) slashed post-harvest losses from 25% to 5 to 10% a real fresh fish win [4, 18].
- EPZs offer duty-free boosts for exports. India and Kenya employ more than 100,000 in the sector.
- Clustering shares utilities, cutting costs 15-20%. Veraval processes 40% of India’s shrimp, proving teamwork works [12, 18, 20]

6.3.5 Economic and Employment Multipliers

Value-added processing can significantly increase the profitability of shrimp and other seafood products, as peeled and further processed items often sell for several times the price of whole, unprocessed raw material. Processing activities and associated services like cold-chain logistics, packaging, and distribution, generate multiple additional jobs for each fishing job, with women frequently forming the majority of the processing workforce, which strengthens household incomes and community welfare. In many developing countries, processed and value-added seafood products contribute a larger share of export earnings than unprocessed fish, and countries such as Kenya are actively promoting value addition to raise the economic contribution of their fisheries sector and support national growth [5, 18, 21].

6.4 Blue Economy Integration and Policy Support

“The blue economy links fisheries and aquaculture with tourism, shipping, renewable energy, and marine biotechnology as part of a single development vision” [2, 15, 18, 20]. It aims to promote sustainable economic growth while protecting ocean ecosystems rather than degrading them [1, 8, 15, 18]. In many development countries governments support this approach by offering incentives and investing in coastal and maritime infrastructure, and improving coordination among different ocean based sectors [10, 11, 18, 19, 20]. Zanzibar’s eco-lodges mix tourism and fisheries, boost earnings 2-3 times [15, 18]. Fish waste becomes pharma, cosmetics, and omega-3 [4, 5, 7]. This adds 10-15% profits. Wind farms act as fish reefs. India’s sagarmala ports add \$100 Billion to blue GDP. IoT and AI connect small fishers to e-commerce. AfCFTA increases African trade 25%. IORA, Australia, and PSIDA make

ocean plans. WTO and UNCTAD attract \$500 billion private funds [11,15, 18, 19, 20].

6.5 Social Inclusion and Building Strength

- Fair jobs and voice for women, youth, indigenous, small fishers. Toughens communities against shocks via extra incomes, safety nets, team work [2, 9, 21]
- Women has over 50% workforce, low pay. Training plus equal pay and rights increase family income 20-30 percent [9, 15, 21]
- Youth innovate tech and stay home; indigenous lead management. Goals: 2 million markets, 1 million people out of poverty [14, 18, 21].
- Co-management allows fishers join advisory groups and determine quotas, prompting increased compliance and lower unlawful fishing by 30%.
- Digital solutions provide communities with rapid access to markets and timely weather related information, while supporting community-based protocols. [3, 8, 19].

7 Conclusion

Fisheries and aquaculture are essential to global food systems, and drive economic progress. They also play a role in preserving ecological equilibrium. These sectors offer nutritious food, and create jobs. They support the social and cultural lives of millions, especially true for coastal and island communities. Beyond food, fishing activities generate trade revenue. The process encompasses capture, processing, distribution, and marketing. The global seafood sector is changing now major focuses are the sustainable aquaculture practices. Consequently, production levels have risen and boosted rural businesses as well as decreasing reliance on overexploited wild fish resources. The new technological innovations, eco-friendly farming practices.

Furthermore, the development of value added manufacturing and diversification in exporting routes has contributed to enhancing international competitiveness by moving toward value added products that are processed and certified with a higher level of quality, safety and sustainability recognized in word market. The blue economy also enhance their contribution by establishing links to other sectors such as tourism, renewable energy, marine biotechnology and coastal development. This inner sector collaboration forges economic diversification, climate adaptation capacity, and marine conservation efforts. Efforts should also be made to further invest, develop coherent policy architectures and enhance international cooperation

to improve governance mechanisms and create space for inclusiveness in all fish value chains. Fisheries and aquaculture when responsibly managed to support livelihoods, promote inclusive development, enhance food security, and protect marine ecosystems.

References

- [1] The Nature Conservancy. A healthy ocean depends on sustainably managed fisheries. Arlington (VA): The Nature Conservancy; 2021.
- [2] Crona BI, Wassénius E, Jonell M, Koehn JZ, Short R, Tigchelaar M, et al. Four ways blue foods can help achieve food system ambitions across nations. *Nature*. 2023;616: 104–112.
- [3] Cochrane KL. Chapter 1: Fisheries management. Rome: Food and Agriculture Organization of the United Nations (FAO); 2001.
- [4] Food and Agriculture Organization of the United Nations. The state of world fisheries and aquaculture 2022: Towards blue transformation. Rome: FAO; 2022.
- [5] Food and Agriculture Organization of the United Nations. The state of world fisheries and aquaculture 2024: Blue transformation in action. Rome: FAO; 2024.
- [6] Farmery AK, et al. Assessing seafood nutritional diversity together with climate impacts. *Commun Earth Environ*. 2022.
- [7] Froehlich HE, et al. The vital roles of blue foods in the global food system. *Rev Aquac*. 2022.
- [8] Garcia SM, Cochrane KL. Ecosystem approach to fisheries: A review of implementation issues. *ICES J Mar Sci*. 2005;62(3):311–318.
- [9] Golden CD, Koehn JZ, Shepon A, Passarelli S, Free CM, Viana DF, et al. Aquatic foods to nourish nations. *Nature*. 2021;598:315–320.
- [10] Government of India. Pradhan Mantri Matsya Sampada Yojana (PMMSY): Guidelines and implementation framework. New Delhi: Ministry of Fisheries, Animal Husbandry & Dairying; 2020.
- [11] Ministry of Ports, Shipping and Waterways. Sagarmala programme: Impact on blue economy and fisheries infrastructure. New Delhi: Press Information Bureau, Government of India; 2025.
- [12] Marine Products Export Development Authority. India's seafood exports touch all-time high by volume: Export performance 2023–24. Kochi: MPEDA; 2024.
- [13] Marine Products Export Development Authority. EU approves 102 new Indian fishery establishments: Boost for seafood exports. New Delhi: New Indian Express; 2025.
- [14] Naylor RL, et al. Aquaculture for food and nutrition security. *Anim Front*. 2021.
- [15] United Nations. Blue economy: Opportunities and challenges of sustainable development of SIDS. New York: United Nations; 2014.
- [16] United Nations Conference on Trade and Development. South–South trade in the marine fisheries and aquaculture sectors: Opportunities for sustainable development. Geneva: UNCTAD; 2024.
- [17] Vietnam Association of Seafood Exporters and Producers. Vietnam seafood exports report 2024: Trends and forecasts for 2025. Vietnam: VASEP; 2024.

- [18] World Bank. The potential of the blue economy: Increasing long-term benefits of the sustainable use of marine resources for small island developing states and coastal least developed countries. Washington (DC): World Bank; 2017.
- [19] World Bank. PROBLUE: Annual report on blue economy program – fisheries, aquaculture and ocean investments. Washington (DC): World Bank; 2024.
- [20] World Bank. Oceans, fisheries and coastal economies. Washington (DC): World Bank; 2025.
- [21] WorldFish. Aquaculture, fisheries, poverty and food security. WorldFish Centre Working Paper 2011-65. Penang (Malaysia): WorldFish; 2011.
- [22] Salisu, Monsuru and Raimi, Lukman and Bamiro, Nurudeen and Elegbede, Isa. Green and Blue Economy Frameworks for Halal Industry Sustainability, Springer Nature, 2025.

Chapter 4: Economic Importance and Trade Potential of Tuna in India and Global Marine Fisheries

1. Introduction

“Tuna fisheries are very valuable economically, found all over the world, and play a big part in international trade, they are the most important marine catch fisheries in the world” [4, 19, 24]. “Tuna species are highly migratory pelagic fishes that support the livelihoods of millions of people worldwide, particularly in coastal and island nations” [4, 6, 24]. Over the decades, technological advancements in fishing, processing, and trade have transformed tuna fisheries into highly globalized industry [19, 22]. However, increasing fishing pressure, environmental changes, and governance challenges have raised serious concerns about the long term sustainability of tuna resources [1, 16, 21, 24]. “This study provides a comprehensive overview of the biology, fisheries, economics, trade, governance, sustainability issues, and future prospects of tuna fisheries, with special emphasis on global trends, India’s tuna resources and export potential and the significance of India’s first tuna fishing harbor in Tamil Nadu”[4, 11, 12, 18,19, 20,21,24].

2. Biology and Commercial Characteristics of Tuna

2.1 Taxonomic Classification of Tuna Species

“Tunas are marine pelagic fishes belonging to the family Scombridae, which also includes mackerels and bonitos”. “True tunas belong to the tribe Thunnini under the subfamily Scombrinae”. Their taxonomic classification is as follows: Kingdom Animalia, Phylum Chordata, Class Actinopterygii, Order Perciformes, Family Scombridae, Subfamily Scombrinae and Tribe Thunnini. Important genera include *Thunnus* (yellowfin, bigeye, albacore, blue fin), *Katsuwonus* (skipjack), *Euthynnus* (little tuna), and *Auxis* (frigate and bullet tuna), among which *Thunnus* and *Katsuwonus* species form the backbone of global commercial tuna fisheries [6, 19].

2.2 Geographic Distribution and Migratory Behaviour

Tunas are distributed widely across tropical, subtropical, and temperate oceans, with major fishing grounds in the Pacific, Indian, and Atlantic Oceans [4, 9, 10, 14, 23]. They do not occur in polar waters due to low temperatures [19]. These fishes are highly migratory, moving both horizontally across ocean basins and vertically between surface and deep waters [15]. Their migrations are mainly for spawning, feeding, and to follow favourable temperatures, currents, and prey [9, 14]. Physiological adaptations such as a streamlined body, strong red muscles, and a head-retaining circulatory system support their long-distance movements [19].

2.3 Life History Traits Influencing Fishery Economics

Tuna life history traits strongly influence their economic importance [16,19]. They exhibit rapid growth, high fecundity, and in some species like skipjack, early sexual maturity, which enhances productivity [9, 14]. However, species like blue fin tuna that mature late and live long are more prone to overfishing [13, 15]. Their schooling behaviour makes them easy to catch but also increases vulnerability, making sustainable management essential [1, 16].

2.4 Major Commercial Tuna Species of the World

Major commercial species include skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), bigeye (*Thunnus obesus*), albacore (*Thunnus alalunga*), and Bluefin (*T. thynnus*, *T. orientalis*, *T. maccoyii*) [4, 19]. Skipjack dominates global catches, mainly for canning [4, 23]; yellowfin and bigeye are valued in fresh and sashimi markets [10,14]; albacore is known as “white meat tuna” used in canning [19]; and blue fin is the most valuable but overexploited species[13,15].

2.5 Nutritional and Market Attributes of Tuna

Nutritionally, tuna is rich in high-quality protein (20-25%), Omega-3 fatty acids (EPA and DHA), vitamins A, D, and B-complex, and essential minerals like selenium, iodine and iron [11, 19]. In the market, tuna is sold fresh, frozen, canned, smoked and as sashimi-grade fish, with high demand in Japan, the USA, and the European Union [22, 25].

3. Global Tuna Fisheries: Production and status

3.1 Current Global Production Levels

“Global tuna production exceeds 7 to 8 million tons annually”, with skipjack, yellow fin, big eye, and albacore tuna being the major contributors [4, 5]. The Pacific Ocean accounts for the largest share of tuna production, followed by the Indian and Atlantic Oceans which also contribute significantly [4, 14, 23].

Despite high level of production, many tuna stocks face risks of overexploitation particularly in key regions [10, 13,14]. Regionally, the Pacific Ocean remains the most productive area especially in the Western and Central Pacific zones [9, 23], while the Indian Ocean led by countries such as India, Sri Lanka, Indonesia, and the Maldives ranks second in output [4, 14]. The Atlantic Ocean, though smaller in overall production, supports valuable fisheries for Bluefin, Yellowfin, and Bigeye species [10,13], whereas the Mediterranean Sea focuses mainly on Bluefin tuna of high economic value but with severe conservation concern due to overfishing pressures[13,15].

3.2 Regional Distribution of Tuna Fisheries

Tuna are caught by both industrial distant-water fleets and artisanal coastal fishers providing livelihoods to thousands of coastal communities which is currently at great risk of being lost unpaid to irresponsible fishing activities [6, 21]. Major fishing nations include Japan, China, Spain, Taiwan, Indonesia, and the Philippines contributing significantly to food security, employment generation and international trade [4, 23]. The main fishing gears used are purse seines, longlines, pole and line, gillnets, and hand lines mainly within coastal water and deeper areas indicating a huge quantity of life that the fishing industry taps into [19, 23].

Purse seines are the most common and efficient method, targeting schooling species like skipjack and yellowfin but often causing bycatch [2, 16]. Longlines target bigeye and blue fin tuna for the sashimi market, offering high value despite lower volumes [10, 13]. Pole and line fishing, practiced in the Maldives and Indonesia, is environmentally friendly with minimal bycatch [6, 17]. Technological advancements have improved efficiency but also intensified stock pressure [1, 16].

3.3 Fishing Fleets and Gear Technologies

Tuna stock assessments are conducted by Regional Fisheries Management Organisations (RFMOs) such as ICCAT in the Atlantic, IOTC in the Indian Ocean, WCPFC in the Pacific, and IATTC in the Eastern Pacific [10, 13, 14, 23].

3.5 Stock Assessment and Exploitation Status

“Current stock assessments indicate that skipjack tuna are generally sustainably fished” [14, 23], “yellowfin stocks are fully exploited with some overfishing, bigeye tuna are overfished in several regions and blue fin tuna, historically overexploited”, are showing signs of fleets [10,13,14,15], illegal and unregulated fishing, bycatch of non-sustainability of global tuna fisheries requires effective stock assessments, responsible fishing practices, and strong international cooperation [1, 2,4,10,13,14, 21,23, 24].

4. Tuna Resources and Fisheries in India

4.1 Tuna Resource Potential in Indian EEZ

“India’s Exclusive Economic Zone (EEZ), covering about 2.37 million km², provides considerable potential for tuna and other large pelagic fisheries” [7, 12]. However, the oceanic tuna resources in the Indian EEZ remain under-exploited due to the absence of a fully developed and specialised tuna fishing fleet [7, 12]. “The estimated potential yield of oceanic tunas is around 213,000 tonnes annually”, consisting mainly of yellow fin tuna (about 54%), skipjack tuna (around 40%), and big eye tuna (6%) [12]. When combined with coastal or neritic stocks, the total tuna potential is even greater, though much of it remains untapped due to limitations in gear and fishing effort concentrated in near-shore areas [7,12, 18].

4.2 Species Composition of Indian Tuna Landings

Indian tuna fisheries comprise both neritic and oceanic species, with common varieties including *Euthynnus affinis* (little tuna), *Auxis thazard* (frigate tuna), *Auxis rochei* (bullet tuna), *Thunnus tonggol* (long tail tuna), *Katsuwonus pelamis* (skipjack), *Thunnus albacares* (yellowfin), and *Thunnus obesus* (bigeye tuna) [12, 18]. Coastal tunas, particularly the neritic forms, dominate present landings, while organized oceanic fishing remains limited [12].

4.3 Fishing Methods and Craft-Gear Combinations

Tuna fishing in India involves diverse craft–gear combinations ranging from artisanal to mechanized operations [12, 18]. Drift gillnets are the most widely used gear targeting coastal tunas, whereas pole-and-line fishing, practiced mainly in the Lakshadweep Islands with live bait, targets skipjack tuna [6, 12]. Hook-and-line and hand line methods are popular among small-scale fishers [12], while longlines are increasingly employed on mechanized vessels to harvest deep-water oceanic tunas [7, 12]. Troll lines, purse seines, and ring seines are used seasonally or regionally where tuna schools aggregate

[12, 18]. Artisanal and non-motorized boats primarily use gillnets, hand lines, and pole-and-line methods in coastal waters, while small motorized boats operate medium-mesh gillnets. Larger mechanized vessels, equipped with inboard engines, employ gillnets and longlines, enabling multi-day offshore trips [12].

4.4 Regional Tuna Fisheries (West Coast, East Coast, Islands)

Regionally, the west coast of India covering Gujarat, Maharashtra, Karnataka, and Kerala accounts for the bulk of tuna landings, mainly of coastal and neritic species, supported by extensive use of gillnets and small gears [12, 18]. On the east coast, covering Tamil Nadu, Andhra Pradesh, and Odisha, tuna catches are relatively low, with operations involving gillnets, hooks, and small mechanized units [12].

In the Lakshadweep Islands, a well-established pole-and-line fishery targets skipjack tuna using live bait [6, 12], whereas the Andaman and Nicobar Islands are recognized for significant tuna potential and have been included in government-supported tuna development clusters [7, 8].

4.5 Role of Artisanal and Mechanized Sectors

The ecological and environmental significance of tuna fisheries in India is in nature mainly related to the states position as biodiversity access point like Kerala, Tamil Nadu, and Gujarat and essential ecosystem service, The coastal region of the country specifically supports important marine habitats that are completely essential for regional and global tuna life, for example thousands of coastal fishers utilizing traditional gear such as gillnets and hand lines mainly within coastal waters it indicates a quality of the life to fishing industry [12, 18]. The mechanized sector complements artisanal operations by extending the fishing range into deeper waters using longlines and advanced vessels [7, 12]. Supported by government initiatives through organizations like the Marine Products Export Development Authority (MPEDA) and INCOIS, these mechanized fleets are gradually entering the oceanic tuna sector with live monitoring for environment health [8, 20]. Despite this progress, India's tuna resources remain underutilized, indicating a strong potential for sustainable expansion through fleet modernization, infrastructure development, and improved resource management [7, 12].

5. Economic Significance of Tuna Fisheries

- Tuna fisheries are a part of marine fisheries sector since they help the economic growth, provide employment, export earnings, and keep people in coastal and island areas safe [4, 12, 18, 20, 24].

- They promote food security, rural incomes, and linked businesses such as processing, transport, and marketing [11, 18, 19, 22].
- The fisheries sector provides roughly 1.24% to India's GVA, demonstrating its economic importance [18].
- Underexploited tuna resources in the Andaman and Nicobar Islands and Lakshadweep have considerable potential for sustainable regional development [7, 8, 12].

6. Tuna Value Chain: Harvesting to Quality Management

- The tuna value chain covers harvesting, on-board handling, processing, value addition, cold chain management, and quality control [11, 19, 25].
- After capture tuna fish, it needs to be immediately frozen, and the bleeding and gutting must be done to control bacterial and enzymatic spoilage [11, 19].
- For high value fresh tuna should kept in the freezer around -60°C is helps to preserve colour and texture [11, 20, 25].
- Raw tuna processing turns into frozen loins, steaks, canned tuna, and methods like freezing, canning, smoking, drying, and IQF [11, 19, 25].
- Export units like HACCP and ISO, while better packaging, longer shelf life, and by product use add value and support ocean economy [4, 11, 21, 25].

7. Global Tuna Trade Dynamics

- The global tuna trade links fishing nations, processors, corporations and consumers worldwide contributing significantly to food security, employment generation and international trade activities which is currently at great risk of being lost unpaid to irresponsible fishing activities [4, 19, 22].
- Processed and canned tuna dominates making up about 43% of traded volume indicating a huge quantity of life that the fishing industry taps into [5, 19].
- The supply chain from catch to shelf relies on refrigerated transport, international trade deals, and regional agreements which supports important marine habitats that are completely essential for regional and global marine life [3, 11, 25].
- "In the year 2023, the countries that export the tuna are Thailand, Ecuador, China, Spain, Indonesia and the Philippines." [5, 19].
- Major importers were the US, they driven by consumer demand, "Japan also imports a lot of tuna especially bluefin tuna" [13, 15, 19, 22].

8. India's Tuna Export Performance and Trade Potential

- In 2023-24, India exported 51,626 tons of tuna valued at \$88 million, reflecting a 32% increase, yet comprising merely 0.6% of global tuna trade [5, 18, 20].
- In Indian Ocean accounts for about 21% of global tuna production, offering scope for premium exports with better infrastructure and certification [5, 14, 19].
- Key challenges include limited deep-sea fishing vessels, poor cold storage, post-harvest losses, and histamine contamination, affecting quality and buyer confidence [11, 12, 25].
- Strengthening cold-chain infrastructure, processing facilities, deep sea fleets, quality control, training, certification, and eco-labelling, along with market diversification and PMMSY support, can significantly improve export earnings and livelihoods [3, 7, 8, 11, 17, 18, 20, 25].

9. Governance, Regulations, and Certification in Tuna Fisheries

- Strong governance is essential for sustainable tuna fisheries because tuna are highly migratory, valuable, and fished across national and international waters [9, 14, 15, 16, 21].
- At the global level, tuna fisheries are managed by Regional Fisheries Management Organizations (RFMOs) such as IOTC, WCPFC, IATTC, and ICCAT [10, 13, 14, 15, 23].
- RFMOs are responsible for stock assessment, catch limits, fishing effort control, and compliance enforcement [14, 15]
- India is an active member of the Indian Ocean Tuna Commission (IOTC) [3, 14, 21].
- In India, tuna fisheries are governed jointly by central and state governments under laws such as the Indian Fisheries Act, 1897, Maritime Zones of India Act, 1976, and CRZ Notification [7, 18].
- Sustainable offshore fishing is promoted through the Deep Sea Fishing Policy, 2017, and fisheries development and exports are supported by PMMSY [7, 8]
- International tuna trade follows WTO SPS and TBT regulation, including EU Catch Certification and US FDA standards (HACCP, histamine control, traceability) [3, 11, 25].
- In India, MPEDA regulates seafood exports, and non-compliance can lead to trade restrictions [11, 20, 25].
- Eco-labelling and sustainability certification promote responsible fishing and help access premium markets in the EU, USA, and Japan [16, 17, 19, 22].

- Monitoring Control and Surveillance tools such as VMS, catch documentation, and Post State Measures are essential to control IUU fishing, with India implementing the FAO PSMA [3, 14, 15, 21].

10. Opportunities and Future Prospects

Although tuna fisheries face several challenges, they present considerable growth prospects, especially for developing coastal nations like India [4, 21]. Opportunities exist for the sustainable exploitation of underutilized oceanic tuna stocks, along with the expansion of pole-and-line and hand line fishing techniques [12, 16], and the introduction of fuel-efficient, environmentally sustainable fishing vessels [6, 24]. In terms of trade and value addition, the rising global demand for ready-to-eat tuna products as well as premium sushi and sashimi-grade tuna opens avenues for establishing processing plants and cold-chain infrastructure [19, 22], while also enabling higher profits from eco-certified and labeled tuna products [17, 19].

Advancements in technology and institutional frameworks including the implementation of digital traceability and monitoring systems, enhanced data collection and scientific evaluations, and reinforced regional collaboration through Regional Fisheries Management Organizations (RFMOs) foster sustainable development and strengthen the competitiveness of the tuna fisheries sector [3, 14, 21].

11. India's First Dedicated Tuna Fishing Harbor in Tamil Nadu

Tamil Nadu is home to India's first exclusive tuna fishing harbor located at Tiruvottiyur near Chennai in Thiruvallur District. The facility was officially inaugurated in May 2025 by Chief Minister M.K. Stalin contributing significantly to food security, employment generation and international trade activities. To address these limitations, dedicated infrastructure projects have been initiated. Constructed at an estimated cost of ₹272.70 crore, the harbor has been developed specially to strengthen deep-sea tuna fishing activities in the region indicating a huge quality of the life that the fishing industry and supports the most biologically diverse ecosystems [26].

12. Conclusion

The economic analysis of tuna fisheries reveals sector characterized by high economical potential for global food security, employment generation, jobs, and

economic growth, especially in coastal communities depending on the sea for their livelihoods, a traditional resource productivity problem caused greater by biological fast growth, high reproduction, vast migrations, vulnerable challenges the sectors long term viability to overfishing. Tuna fisheries are a powerhouse worldwide with cutting-edge fishing tech and skyrocketing demand are piling pressure on stocks.

India's EEZs, offer a wealth of opportunities for the fishing industry. To utilize this opportunity, the number of fishing vessels must be increased and after catching the fish it need to be modernized and transformed into a high value product, a specialized integrated process of freezing and transportation facilities, through global partnerships, vigilant monitoring, sustainability certifications, inclusive policies all require significant public investment to conquer environment, trade and social challenges.

This will improve the tuna exports duration of storage, minimize losses after harvest, and promote value added products throughout this process it will increase the financial benefit for every participant those involved in this sector including fishers, our economy and the world seafood market. The best way to protect coastal communities incomes and sustainably manage Tamil Nadu's valuable tuna resources is a balanced approach with modern facilities and eco-friendly practices Tamil Nadu shines as India's tuna leader and must back coastal peoples.

Dedicated tuna fishing harbours along our coast would offshore catches, smooth post-harvest, processing as the marketplace as the effects. Backed by sustainable practices, this infrastructure safeguards livelihoods and tuna stocks for generations which is currently at great risk of being lost unpaid to irresponsible fishing activities and climatic change. The only way to protect coastal communities sources of income and sustainably manage one of the state's most valuable natural resources is to implement a balanced approach.

References:

- [1] Bailey M, Sumaila UR, Lindroos M. Application of game theory to fisheries overexploitation: The case of global tuna fisheries. *Fish Fish.* 2010;11(3):225–239.
- [2] Dagorn L, Holland KN, Restrepo V, Moreno G. Is it good or bad to fish with FADs? What are the real impacts of the use of drifting FADs on pelagic marine ecosystems? *Fish Fish.* 2013;14(3):391–415.

- [3] Food and Agriculture Organization of the United Nations. Voluntary guidelines for catch documentation schemes. FAO Fisheries and Aquaculture Technical Guidelines No. 14. Rome: FAO; 2016.
- [4] Food and Agriculture Organization of the United Nations. The state of world fisheries and aquaculture 2022: Towards blue transformation. Rome: FAO; 2022.
- [5] Food and Agriculture Organization of the United Nations. Fishery and aquaculture statistics: Global tuna production and trade. Rome: FAO; 2024.
- [6] Gillett R. Tuna fisheries in the Pacific Islands: Regional and national issues. FAO Fisheries and Aquaculture Technical Paper No. 519. Rome: FAO; 2016.
- [7] Government of India. Deep sea fishing policy. New Delhi: Ministry of Fisheries, Animal Husbandry and Dairying; 2017.
- [8] Government of India. Pradhan Mantri Matsya Sampada Yojana (PMMSY): Operational guidelines. New Delhi: Ministry of Fisheries, Animal Husbandry and Dairying; 2020.
- [9] Hampton J, Williams P, Nicol S. The western and central Pacific tuna fishery: 2017 overview and status of stocks. *Mar Policy*. 2017;81:1–8.
- [10] Inter-American Tropical Tuna Commission. Status of tuna stocks in the Eastern Pacific Ocean. La Jolla (CA): IATTC; 2023.
- [11] ICAR–Central Institute of Fisheries Technology. Post-harvest handling, value addition and quality management of tuna. Kochi: ICAR–CIFT; 2022.
- [12] ICAR–Central Marine Fisheries Research Institute. Marine fisheries census and tuna resource potential of India. Kochi: ICAR–CMFRI; 2021.
- [13] International Commission for the Conservation of Atlantic Tunas. Report of the Standing Committee on Research and Statistics (SCRS). Madrid: ICCAT; 2023.
- [14] Indian Ocean Tuna Commission. Status of the Indian Ocean tuna stocks and fisheries. Seychelles: IOTC Secretariat; 2023.
- [15] Joseph J. Managing tuna fisheries in the eastern Pacific Ocean. *Mar Policy*. 2003;27(2):111–118.
- [16] Lecomte F, Rochet MJ, Cornu JF. Tuna fisheries sustainability: Trade-offs between economic efficiency and ecological impacts. *Mar Policy*. 2017;84:148–156.
- [17] Marine Stewardship Council. Tuna fisheries certification and sustainability standards. London: MSC; 2023.
- [18] Ministry of Fisheries, Animal Husbandry and Dairying. Handbook on fisheries statistics. New Delhi: Government of India; 2023.

- [19] Miyake MP, Guillotreau P, Sun CH, Ishimura G. Recent developments in the tuna industry. FAO Fisheries and Aquaculture Technical Paper No. 543. Rome: FAO; 2010.
- [20] Marine Products Export Development Authority. Marine products export statistics of India. Kochi: MPEDA; 2024.
- [21] Organisation for Economic Co-operation and Development. Rebuilding fisheries: The way forward. Paris: OECD; 2022.
- [22] OECD–FAO. Agricultural outlook 2023–2032: Fisheries and aquaculture. Paris: OECD Publishing; 2023.
- [23] Western and Central Pacific Fisheries Commission. Annual report on tuna fisheries in the Western and Central Pacific Ocean. Pohnpei: WCPFC; 2023.
- [24] World Bank. The sunken billions revisited: Progress and challenges in global marine fisheries. Washington (DC): World Bank; 2017.
- [25] World Trade Organization. Sanitary and phytosanitary measures and technical barriers to trade in fisheries. Geneva: WTO Secretariat; 2022.
- [26] Government of Tamil Nadu, Department of Fisheries (project details), News reports: Projects Today (2025), New Indian Express (2025), Under Current News; 2025.

Chapter 5: Emerging Trends in Fish Processing Technology

1. Introduction

The global economy is crucially impacted by the seafood market. It creates jobs, sustains millions of people and brings in a substantial amount of money. The industry employs over 56 million people and brings in over \$200 billion annually. This constitutes a significant financial contribution. Still the industry faces a number of difficulties. Food safety is one of the industry's most processing issues. Almost 50 % of seafood imports have high levels of bacterial or proved drug contamination, according to the FDA. This brings up serious issues-public wellbeing hangs in the balance, just as much as how consumers see the business itself. For countless individuals around the globe, fish stands tall as a main source of nutrients. The seafood market pays a major role in the global economy. It creates jobs, supports millions of peoples and brings in a significant amount of money. The industry provides jobs for over 56 million people and generates more than \$200 billion each year, this reflects a major financial impact. This sector faces several challenges, one major issue is food safety. The FDA data that nearly 50% of seafood imports have maximum levels of bacterial contamination or unsafe drug residues. This increase serious public health concerns and affects the way of consumers view the industry and for the many people around the world, fish is an essential source of nutrition. From the moment fish are caught until they reach consumers every step including catching, careful handling, processing and delivery, many job opportunities and significantly add to national revenue. The way of food processing affects, hoe the people get benefit from nature and changes basic products into something more valuable. This leads to an increase in profits. Although there are more challenges like the industry faces environmental issues like overfishing, habitat destruction and pollution these problems not only harm the environment but also affects the fishing industry's sustainability.

Fish processing includes all the steps from when fish are caught until they reach the consumer. While fish processing refers specially to handling fish, it also covers all the marine species that is commercially harvested whether natural or farmed. Processing techniques have advanced significantly. While traditional methods like drying, Salting and smoking are still used there are now advanced options like freezing, canning, vacuum packing and even High-pressure processing. By controlling things like moisture, microbes and oxygen, processors can keep fish fresher for longer and offer more choice to buyers. The aim of all these techniques is to protect fish, increase their shelf life and produce varieties of added value products.

Most of these products go to grocery stores or to distributors. But here's the thing: fish go bad fast. That's why the main goal in fish processing is and always will be to keep fish from spoiling, no matter what else is going on in the production line.

2. Traditional methods

- Drying
- Fermenting
- Salting
- Smoking

2.1 Drying Methods

Fish may still be preserved using traditional method today. Maintaining quality is the true challenge, preventing recourse to outdated methods. Bad fish can be produced as easily in a modern cannery or freezing plant as in any old-fashioned curing shed. The problem is that we frequently ignore traditional methods when talking about developing fisheries. We concentrate on high -tech packing lines, large freezing units and costly technologies. Yes, those are essential number of people in Asia. They just need a lot of hands-on work and not much money. The issue is that we have nearly forgotten how to do it correctly and we have only lately started to focus on making high-quality, reasonably priced cured fish once more.

2.2 Control of Fish Quality

If we want to upgrade these traditional products, we have to start at the beginning with how we handle the fish. If the fish isn't good when it comes in, no fancy process can fix it. There are three main things to watch before processing even starts follow up the best Handling method, proper cleaning, speed up to selling.

2.3 Better Curing and Drying

In remote villages, people mostly dry fish in the sun. But laying fish on the ground, exposed to dirt, flies, or sudden rain, leads to many problems. Solar fish dryers can

tackle many of these issues, they dry fish faster and more effectively while keeping out insect's dirt and also it's surprising that didn't start earlier and this method is inexpensive and its benefits are clear.

A solar fish dryer is simple, it mainly has a frame made of bamboo or wood, covers with glass or plastic. The best designs use dark plastics or black channelled iron underneath to improve heat retention. It is also critical to include some ventilation to decrease moisture expansion inside. The hotness usually keeps flies always but if have fly screens been sure to use it. Each square meter can dehydrate about 5 kilograms of fish every day. By spoiling the spoilage of 1.2 kilograms daily the drier will pay for itself in about 20 days at a cost of \$10 per square meter. Individuals have suggested using solar ovens to get rid of any insects or larvae that might invade dried fish. While this method works the reality is that drying the fish from beginning and need extra steps.

3. Advantages

1. Quicker and more consistent drying comes from higher heat.
2. It keeps flies and beetles out, which stops maggot issues.
3. It also removes the need to hurry and shield fish from sudden rain, which is important in mountainous areas.

4. Fermenting

Fermenting food is not a new idea; it's one of the oldest ways that people have found to make food last longer and taste better. This has been going on for a long time. Fermenting food does a lot of things, which is what makes it interesting. It makes the food feel different in your mouth. Fermenting food also make it more nutritious. Some people learn how to make fermented foods from their families. Over the years, they teach their families what they have learned. For instance, people have been doing this for as long time, and fermented foods are a big part of their culture [1].

These days, fermentation is very popular. People don't just want food that tastes good; they also want food that makes them feel good. These foods are special because they are fermented. They want to know how these foods are made, how to tell if fermented foods are good for us, and what fermentation does to our health [2].

4.1 Fermented fish product

Shidal is a type of food that people make in North East India. They make Shidal with fish like *Puntius sophore* or *Setipinna Phasa*. People in this area refer to it Phasa Shidal or Puntis Shidal. Shidal is known for its strong smell and taste. In places like Tripura, Assam, Mizoram, Arunachal Pradesh and Nagaland People give Shidal names, such as

seedal, sepaa, verma or just Shidal. The main places where you can find it are Assam and Tripura. These places are great for it. You will locate it in both Assam and Tripura.

This thing has a really bad smell. The smell of this thing is because of what happens when fats and proteins in thing eliminate down. When fats and proteins in thing break down they make a lot of things, like peptides, amino acids and fatty acids and indole and skatole compounds. This thing breaking does make the smell of this thing even stronger. The way fats break down in this thing is what makes the smell of this thing so unique.

Shidal is a solid fish but it can look a little pastry and it is flat on both sides when you take a closer look, at the shidal. The shidal usually keeps its shape. Sometimes the shidal can break apart near the tail of the shidal or belly of the shidal. The best kind of shidal is the one starts out as white colour but if you leave the shidal out for a while the color of the shidal will change from a light brown to a dark brown [4].

Fish Shiokaras are made with fish and salt. They use salt to preserve the fish. The fish looks fresh for a while after they ferment it, whether they cut it up or leave it whole. This is the first step in making fish shiokaras, and it's the same for all kinds of fish shiokaras.

People usually have fish shiokara as a side fish. In Lower Myanmar and other places people really like fish shiokara. Consumers dry fish to make fish shiokara. Then they pound the fish or grate the fish into a paste. Thus it renders it easier to eat fish shiokara. Fish shiokara is like a sauce. You can use fish shiokara as a dip. You can dissolve fish shiokara in water to make a soup stock. Some people also add boiled rice to the fish shiokara mix.

These foods always have salt and other stuff in them that make them taste better. When food ferments, it alters in a way that helps it taste better. That's where the magic of eating happens. It's not easy to describe [3].

Fish sauce is made in a way that's really similar to making shiokara. When they make fish sauce in factories they leave out the part where they make shiokara and just go ahead and make the fish sauce. The thing is, they make fish sauce in locations. This is probably the reason why the recipes, for sauce are not all the same [3].

Narezushi is a little different. You addboiled rice to the fish and salt you use to make shiokarawhen you make Narezushi. This is what sets Narezushi apart from other foods. Narezushi is mostly found in Southeast Asia and Northeast Asia these days. I'm not sure if you can find Narezushi everywhere [3].

5. Salting

People were using salt to keep seafood fresh for a long time. This is because salt pulls water out of fish. Bacteria can't grow in fish that has water in it. Salt is great at taking moisture out of things like fish. This is why fishers always use salt [5].

Really it is not just about keeping the fish from going bad. The salt makes the taste of the fish stronger. It keeps the fish fresh by giving microbes less to work with. The salt even makes the proteins, in the fish stronger. You can hang the fish out to dry after you salt the fish and the fish will last longer [6].

6. Smoking

Cooking skills, tradition, and a little bit of food science are all used in fish smoking to make fresh fish taste good and last. People have been doing this for a long time, and not just because it makes food taste good. It is also safe.

This thing works in a lot of ways at once. The smoke helps to dry the wood. The wood has a lot of good things in it. The smoke and the wood do a lot of things for the fish. They keep the fish fresh they make the fish taste better. They even make the fish healthier. The wood and the some are really good, for the fish. When you want to smoke fish you have two options: hot smoking and cold smoking. Hot smoking and cold smoking are very different. They do things and the fish turns out different too.

6.1 Cold Smoking methods

Cold smoking is not really about cooking the fish it is, about making the fish taste better and keeping the fish fresh. The cold smoking process happens at temperatures usually between 70 and 90 degrees Fahrenheit. The first thing you do is salt the fish or put the fish in brine. If the fish is not very thick a few hours might be time. If the fish is very thick it can take the fish a few days.

After you do that the fish stays in smoke for a very long time. The fish stays in the smoke to make the fish taste really good and to keep the fish fresh. Cold smoking the fish is what makes the fish so good. The smoke slowly works its way into the food adding lots of smoke flavours to the food while the outside of the food dries out just the right amount.

6.2 Hot Smoking Methods

Hot smoking is a way of doing things. When you hot smoke you cook the fish at temperature of 225 to 250°F (107 to 121°C). This way the fish gets to soak up all the flavours. You can eat the smoked fish right away after you are done with it. The smoked fish is flakier than the cold-smoked fish. Smoked fish does not last as long, as cold-smoked fish but hot-smoked fish is a lot safer to eat and easier to make especially if you are just starting out with hot smoking.

6.3 Gunchi

This is a smoked fish dish that they really like. They catch go the river. The fish they catch are *Labeo dero*, *Schizothorax richardsonii*, *Channa* and *acrossocheilus*.

The Lepcha people make gunch by cleaning the fish. They clean the fish well. Then they dry the fish. After the fish is dry the Lepcha people add salt and turmeric to the fish. The Lepcha people use salt and turmeric to make the gunch taste good. The Lepcha people hang the fish from bamboo strips. These bamboo strips are hung above the oven. The oven gives out smoke that reaches the fish. This smoke helps to make the gunch. The Lepcha people do smoothing with the bigger fish. They put the fish on a rack over the heat. The heat, from the oven helps to make the gunch ready to eat. The Lepcha people wait for some time. Then the gunch is ready. The Lepcha people can now eat the gunch. The gunch gets a deep, smoky flavour after being smoked for about ten to fourteen days. People usually eat it as a curry, and it can stay good for a couple of months at room temperature, or even three. time. Then the gnuch is ready. The Lepcha people can now eat the gnuch. The gnuch gets a deep, smoky flavour after being smoked for about ten to fourteen days. People usually eat it as a curry, and it can stay good for a couple of months at room temperature, or even three.

7. Advanced Fish Preservation Technology

- High-pressure preservation [HPP]
- Irradiation Processing
- Microwave Processing
- Frozen processing

7.1. High-Pressure Processing Technology

This is a new technique that needs little heat [7]. It works well for keeping different varieties of food fresh. Here's how it works, need to soak the food in a liquid like water, castor oil, ethanol or glycol. Then, we need to seal it in a pressure vessel that

also maintain the correct pressure. These liquids also keep out the inside of the vessel from rusting.

HPP secure food safety and quality by using a mix of average heat up to 120°C and high pressure up to 900MPa for short period. The main benefits are even pressure distribution, less thermal impact and the preservation of the food's original qualities.

Fungi are the most sensitive to high pressure processing (HPP) at pressure between 300 and 400MPa for killing micro organisms. Next in line are gram-negative bacteria. In practice a piece of yellow fin tuna stayed fresh for a mucus longer period after HPP treatment at 250 MPa and 200 MPa.

7.2 Irradiation Processing Technology

Radiation commonly called cool pasteurization. It is a unique way to preserve fish without increasing the temperature. When fish are brighter they keep their natural aroma and taste. This method eliminates the need for chemicals like pesticides or cleaning to control bacteria or pests. As a result, consumers get high quality fish and fish products, these all made possible through radiation.

Gamma irradiation is a popular method. It extends the shelf life of fish it reduces microbial counts and significantly does not increase temperature. The process involves exposing fish to a carefully controlled amount of high energy radiation. This treatment helps delay spoilage, decreases the risk of food borne illnesses and maintains the fish freshness, all while keeping its nutritional value and entire flavour.

Considering the issues with poor fish hygiene and changing our preservation methods looks necessary. Instead of sticking with traditional techniques, using irradiation at different doses gives us a safe option. It effectively eliminates tough pathogens while maintaining the fish's quality and flavour and this method is a sensible choice [5].

7.3 Microwave Processing Technology

Microwave heating works by releasing electromagnetic waves usually at a frequency of 2.45 GHz. These waves penetrate the materials and make molecules, especially water move quickly enough to create heat from the inside. Unlike a conventional oven that heats from the outside in, microwaves produce heat within the substance itself. This leads to a quicker and more even heating process [9]. People have been using microwaves for years as an alternative way to cook and lately, they've started using them for shucking shellfish, too, that's opening the shells, in case you're wondering [10].

The closer look at how different heat treatments, boiling, steaming, baking and microwaving, affect how easy it is to open fresh mussels (*Mytilus galloprovincialis*) and how much they lose during cooking [16]. Out of all methods, microwaving came out on top. It reduced cooking loss the most and worked best for opening up the shells. Because microwave treatment delivers a higher-quality final product, the authors think it is a strong option for industrial mussel processing. Still, there's more to figure out. They point out that we need more research to see how using microwaves continuously affects the texture, taste and physical properties of mussel meat when it is done on a larger scale [10].

8. Fish Frozen Technology

Micro-freezers (MF), liquid nitrogen spray freezing and ultra low temperature refrigerators are technologies that allow rapid freezing, control ice crystal formation and reduce cellular damage. Micro-freezing provides speed results because liquid coolants rapidly reduce heat. The coolant can be recycled which helps lower costs, so that (MF) is often used for fruits, vegetables and meat [14].

Liquid nitrogen works even faster and quickly cools samples. However if the temperature fall too low the food may crack or break apart and also have ultra low temperature freezers that keep a minimum temperature and efficiency to transfer heat from the food to the freezing agent. These freezers are often used in different industries to preserve the quality of food like potatoes, tofu and beef. Still there is not enough research on how these quick freezing methods affect the quality of fresh water fish [13].

9. Fish Waste Utilization Processing

The majority of fish processing businesses in India only deal with fish and shellfish. After cleaning and freezing them, they are taken out. The majority of the waste and by-products left over from that process are used as animal or poultry feed, sometimes as fertilizer or simply thrown out of. Although some companies recently started observing these leftovers in a different way. They are being transformed into pure proteins like collagen, gelatine, hydrolysates, chitin and chitosan, PUFA-rich oils, enzymes, biochemical's, health products and components for drugs. But this area has remained in its early stages. In India this part of the industry is just getting started. Although it is still relatively fresh and many people see a lot of opportunity for both local and export markets. The technology required to transform fish waste into useful products is already in place or is being developed by Indian companies and scientists. But the industry continues to be restricted by a few major challenges [11].

10. Conclusion

Additionally becoming a major contributor to the global economy, the fishing industry faces numerous challenges. A few of the challenges include food safety, environmental issues and an increasing need of fresh, less processed goods. The use of new technology to produce high quality, sustainable and safe products. While still satisfying consumers demands will determine the future of sea food processing. It is not easy to get there, it involves considering the issue from every perspective, including careful finance management, consumer education, clear and effective regulations and accurate scientific research.

Everyone disagree that technology is the best option in every situation, while each has advantages of its own. There are disadvantages as well, such as high capital costs, legal restrictions and problems with consumer acceptance. Which suits one company or one kind of sea food may not be suitable for another. The best choice is determined by the particular product, the available resource and expectations of quality.

Sea food processing has made significant improvements but achieving a balance between sustainability, quality, safety and consumers preferences is challenging. The task at hand requires a variety of approaches to solve. Future studies should look closely at these issues, particularly how to successfully scale up these technologies and how people truly feel about them. It is also beneficial to investigate the potential benefits of combining various technologies; a perfect combination may increase the advantages while avoiding the disadvantages.

Reference

- [1]. Dirar, H.A. (1993). The indigenous fermented foods of the Sudan: A Study in African food and nutrition. Agricultural and Food Sciences. Corpus ID – 128509367.
- [2]. Ahmad Rosma, Amarj It Singh, Anton Ann. Indigenous fermented food of South Asia 2015. Edition: 1. Chapter: 11. Publisher: CRC Press. Editors: V.K.Joshi.
- [3]. Kenneth Ruddel, Naomichi Ishige. On the Origins, Diffusion and Cultural Context of Fermented Fish Products in Southeast Asia. (Globalization, Food and Social Identities in the Asia Pacific Region – 2010).
- [4]. Ranendra K. Majumdar, Deepayan Roy, Sandeep Kumar Bejjnski, Nimisha Baskar (2016). An Overview of Some Ethnic Fermented Fish Products Of Eastern Himalayan Region Of India. Journal of Ethnic Foods 3(4). DOI: 10.1016/j.jef.2016.12.003.

- [5]. Mohammed Ziyarah Eskander (2020). Drying and Salting Fish Using Different Methods and Their Effect on The Sensory, Chemical and Microbial Indices. *Multidisciplinary Reviews* 3(ISSN 2595- 3982):1-7
- [6]. Paresh A.Valu, D.V. Bhola, Mitul U. Tandel, Traditional fish preservation methods and products of India. e-ISSN: 2582 – 6654. *Biotica Research Today* 5(9), 703-705.
- [7]. Tewari,Vijay K. Juneja, *Advances in Thermal and Non-thermal Food Preservation* (2007). Blackwell Publishing. ISBN- 13:978-0-8138-2968-5.
- [8]. Eman F.E. Mohamed, Abd EI-Salam E. Hafez, Hanan G. Seadawy, Mohamed F. M. Elrefai (2023). Irradiation as a Promising Technology to Improve Bacteriological and Physicochemical Quality of Fish. *Microorganisms* 2023, 11, 1105.
- [9]. Viji Pankyamma, Madhusudana Badireddy Rao, Jasmi Debbarma, C. N. Ravishankar. *Research Developments in the Applications of Microwave Energy in Fish Processing: A Review* (2022). *Trends in Food Science & Technology*. 123
- [10]. Anna Marinopoulou, Dimitris Petridis., A comparative study of the effect of different cooking methods on the quality and shucking of mussels. *Journal of Food Processing and Preservation* 2021-46(4).
- [11]. C.N. Ravishankar, Elavarasan Krishnamoorthy (Feb 2024). *Innovations in fish processing Technology. Transformation of Agri-Food System 2024*. Pp 205-221.
- [12]. Chandrasekaran S, Ramanathan, Tanmy Basak. *Microwave food processing: A Review*, *Food Research International* 2013; 52: 243-261.
- [13]. Dhaswadikar Usha Sitaram. *New Technologies in fish processing and fishery products*, *World Journal of Advanced Research and Reviews* 2021, 09(02),141-143.
- [14]. Sirintra Boonsumrej, Saiwanichsiri, Sumate Tantratian, Toru Suzuki, Rikuo Takai. Effects of freezing and thawing on the quality changes of tiger shrimp (*Penaeus monodon*) frozen by air-blast and Cryogenic Freezing. *Journal of Food Engineering* 2007. 80; 292-299.
- [15]. Giovanni Luca Russo, Antonio L. Langellotti, Elena Torrieri, Paolo Masi. *Emerging technologies in seafood processing: An overview of innovations reshaping the aquatic food industry. Comprehensive Reviews in Food Science and Safety*. 2023.

[16]. Marinopoulou, A and Petridis, D. (2022). A Comparative study of the effect of different cooking methods on the quality and shucking of mussels. *Journal of Food Processing and Preservation*, 46(10), e15875.