

## RIDING THE BLUE WAVE: TRENDS, FORECAST, AND FUTURE PROSPECTS OF FISH SEED PRODUCTION, FISH PRODUCTION, AND EXPORTS IN INDIA

P. Vinothini<sup>1</sup> and V. Suthacini<sup>2</sup>

1.Ph.D, Res.Scholar, Dept. of Agricultural Economics, School of Economics, Madurai Kamaraj University, Madurai-625021

2.Asst. Professor and Head, Dept of Agricultural Economics, School of Economics, Madurai Kamaraj University, Madurai-625021

## ABSTRACT

The fisheries sector in India plays a crucial role in food security, employment generation, and economic growth, contributing significantly to agricultural GDP and export earnings. This study examined the historical trends and future projections of fish seed production, total fish production, and seafood exports in India using regression analysis on time-series data from 2010 to 2021, with forecasts extending to 2030 and 2040. The findings showed consistent upward trajectory, with fish seed production projected to reach 861,485.6 lakh fry, 251.65 lakh tonnes total fish production, and 2.34 million tonnes of seafood exports by 2040. The study highlighted key drivers of growth, including technological advancements in aquaculture, government policy interventions such as the Pradhan Mantri Matsya Sampada Yojana (PMMSY), and increasing global demand for Indian seafood. Despite this positive outlook, challenges such as climate change, disease outbreaks, overfishing, and international trade restrictions pose potential risks to sustainable growth. To address these challenges, the study suggest to enhance hatchery and breeding infrastructure to promote climate-resilient aquaculture, strengthening of cold-chain logistics, and to expanding export markets. The results of the study provided significant insights for policymakers, fisheries researchers, and industry stakeholders. The findings highlighted how data-driven decision-making supported more effective planning and management within the fisheries and aquaculture sectors. The analysis also emphasized that sustainable resource management practices were essential for maintaining India's leadership in global fisheries production. Overall, the study contributed valuable evidence that helped stakeholders understand past trends, evaluate performance, and frame strategies for improving the long-term sustainability of the sector. This study concluded that **study projected strong future growth** in fish seed production, total fish output, and seafood exports by 2040. **Sustaining this growth requires tackling challenges** like climate change and improving technology, sustainability, and trade networks.

(**Keywords:** Fisheries sector, fish seed production, aquaculture, seafood exports, regression analysis, sustainable fisheries, India.)

## INTRODUCTION

Fisheries and aquaculture have emerged as key sectors in India's agricultural and economic landscape, significantly contributing to food security, employment generation, and export earnings (Anonymous, 2020). The sector has witnessed remarkable growth over the past few decades, driven by advancements in aquaculture technologies, government policies, and increasing global demand for seafood (Sharma and Kumar, 2019). With a vast coastline of 7,516 kilometers, extensive inland water resources, and a favorable climatic environment, India ranks as the third-largest fish producer globally and the second-largest producer of aquaculture fish (Anonymous, 2022). The Blue Revolution and subsequent initiatives like the Pradhan Mantri Matsya Sampada Yojana (PMMSY) have significantly accelerated production, reinforcing India's position in global fisheries trade (Anonymous, 2022). However, while historical trends indicate steady growth in fish seed production, fish production, and exports, it is imperative to assess the future trajectory of these parameters to ensure sustainable sectorial growth, resource optimization, and economic viability. **Importance of proper fish feeding in aquaculture** fish feeding is one of the most crucial factors in commercial fish farming because feeding regime directly affects fish growth, health, feed efficiency, and feed wastage. A balanced feed containing essential nutrients such as proteins, carbohydrates, lipids, vitamins, and mineralization is necessary for improving the survival, health, and growth performance of fish. **Potential of Wheat grass as a natural feed supplement** Wheat grass (*Triticum aestivum*) is highlighted as a promising natural supplement in fish feed due to its rich nutritional profile, including vitamins, minerals, antioxidants, and bio active compounds. It has several medicinal properties—anticancer, immune-modulatory, antibacterial, and anti-inflammatory—which can enhance fish health without relying on synthetic antibiotics (Butle *et al.*, 2022). *Bacillus thuringiensis* is a natural bacterium that produces insecticidal crystal proteins effective against many insect pests. It is widely used as a safe biological control agent because it does not harm mammals, fish, birds, or most non-target organisms (Bodhe *et al.*, 2022).

**The rising significance of the fisheries sector in India:** The fisheries sector is a vital pillar of India's agrarian economy, contributing over 1% to the national Gross Value Added (GVA) and nearly 7% to agricultural GVA (Anonymous, 2022). The sector provides livelihoods to approximately 28 million people, particularly in coastal and rural regions, reinforcing its socioeconomic importance (Anonymous, 2020). India's fish production increased from 76.16 lakh tonnes in 2010 to 141.64 lakh tonnes in 2021, representing a remarkable 86% growth over a decade (Anonymous, 2022). Simultaneously, the country's fish seed production witnessed a significant rise from 293,130 lakh fry in 2010 to 540,690 lakh fry in 2021, reflecting enhanced hatchery capacity, improved breeding techniques, and increased aquaculture adoption (Anonymous, 2022). These factors have also contributed to export expansion, with seafood exports peaking at 1.37 million tonnes in 2021, despite disruptions caused by the COVID-19 pandemic and global trade constraints (Anonymous, 2022).

**Trends and the need for future projections:** While past and present trends indicate strong sectorial growth, understanding the future trajectory of fish seed production, fish production, and exports is crucial for policy formulation, investment planning, and environmental sustainability. Fisheries in India face challenges such as climate change, overexploitation of marine resources, disease outbreaks, and fluctuating international demand (Sharma and Kumar, 2019). Therefore, reliable forecasting models are required to anticipate potential growth patterns, assess infrastructural needs, and optimize production strategies. Based on current trends, projections suggest that India's fish seed production will reach 675,358 lakh fry by 2030 and 861,485 lakh fry by 2040, while fish production is expected to grow to 191.10 lakh tonnes by 2030 and 251.65 lakh tonnes by 2040 (Anonymous, 2022). Similarly, seafood exports are forecasted to rise to 1.84 million tonnes by 2030 and 2.34 million tonnes by 2040, reinforcing India's expanding role in global seafood markets (Anonymous, 2022a).

**Research objectives:** The present study aimed to analyze the historical trends and future projections of fish seed production, fish production, and exports in India. The specific objectives of the study were:

- To examine the trends in fish seed production, fish production, and exports in India from 2010 to 2021.
- To forecast future trends in fish seed production, fish production, and exports in India up to 2040.
- To assess the implications of forecasted trends for India's fisheries sector in terms of sustainability, policy measures, and market expansion.

**Significance of the study:** This study is highly relevant in the context of India's evolving fisheries sector, where scientific forecasting and data-driven decision-making are critical for ensuring long-term sustainability. With India's ambitious vision to become a leading player in global aquaculture and marine exports, understanding the sector's growth potential, challenges, and future opportunities will help in framing evidence-based policies and strategies (Anonymous, 2020). Additionally, this study will provide valuable insights for policymakers, fisheries researchers, aqua culturists, and export agencies, enabling them to align sectoral growth with economic and environmental sustainability goals.

## MATERIALS AND METHODS

This study adopts a quantitative research approach to analyze historical trends and forecast future values of fish seed production, fish production, and seafood exports in India. The research relies on secondary data sources obtained from government agencies such as the Handbook on Fisheries Statistics (2022), reports from the Marine Products Export Development Authority (MPEDA), and datasets from the Food and Agriculture Organization (FAO). The study covered the period from 2010 to 2021, with forecasts extending to 2030 and 2040 to provide a long-term perspective on India's fisheries sector. The dataset consisted of three key variables: fish seed production (Lakh Fry), total fish production (Lakh tonnes), and seafood exports (Tonnes). The data was carefully examined to identify growth patterns, seasonal variations, and structural changes over time. To ensure accuracy and consistency, multiple sources were cross verified, and statistical validation techniques were applied. For forecasting, the study employed regression analysis, a widely used econometric technique for time-series prediction. A linear regression model was developed using historical data, where time was treated as the independent variable and fish seed production, fish production, and exports as the dependent variables.

## Linear Regression

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k + \varepsilon$$

Where:

Y = Dependent variable

X<sub>1</sub>, X<sub>2</sub>, ..., X<sub>k</sub> = Independent variables

β<sub>0</sub> = Intercept

β<sub>1</sub>, β<sub>2</sub>, ..., β<sub>k</sub> = Regression coefficients

ε = Error term

## RESULTS AND DISCUSSION

India's fish production exhibited a consistent and exponential growth trajectory from 76.16 lakh tonnes in 2010 to 141.64 lakh tonnes in 2021, reflecting the sector's increasing productivity, technological advancements, and policy-driven enhancements. The steady rise in output, particularly after 2015, when production escalated from 95.79 lakh tonnes to 141.64 lakh tonnes in just six years, underscored the intensification of aquaculture practices, improved hatchery management, and strategic governmental interventions such as the Blue Revolution and Pradhan Mantri Matsya Sampada Yojana (PMMSY). The sharp acceleration after 2018, with production surging from 114.31 lakh tonnes to 141.64 lakh tonnes by 2021, signaled enhanced resource utilization, expansion of inland and marine fisheries, and increased market demand. This sustained growth trajectory highlighted the sector's crucial role in national food security, rural livelihoods, and India's emergence as a key player in global fisheries trade, reinforcing its position as one of the world's fastest-growing aquaculture economies.

Chakraborty *et al.* (2020), Das and Mohanty (2021) and Sharma and Kumar (2019) opined that the continuous rise in India's fish production reflected the successful integration of technological advancements, strengthened aquaculture systems, and supportive government interventions. They observed that the sharp increase after 2015, where production grew rapidly from 95.79 lakh tonnes to 141.64 lakh tonnes, aligned with improvements in hatchery management, better breeding and seed production practices, and policy initiatives like the Blue Revolution and PMMSY. Researchers emphasized that the accelerated growth after 2018 indicated enhanced resource utilization, expansion of both inland and marine fisheries, and rising domestic as well as international demand. According to these scientific perspectives, the sustained upward trend highlighted the sector's vital contribution to national food security, income generation for rural communities, and India's increasing prominence in global fisheries trade. Overall, scientists concluded that the exponential production growth reaffirmed India's status as one of the world's fastest-growing aquaculture economies.

The fish seed production in India exhibited a long-term upward trajectory from 2010 to 2021, characterized by periodic fluctuations and subsequent recoveries, indicative of dynamic sectoral growth. An initial surge from 293,130 lakh fry in 2010 to 365,651 lakh fry in 2011 was followed by a phase of stagnation and moderate decline (2012-2017), reflecting possible ecological constraints, policy shifts, or infrastructural bottlenecks. However, from 2018 onwards, a sustained acceleration in production was observed, reaching a peak of 540,690 lakh fry in 2021, underscoring advancements in hatchery technology, enhanced breeding practices, and robust government interventions. The recent exponential growth suggests greater sectoral resilience, heightened aquaculture commercialization, and improved resource management, positioning India's fisheries sector as a pivotal contributor to sustainable food security, economic expansion, and global seafood markets.

Sharma and Kumar (2019) and Chakraborty *et al.* (2020) opined that the rise in fish seed production reflected improved hatchery technologies, better breeding practices, and effective government support. They noted that despite fluctuations between 2012 and 2017. Das and Mohanty (2021) observed strong growth after 2018 and showed increasing sectorial resilience and modernization, strengthening India's role in sustainable aquaculture and food security.

India's seafood exports demonstrated a long-term expansionary trend from 813,091 tonnes in 2010 to 1,369,264 tonnes in 2021, driven by enhanced aquaculture practices, diversification of export markets, and advancements in processing and cold-chain infrastructure. The period from 2010 to 2014 witnessed a steady rise, peaking at 1,051,243 tonnes in 2014, reflecting increased production capacity and global demand for Indian seafood, particularly shrimp exports. A temporary contraction in 2015 (945,892 tonnes) likely resulted from regulatory shifts, trade barriers, or environmental challenges. The sector rebounded sharply, reaching an all-time high of 1,397,244 tonnes in 2017, fueled by technological interventions, expansion of Vannamei shrimp farming, and strengthened trade relations. Post-2018, export volumes exhibited volatility, declining to 1,149,510 tonnes in 2020, possibly due to COVID-19-induced disruptions, global supply chain constraints, and demand fluctuations. The subsequent recovery in 2021 (1,369,264 tonnes) underscores the resilience of India's seafood industry, reaffirming its position as a key global exporter and highlighting the sector's potential for sustained growth through policy support, market diversification, and value-added processing innovations.

Mukherjee *et al.* (2021) and Sharma and Kumar (2019) opined that the long-term growth in India's seafood exports reflected the positive influence of improved aquaculture practices, strengthened cold-chain systems, and expanding global market linkages. They noted that the steady rise in exports from 2010 to 2014 indicated strong international demand, particularly for shrimp, while the temporary decline in 2015 aligned with regulatory pressures and environmental challenges reported in the sector. Researchers further emphasized that the sharp rebound in 2017 was consistent with technological advancements and the rapid expansion of Vannamei shrimp farming. According to these scientific perspectives, the fluctuations observed after 2018, especially the drop in 2020, corresponded with COVID-19-related disruptions and supply-chain constraints. Overall, the recovery in 2021 reaffirmed the resilience of India's seafood industry and supported the view that continued policy support, market diversification, and value-added processing are essential for sustaining export growth.

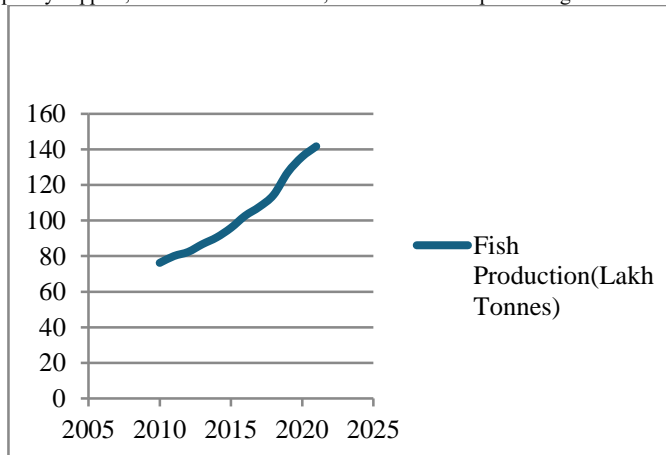


Figure1. Fish production (Lakh tonnes)

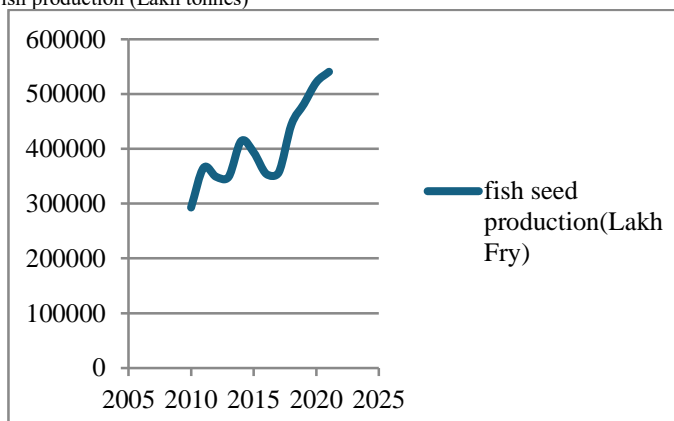


Figure 2. Fish seed production (Lakh fry)

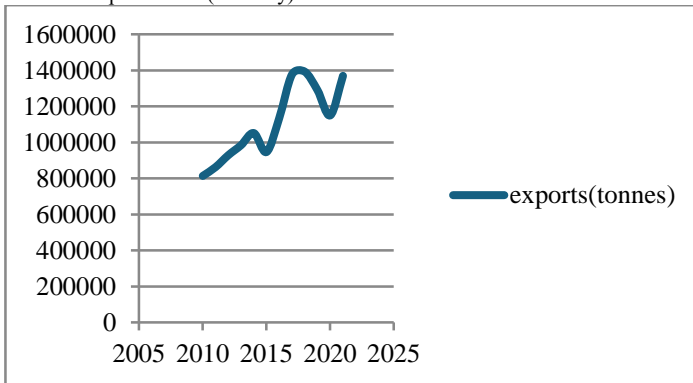


Figure 3. Exports (Tonnes)

Table 1. Forecast of India's fisheries sector: fish seed production, fish production, and exports (2010-2040)

Year	Fish seed production (Lakh fry)	Fish production (Lakh tonnes)	Export (tonnes)
2010	293130	76.16	813091
2011	365651	79.98	862021
2012	349202	82.31	928215
2013	349202	86.66	983756
2014	414484	90.46	1051243
2015	393487	95.79	945892
2016	354350	102.6	1134948
2017	357439	107.62	1377244
2018	444207	114.31	1392559
2019	481974	127.04	1289651
2020	521865	135.73	1149510
2021	540690	141.64	1369264
2030	675358.2*	191.1022*	1840540*
2040	861485.6*	251.6502*	2345660*

Source: Hand Book on Fisheries Statistics 2022,\* indicates forecasted values

India's fisheries sector has exhibited a robust and sustained growth trajectory, with fish seed production, total fish production, and exports expanding significantly from 2010 to 2021, driven by technological advancements, policy interventions, and increasing global demand. Fish seed production grew from 293,130 lakh fry in 2010 to 540,690 lakh fry in 2021, directly influencing the consistent rise in fish production, which surged from 76.16 lakh tonnes to 141.64 lakh tonnes during the same period. Exports, a critical indicator of India's global fisheries market presence, peaked at 1,369,264 tonnes in 2021, despite periodic fluctuations due to external trade dynamics and pandemic-induced disruptions. The forecasted values for 2030 and 2040 projected exponential growth, with fish seed production expected to reach 675,358.2 lakh fry in 2030 and 861,485.6 lakh fry in 2040, reinforcing the sector's increasing capacity and productivity. Correspondingly, fish production is anticipated to surpass 191.10 lakh tonnes in 2030 and 251.65 lakh tonnes in 2040, aligning with India's strategic initiatives under the Blue Revolution and Pradhan Mantri Matsya Sampada Yojana (PMMSY). The export forecast suggests a remarkable expansion to 1,840,540 tonnes by 2030 and 2,345,660 tonnes by 2040, emphasizing India's growing prominence in global seafood trade, driven by enhanced aquaculture efficiency, value-added processing, and diversified market access. This projected growth underscores India's potential to emerge as a global leader in sustainable fisheries and aquaculture, provided that investments in infrastructure, climate-resilient practices, and international trade agreements continue to support the sector's upward momentum.

**Suggestions:** Based on the findings of this study, several strategic recommendations can be made to ensure the sustainable growth and long-term viability of India's fisheries sector.

**Enhancing hatchery and breeding infrastructure:** Given the projected increase in fish seed production, investments should be made in modern hatcheries, selective breeding programs, and disease-resistant fish strains to ensure high-quality seed availability. Strengthening brood stock management will further enhance productivity.

**Technological interventions in aquaculture:** To support the rising trend in fish production, advanced aquaculture techniques such as biofloc technology, recirculating aquaculture systems (RAS), and genetic improvements should be promoted. Integrating IoT-based monitoring systems and AI-driven analytics can optimize production efficiency.

**Strengthening export competitiveness:** With seafood exports projected to reach 2.34 million tonnes by 2040, efforts should be directed toward value-added processing, cold-chain infrastructure, and international quality certifications. Expanding to new global markets and reducing trade barriers will ensure sustained export growth.

**Climate resilience and sustainable fisheries management:** Climate change and overexploitation of marine resources pose significant threats to future fisheries growth. Adaptive measures such as eco-friendly fishing practices, coastal zone management, and sustainable feed production should be implemented. Research on climate-resilient fish species can help mitigate environmental risks.

**Policy and financial support:** Government policies like the Pradhan Mantri Matsya Sampada Yojana (PMMSY) should be expanded and refined to provide financial aid, subsidies, and credit facilities to small-scale fish farmers. Establishing public-private partnerships can further drive investments in the sector.

India's fisheries sector has witnessed consistent growth in fish seed production, total fish production, and exports, reinforcing its economic and strategic significance. The study highlighted that fish seed production is expected to reach 861,485.6 lakh fry, fish production 251.65 lakh tonnes, and seafood exports 2.34 million tonnes by 2040, emphasizing the need for technological advancements, policy interventions, and market expansion. While past trends demonstrate resilience and sectoral strength, future growth depends on addressing challenges such as climate change, disease outbreaks, and trade regulations. Investments in hatchery technology, sustainable fisheries management, and global trade networks will be crucial in sustaining the projected trajectory. The findings of this study provide a data-driven roadmap for policymakers, industry stakeholders, and researchers to capitalize on future opportunities while ensuring environmental sustainability. If strategic measures are implemented effectively, India is well-positioned to become a global leader in fisheries and aquaculture in the coming decades.

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