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Original Article

Market transition dynamics and export forecasting of India's marine products: a phase-wise analysis using Markov Chain and ARIMA models

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Abstract
India is one of the world's leading exporters of marine products, contributing substantially to foreign exchange earnings, employment, and coastal livelihoods. Understanding long-term export growth, market transitions, and future trade prospects is essential for strengthening export competitiveness and policy planning. This study analysed India's marine product exports using secondary data from 2005–2006 to 2024–2025 covering eight product groups (frozen shrimp, frozen fish, frozen cuttlefish, frozen squid, dried items, live items, chilled items, and others) and seven major export markets. Export growth, instability, market concentration, market transition, and future export trends were evaluated using Compound Annual Growth Rate (CAGR), Cuddy–Della Valle Instability Index (CDVI), Herfindahl–Hirschman Index (HHI), Markov Chain analysis, and Auto-Regressive Integrated Moving Average (ARIMA) models, respectively. The results indicated that frozen shrimp remained the dominant export commodity, while China recorded the highest growth with comparatively high instability. Markov Chain analysis revealed a structural shift in export market retention, with the United States of America (USA) emerging as the most stable destination during the later period. ARIMA forecasts indicated a gradual decline in export values across most product categories through 2035 under existing trends. The findings suggest the need for export diversification, value addition, and market expansion to enhance the long-term resilience and competitiveness of India's marine products sector

Keywords: ARIMA forecasting; export growth; export instability; marine product exports; Markov Chain analysis; market transition dynamics

1 | INTRODUCTION

Marine fisheries and aquaculture occupy a central place in global food systems, international trade, and national economies, providing a critical source of animal protein, livelihoods, and foreign exchange earnings for millions of people across the world (Purkait *et al.* 2025). Frozen shrimp has consistently dominated India's export basket, accounting for a substantial share of total export earnings across the study period, while key destination markets including the United States of America (USA), European Union (EU), China, Southeast Asia, Japan, and the Middle East have exhibited dynamic and shifting demand patterns (More and Kuthe 2016; Arindam 2023).

The international seafood market has undergone a profound transformation in recent decades, driven by expanding trade integration, the emergence of global market segments for similar species, and the rapid growth of aquaculture as wild fish landings stagnated (Anderson *et al.* 2018). This expansion has increased global seafood consumption and reshaped trade patterns, with Asian fleets gaining increasing dominance in catch volumes and many lower-income countries exporting higher-value seafood while retaining or importing lower-value products to balance income and food security needs (Watson *et al.* 2017). However, recent post-pandemic projections indicate that although global seafood trade will continue to grow, its pace may remain weaker than the pre-2020 trend, and developing countries are likely to bear disproportionately larger export losses and trade uncertainty, highlighting the need for stronger international cooperation in seafood trade recovery (Wei *et al.* 2023).

Fluctuations in India's marine product exports were driven by several factors, including stringent sanitary and phytosanitary (SPS) standards imposed by importing countries, increasing competition from major seafood exporters such as Vietnam, Ecuador, and Thailand, exchange rate fluctuations, disease outbreaks in aquaculture, and disruptions in global demand caused by economic slowdowns and geopolitical developments (Guledagudda *et al.* 2020; Jeevitha *et al.* 2023). During 2024–2025, weak demand in the USA and European Union resulted in a 5.4% decline in export volume and a 2.4% decline in export value. These fluctuations emphasized the need for a comprehensive assessment of the structural dynamics and future export prospects of India's marine products.

Export market transition refers to the changes in the distribution of export shares among importing countries over time, reflecting the dynamics of market retention and switching behaviour (Chandrasekar *et al.* 2020; Singh *et al.* 2023). Understanding these transitions is essential for identifying stable markets, declining destinations, and emerging export opportunities for Indian marine products (Ramadhan *et al.* 2024). Earlier studies using Markov chain analysis for Indian marine product exports — particularly for the period up to 2015 — found that Southeast Asian countries exhibited the highest market loyalty with a retention probability of 73 per cent, followed by the European Union (65 per cent), Japan (58 per cent), and the United States (52 per cent), while Middle Eastern markets showed the highest degree of instability (Satishkumar and Gururaj 2016; Manjunath *et al.* 2017). However, the post-2015 period has witnessed a fundamental reshaping of India's export geography — particularly the dramatic rise of China as a destination market and the emergence of Southeast Asian and Middle Eastern markets as growing trade corridors — making a fresh phase-wise Markov chain analysis for the period 2005–2025 both timely and analytically necessary (Singh *et al.* 2023; Ramadhan *et al.* 2024).

Predicting future export trends with statistical rigor is equally important for understanding on going structural transformations in India's marine export sector. One of the most popular and methodologically sound techniques for forecasting fisheries and trade data is time series forecasting (Das *et al.* 2016). The model's capacity to handle non-stationary series through differencing, detect autocorrelation structures through ACF and PACF plots, and produce reliable short to medium term forecasts has made it especially valuable in fisheries science and agricultural trade research (Stergiou *et al.* 1997; Gutiérrez-Estrada *et al.* 2007).

The ARIMA model has been extensively validated in fisheries and seafood trade forecasting contexts. Stergiou *et al.* (1997) demonstrated the superiority of ARIMA over regression-based approaches in forecasting monthly commercial fisheries landings across sixteen species in Hellenic marine waters, finding that ARIMA models consistently produced statistically acceptable and accurate forecasts. Bako *et al.* (2013) further confirmed the efficacy of the seasonal ARIMA framework for predicting monthly catches of two pelagic fish species in Malaysian waters, establishing the Ljung–Box test and AIC as reliable model selection criteria in fisheries time series applications.

Despite the growing body of research on India's marine product exports, significant research gaps remain regarding long-term temporal analysis and comprehensive analytical integration.. In order to address these shortcomings, this analysis uses a phased methodology, Phase I (2005–2006 to 2014–2015) and Phase II (2015–2016 to 2024–2025), to capture structural changes in India's marine product exports influenced by changes in international trade policies, the COVID-19 pandemic, geopolitical conflicts, supply chain disruptions, and shifting global trade patterns.

India's marine product exports have primarily focused on individual aspects such as export growth, market instability, trade direction, or forecasting, often using a single analytical approach and covering only the pre-2015 period. Consequently, limited evidence is available on how export growth, instability, market concentration, market transition, and future export trajectories interact over time within a unified analytical framework. To address this research gap, the present study integrates Compound Annual Growth Rate (CAGR), Cuddy–Della Valle Instability Index (CDVI), Herfindahl–Hirschman Index (HHI), Markov Chain analysis, and Auto-Regressive Integrated Moving Average (ARIMA) modelling. The combined application of these complementary methods provides a comprehensive assessment of export performance by simultaneously evaluating growth dynamics, instability, structural concentration, market transition, and future export trends. This integrated framework offers a more holistic understanding of India's marine export transformation and provides stronger evidence for strategic policy formulation and long-term export planning.

2 | METHODOLOGY

2.1 Data source and period of study

The study was based on secondary time-series data on India's marine product exports obtained from the Marine Products Export Development Authority (MPEDA), Government of India. Export quantity (tonnes) and value (₹ crore) data were collected for eight major product groups, namely frozen shrimp, frozen finfish, frozen cuttlefish, frozen squid, dried items, live items, chilled items and others (e.g. frozen lobster, crab, surimi and surimi analogue products and fish meal), as well as seven major destination markets comprising the USA, European Union, China, Southeast Asia, Japan, Middle East and others (Satishkumar and Gururaj 2016; Arindam 2023). The study period covered 2005–2006 to 2024–2025 and was divided into Phase I (2005–2006 to 2014–2015) and Phase II (2015–2016 to 2024–2025) to analyse structural changes in export performance (Chandrasekar *et al.* 2020; Jeevitha *et al.* 2023). Export values were obtained from the Marine Products Export Development Authority (MPEDA) and are reported in current (nominal) prices, as published in the official annual export statistics. No inflation adjustment was applied because the primary objective of the study was to analyse observed export performance, structural market transitions, and forecasting based on the reported export series. While inflation may have influenced long-term value trends, the results should be interpreted within the context of nominal export values.

2.2 Compound Annual Growth Rate (CAGR)

Growth in marine exports was assessed using an exponential growth model.

$$Y_t = ab^t e^u$$

Where: Y_t = export quantity in year t, a = intercept term, b= (1+r), with *r* as the compound growth rate, t = time (trend variable), u = random error term.

The model was transformed into a log-linear form for estimation via Ordinary Least Squares (OLS) in the equation:

$$\log Y = \log a + t \log b + \log u$$

The compound annual growth rate (CAGR) was then calculated using equation:

$$CAGR = [\text{Antilog} (\log b) - 1] \times 100$$

Parameters were estimated using OLS regression, with significance tested via t-statistics. Data were smoothed using three-year moving averages to mitigate the influence of outliers (Arindam 2023; Purkait *et al.* 2025).

2.3 Export instability analysis: Cuddy-Della Valle Instability Index (CDVI)

Export instability was measured using the CDVI, which adjusts the coefficient of variation for trend effects. The frollowing CDVI formula was used:

$$CDVI = CV * \sqrt{1 - R^2}$$

Where CV is the coefficient of variation and $\bar{\bar{R}}^2$ is the coefficient of determination from a time-series trend regression adjusted for degrees of freedom. If the estimated coefficient of the regression equation is insignificant, the CDVI equals the CV. Instability levels were categorised as: low (0–15%), medium (15–30%), and high (>30%) (Purkait *et al.* 2025).

2.4 Export concentration analysis: Herfindahl-Hirschman Index (HHI)

The HHI was used to evaluate structural concentration in India's marine exports across both product and market dimensions. This index was calculated using the following equation:

$$HHI = \sum_{i=1}^{n} S_i^2$$

Where S_i = Share of exports to the i^{th} importing country (as a proportion of total exports), *i* = Individual importing country, *n* = Total number of importing countries considered. The HHI ranges between 0 and 1 and is interpreted as follows: HHI < 0.10 indicates a competitive (diversified) market; 0.10 ≤ HHI ≤ 0.25 indicates a moderate concentration; and HHI> 0.25 indicates high concentration (Hirschman 1964, Coelho Junior *et al.* 2018).

2.5 Direction of trade: Markov Chain analysis

To ensure methodological reproducibility, the linear programming model for estimating the transition probability matrix was implemented in Python 3.10 using the scipy.optimize.linprog function. Historical export data were structured into block-diagonal matrices, and the transition probabilities were estimated by minimizing the Mean Absolute Deviation (MAD) subject to the Markov chain constraints that all transition probabilities were non-negative (Pij ≥ 0) and that the probabilities in each row summed to unity (ΣPij = 1). The optimization was performed using the HiGHS linear programming solver with the default convergence criteria implemented in SciPy. Separate transition probability matrices were estimated for Phase I (2005–2006 to 2014–2015) and Phase II (2015–2016 to 2024–2025), and feasible optimal solutions satisfying all model constraints were obtained for both phases.

Market retention and directional shifts in exports were analysed using a first-order Markov chain model. The transitional probability matrix ((P_{ij})) represents the probability of export share shifting from market (i) to market (j). The expected export share was estimated as algebraically from the following equation:

$$X_{jt} = \sum_{i=1}^{n} (X_{it-1}) P_{ij} + e_{jt}$$

Where, Xjt = exports from India to the jth country during year t, $X_{it} - 1$ = exports to the i^{th} country during year t – 1, P_{ij} = probability that exports shift from the i^{th} to the j^{th} country, e_{jt} = error term, statistically independent of $e_{jt} - 1$, *n* = number of importing countries.

The transitional probabilities Pij are arranged in a (c × n) matrix satisfying the following properties in the following equation:

$$\sum_{i=1}^{n} P_{ij} = 1,\ \ 0 \le P_{ij} \le 1$$

The transition probability matrix (TPM) was estimated using a linear programming approach based on minimisation of the Mean Absolute Deviation (MAD), as in the following equation (Singh *et al.* 2023):

Min OP* + Ie

Subject to, XP* + V = Y; GP* = 1; P* ≥ 0

Where P* = vector of the probabilities P_{ij}, O = vector of zeros, I = appropriately dimensioned vector of ones, e = vector of absolute errors, Y = vector of exports to each country, X = block diagonal matrix of lagged values of Y, V = vector of errors, G = grouping matrix constraining row elements of P* to sum to unity. The overall study period covers 2005–2006 to 2024–2025 (20 years), with Markov Chain analysis applied separately for Phase I (2005–2006 to 2014–2015) and Phase II (2015–2016 to 2024–2025) to capture market transition dynamics across the two subperiods (Chandrasekar *et al.* 2020; Singh *et al.* 2023).

2.6 Export forecasting: Auto-Regressive Integrated Moving Average (ARIMA) model

Future export values were projected using the Auto-Regressive Integrated Moving Average [ARIMA ((p,d,q))] model, which combines autoregressive, differencing and moving-average components (Box and Jenkins 1976; Das *et al.* 2016). The general ARIMA model is represented by Combining all three components, the general ARIMA (p, d, q) model is expressed as:

$$\phi(B)(1-B)^d Yt = \theta(B)_{\epsilon t}$$

Where, ϕ(B) = 1 − ϕ1B − ϕ2B2 − … − ϕpBp = autoregressive operator; θ(B) = 1 + θ1B + θ2B2 + … + θqBq = moving average operator. 'B' = backshift operator such that $BY_t = Y_{t-1}$; $(1-B)^d$ = differencing operator of order 'd'

Stationarity was tested using the Augmented Dickey-Fuller (ADF) test. Frozen Shrimp, frozen fish, frozen cuttlefish and frozen squid were found to be stationary at levels ($p < 0.05$), whereas dried items, live items, chilled items and others exhibited non-stationary behaviour ($p > 0.05$). These non-stationary series were transformed through appropriate differencing until stationarity was achieved prior to ARIMA model estimation. Appropriate values of p and q were identified using ACF and PACF plots. Competing models were compared using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), and the model with the minimum information criteria was selected. Diagnostic adequacy was evaluated using residual analysis and the Ljung–Box test. Separate ARIMA models were fitted for each product category and forecasts were generated for the period 2026–2035 (Bako *et al.* 2013; Das *et al.* 2016; Gutiérrez-Estrada *et al.* 2007).

The ARIMA forecasts presented in this study should be interpreted with appropriate caution because they are based on a relatively short annual time series consisting of twenty observations. Forecast uncertainty increases with the forecast horizon, particularly beyond the medium term. Therefore, the projected export values represent trend-based estimates under the assumption that historical patterns continue, and they may be influenced by future changes in international demand, trade policies, technological developments, climatic events, and other unforeseen economic shocks.

3 | RESULTS AND DISCUSSION

3.1 Growth and Instability in India's marine exports

India's marine exports exhibited distinct changes in growth performance and export instability between Phase I (2005–2006 to 2014–2015) and Phase II (2015–2016 to 2024–2025) (Table 1). During Phase I, export growth was robust across most product categories, with frozen shrimp remaining the dominant export commodity and chilled items (22.80%) and dried items (22.52%) recording the highest compound annual growth rates (CAGR). In contrast, Phase II was characterised by moderated growth, as reflected in the decline in frozen shrimp CAGR from 18.06% to 8.01%, while chilled items registered a negative CAGR (−2.03%), indicating contraction in export performance. Export instability also varied considerably across product groups. Frozen shrimp exhibited a substantial decline in instability (CDVI: 31.68% to 8.74%), whereas dried items recorded the highest overall instability (51.18%), indicating greater fluctuations in export performance. Among destination markets, China recorded the highest growth during Phase II (22.24%) but also exhibited the highest export instability (41.65%), while the USA demonstrated comparatively stable export performance with lower instability during the second phase.

The phase-wise analysis indicates that India's marine export sector has transitioned from rapid expansion to relatively moderate growth, accompanied by changing patterns of export stability across products and destination markets. The improved stability observed for frozen shrimp reflects its established position in international markets, supported by sustained aquaculture production and consistent global demand. Conversely, the high instability associated with dried items and the rapid but volatile growth in exports to China suggest increasing sensitivity to fluctuations in international demand, evolving trade policies, and changing consumer preferences. These findings are consistent with Jeevitha et al. (2023), who reported that frozen shrimp continues to dominate India's marine export earnings despite increasing market uncertainties. Similarly, Purkait et al. (2025) and Das et al. (2016) observed that although India's marine exports have maintained positive long-term growth, external market dynamics and demand fluctuations contribute substantially to export instability. Collectively, these results highlight the importance of product diversification and market expansion strategies to strengthen the resilience and long-term sustainability of India's marine export sector.

TABLE 1 Growth and instability profile of India’s marine exports (2005–2025).

Product/markets	CAGR Phase I (%)	*t*-value (*p*-value)	CAGR Phase II (%)	*t*-value (*p*-value)	Overall CAGR (%)	CDVI Phase I (%)	CDVI Phase II (%)	Overall CDVI (%)
Products								
Frozen shrimp	18.06	4.15 ($p<0.01$)	8.01	2.11 ($p<0.05$)	12.98	31.68	8.74	19.99
Frozen fish	14.23	3.02 ($p<0.01$)	4.18	1.85 ($p<0.05$)	9.10	10.57	20.51	16.16
Frozen cuttle Fish	12.81	2.94 ($p<0.05$)	3.88	1.12 ($p<0.05$)	8.05	9.03	11.84	16.00
Frozen squid	8.28	2.04 ($p<0.05$)	6.66	1.98 ($p<0.05$)	9.22	16.01	16.13	24.33
Dried items	22.52	5.31 ($p<0.01$)	14.67	3.42 ($p<0.01$)	17.53	23.19	38.19	51.18
Live items	17.19	3.88 ($p<0.01$)	4.25	1.05 ($p<0.05$)	11.25	14.82	18.15	32.89
Chilled items	22.80	5.12 ($p<0.01$)	-2.03	–0.62 ($p<0.05$)	11.60	20.98	13.81	26.32
Others	14.05	3.16 ($p<0.01$)	9.27	2.45 ($p<0.05$)	11.32	10.11	15.66	21.30
Markets								
USA	18.34	4.22 ($p<0.01$)	10.16	2.89 ($p<0.01$)	14.05	35.91	10.89	23.85
EU	12.15	2.81 ($p<0.05$)	4.10	1.22 ($p<0.05$)	7.71	8.42	10.33	15.18
CHINA	4.73	1.02 ($p>0.05$)	22.24	5.88 ($p<0.01$)	13.49	15.68	32.24	41.65
SEA (South East Asia)	30.85	6.45 ($p<0.01$)	0.86	0.18 ($p<0.05$)	14.08	36.85	33.44	11.8
JAPAN	10.15	2.14 ($p<0.05$)	2.84	0.74 ($p<0.05$)	5.62	11.61	3.84	42.47
Middle East	20.71	4.98 ($p<0.01$)	2.64	0.69 ($p<0.05$)	10.65	17.77	6.78	11.63
Others	17.46	3.92 ($p<0.01$)	10.16	2.74 ($p<0.01$)	12.11	16.6	9.65	17.05

3.2 Structural concentration trends (HHI comparison)

The Herfindahl–Hirschman Index (HHI) analysis indicates an increasing concentration in India's marine product exports over the study period (Table 2). Product concentration increased from 0.356 in Phase I (2005–2006 to 2014–2015) to 0.500 in Phase II (2015–2016 to 2024–2025), indicating a greater dependence on a limited number of export commodities, particularly frozen shrimp. Similarly, market concentration increased from 0.176 to 0.211, suggesting a gradual shift toward reliance on a smaller group of destination markets. Overall, the HHI values indicate persistent structural concentration in both product composition and export markets throughout period. This indicates structural dependence on frozen shrimp; changes in global prices or trade barriers affecting frozen shrimp may influence overall export performance.

The increasing product concentration observed between the two phases suggests that India's marine export earnings have become progressively dependent on frozen shrimp, thereby increasing exposure to commodity-specific risks such as disease outbreaks, price volatility, and trade restrictions. Although market concentration remained within the moderate concentration range, its upward trend indicates growing dependence on a limited number of importing countries, particularly the USA and China. Such concentration may reduce the resilience of the export sector to external economic and geopolitical shocks. These findings are consistent with Coelho Junior et al. (2018), who reported that higher export concentration increases vulnerability to market fluctuations and reduces export resilience. Likewise, Hirschman (1964) emphasized that concentrated export structures are more susceptible to changes in international trade conditions because diversification opportunities remain limited. Therefore, expanding the product portfolio and strengthening market diversification would enhance the long-term stability and competitiveness of India's marine exports.

TABLE 2 Herfindahl–Hirschman Index (HHI) values for product and market concentration in India's marine exports, Phase I (2005–2006 to 2014–2015), Phase II (2015–2016 to 2024–2025), and overall (2005–2006 to 2024–2025).

Period	Product concentration (HHI)	Market concentration (HHI)	Interpretation (market/product value)
Phase I (2005–2006 to 2014–2015)	0.356	0.176	High product concentration / Moderate market concentration
Phase II (2015–2016 to 2024–2025)	0.500	0.211	High product concentration / Increasing market concentration
Overall (2005–2006 to 2024–2025)	0.461	0.195	Persistent product concentration / Moderate market concentration

4.3 Market retention and switching behaviour of marine exports (2005–2006 to 2014–2015)

The Markov transition probability matrix for Phase I (2005–2006 to 2014–2015) illustrates the market retention and switching behaviour of India's marine product exports (Table 3). Among the major destination markets, South East Asia (SEA) recorded the highest retention probability (0.78), followed by China (0.75) and the European Union (0.75), indicating strong market stability during the first phase. The USA exhibited moderate market retention (0.61) while transferring 26% of its export share to the European Union, suggesting partial market reallocation. In contrast, Japan showed relatively low retention (0.44), with 54% of its export share shifting to the "Others" category. Similarly, the "Others" category displayed substantial switching behaviour, with 61% of its exports redirected towards South-East Asia. Overall, the transition matrix indicates that Phase I was characterized by relatively stable trade relationships in emerging Asian markets, accompanied by gradual shifts away from traditional destinations.

The high retention probabilities observed for South-East Asia, China, and the European Union indicate the presence of stable and well-established trade relationships during the first phase of the study. In contrast, the comparatively lower retention recorded for Japan suggests a gradual decline in its importance as a destination market for Indian marine products. The substantial movement of export shares from the "Others" category towards South East Asia further highlights the increasing attractiveness of emerging Asian markets during this period. These findings are consistent with Chandrasekar *et al.* (2020), who identified South East Asia as one of the most stable destination markets for Indian marine exports based on Markov Chain analysis. Similarly, Manjunath *et al.* (2017) reported that emerging Asian economies progressively strengthened their role in India's seafood export network, gradually replacing several traditional markets. The observed transition patterns indicate an early structural reorientation of India's marine exports toward rapidly expanding regional markets, laying the foundation for the market realignment observed during the subsequent phase.

TABLE 3 Markov transition probability matrix for marine exports (Phase I: 2005–2006 to 2014–2015).

From / To	Japan	USA	European Union	China	South East Asia	Middle East	Others
Japan	**0.44**	0.00	0.00	0.01	0.00	0.00	0.54
USA	0.12	**0.61**	0.26	0.00	0.00	0.02	0.00
European Union	0.00	0.00	**0.75**	0.11	0.00	0.00	0.14
China	0.15	0.00	0.10	**0.75**	0.00	0.00	0.00
South East Asia	0.03	0.11	0.00	0.00	**0.78**	0.01	0.07
Middle East	0.06	0.14	0.00	0.00	0.32	**0.48**	0.00
Others	0.00	0.00	0.06	0.00	0.61	0.18	**0.15**

4.4 Market retention and switching behaviour of Marine Exports (2015–2016 to 2024–2025)

The Markov transition probability matrix for Phase II (2015–16 to 2024–25) reveals substantial changes in the market retention and switching behaviour of India's marine product exports (Table 4). The USA recorded the highest retention probability (0.72), indicating its position as the most stable export destination during the second phase. China maintained relatively high market retention (0.57), although a considerable proportion (35%) of its exports shifted to the USA, suggesting increasing trade interactions between these major markets. In contrast, Japan exhibited the lowest retention probability (0.12), with 67% of its export share redirected to the European Union, indicating a marked decline in market loyalty. Similarly, the European Union retained only 43% of its previous export share, while 50% shifted towards South-East Asia, reflecting changing regional trade dynamics. The transition probabilities indicate a noticeable realignment of India's marine export markets during Phase II, characterized by stronger retention in the USA and increased redistribution of exports among Asian markets.

The phase-wise comparison suggests that India's marine export structure underwent a substantial transformation after 2015, with the USA emerging as the most stable destination market while China continued to maintain a relatively strong presence despite increasing market competition. The reduced retention observed for Japan and the European Union reflects changing global demand patterns and the gradual redistribution of export shares toward emerging regional markets. These findings are consistent with Singh *et al.* (2023), who reported increasing market diversification and changing export destinations in India's agricultural trade using Markov chain analysis. Similarly, Ramadhan *et al.* (2024) highlighted that evolving global trade dynamics and increasing competitiveness have altered traditional trade relationships in fisheries exports. The observed market transitions indicate that India's export strategy should continue strengthening trade relationships with emerging markets while maintaining competitiveness and market access in established destinations through product quality improvement, value addition, and compliance with international trade standards.

TABLE 4 Markov transition probability matrix for marine exports (Phase II: 2015–2016 to 2024–2025).

From / To	Japan	USA	European Union	China	South East Asia	Middle East	Others
Japan	**0.12**	0.19	0.67	0.00	0.00	0.02	0.00
USA	0.06	**0.72**	0.04	0.12	0.00	0.04	0.02
European Union	0.00	0.00	**0.43**	0.00	0.50	0.00	0.07
China	0.01	0.35	0.03	**0.57**	0.00	0.00	0.03
South East Asia	0.04	0.28	0.00	0.19	**0.47**	0.02	0.01
Middle East	0.51	0.00	0.00	0.00	0.00	**0.49**	0.00
Others	0.00	0.00	0.33	0.00	0.00	0.00	**0.67**

4.5 Product-wise predictive value forecast (2026–2035) using ARIMA Modeling.

The ARIMA model forecasts indicate a gradual decline in India's marine export values across most product categories during the forecast period (2026–2035) (Table 5; Figure 1). Frozen shrimp, the principal contributor to marine export earnings, is projected to decrease from ₹43,201.09 crore (~US$ 4.53 billion) in 2026 to ₹36,800.59 crore (~US$ 3.86 billion) in 2035, representing a decline of 14.8%. Frozen fish and dried items are expected to experience comparatively larger declines of 25.1% and 36.6%, respectively. In contrast, frozen cuttlefish and frozen squid exhibit relatively moderate declines, suggesting comparatively stable export performance among cephalopod products. Live items, chilled items, and the "Others" category also display gradual downward trends throughout the forecast horizon. Overall, the forecasts suggest a decline of approximately 15–25% in export values across major marine product categories by 2035. The selected ARIMA models satisfied the diagnostic criteria, with stationary series confirmed through the Augmented Dickey–Fuller (ADF) test or appropriate differencing for non-stationary series. Furthermore, non-significant Ljung–Box test results ($p > 0.05$) indicate that the residuals did not exhibit significant autocorrelation, confirming the adequacy of the fitted models.

Figure 1 illustrates the forecast trajectories of India's major marine export products from 2026 to 2035 based on the fitted ARIMA models. The projected trends indicate a general decline in export values across all product categories, although the rate of decline differs among products. Frozen shrimp is expected to remain the largest contributor to export earnings throughout the forecast period despite its gradual decline, whereas frozen cuttlefish and frozen squid exhibit comparatively stable trajectories. In contrast, dried items and frozen fish display steeper downward trends, indicating greater vulnerability to future market conditions. Overall, the figure highlights the structural shift in India's marine export portfolio and underscores the need for product diversification, value addition, and market expansion to sustain export growth over the long term.

The projected decline in export values across most marine product categories suggests that historical growth trends alone may not be sufficient to sustain future export performance. Although frozen shrimp is expected to remain the dominant export commodity, its projected decline highlights the potential risks associated with increasing dependence on a single product. Similarly, the larger projected reductions in frozen fish and dried items indicate the need to improve competitiveness through value addition, product diversification, and technological innovation. These findings are consistent with Das *et al.* (2016) and Bako *et al.* (2013), who demonstrated the usefulness of ARIMA models for forecasting fisheries production and trade using historical time-series data. Likewise, Stergiou *et al.* (1997) and Gutiérrez-Estrada *et al.* (2007) reported that ARIMA models provide reliable forecasts for fisheries datasets and serve as effective tools for medium- to long-term planning. Consequently, the projected trends emphasize the importance of strengthening market diversification, promoting value-added seafood products, enhancing processing infrastructure, and expanding access to emerging international markets to improve the long-term competitiveness of India's marine export sector.

The ARIMA forecasts should be interpreted with caution because they are based on a relatively short annual time series comprising twenty observations. As the forecast horizon extends, prediction uncertainty increases, and the projected values should therefore be considered indicative of long-term trends rather than precise future outcomes. In addition, the present study reports point forecasts only and does not include forecast confidence intervals. Future research may incorporate prediction intervals and alternative forecasting approaches to better quantify uncertainty and improve the robustness of long-term export projections.

4.6 Key policy implications

The findings suggest that enhancing the long-term competitiveness of India's marine exports requires greater product and market diversification. The increasing concentration of exports in frozen shrimp highlights the importance of promoting value-added seafood products and expanding exports of underrepresented product categories. The observed changes in market transition patterns indicate the need to strengthen trade relationships with emerging markets while maintaining competitiveness in established destinations through improved product quality and compliance with international standards. Furthermore, investments in sustainable aquaculture, processing infrastructure, technological innovation, and market intelligence may enhance export resilience and support sustainable growth in India's marine export sector.

TABLE 5 Product-wise ARIMA model specifications, diagnostics, and predictive value forecasts (2026–2035) in 10 million INR (Indian Rupee).

Year / model metric	Frozen shrimp	Frozen fish	Frozen cuttle fish	Frozen squid	Dried items	Live items	Chilled items	Others
Selected ARIMA (p,d,q**)**	(2, 0,1)	(1, 0, 0)	(1, 0, 0)	(1, 0, 0)	(2,1,0)	(0, 1, 0)	(0, 1, 0)	(0, 1, 0)
ADF statistic	-16.240	-4.569	-3.526	-15.775	2.013	-1.813	-1.938	3.401
ADF test (*p*-value)	<0.001	0.0001	0.0074	<0.001	0.9987	0.3742	0.3145	1.000
AIC	396.42	327.94	287.00	305.82	294.90	215.40	234.03	292.76
BIC	401.40	330.93	289.99	308.81	297.73	216.34	234.97	293.70
Ljung-Box Q statistics	0.04	0.21	1.24	0.31	0.01	2.48	0.99	2.56
Ljung-Box (*p*-value)	0.9839	0.9161	0.5282	0.8780	0.9965	0.2891	0.6110	0.2781
2026	43201.09	4933.31	2336.89	2976.30	1916.34	441.71	643.08	4429.10
2027	42374.78	4669.96	2303.82	2842.68	1678.20	432.77	627.74	4224.42
2028	41579.89	4452.67	2272.18	2723.81	1518.63	424.27	613.46	4039.11
2029	40815.23	4273.38	2241.91	2618.07	1411.71	416.18	600.18	3871.32
2030	40079.64	4125.45	2212.94	2524.00	1340.08	408.47	587.82	3719.40
2031	39372.03	4003.39	2185.22	2440.32	1292.08	401.14	576.33	3581.86
2032	38691.32	3902.68	2158.7	2365.87	1259.92	394.16	565.63	3457.33
2033	38036.49	3816.58	2133.32	2299.65	1238.37	387.52	555.68	3344.57
2034	37406.57	3751.01	2109.03	2240.74	1223.93	381.19	546.43	3242.49
2035	36800.59	3694.43	2085.80	2188.33	1214.25	375.17	537.81	3150.06

Note: ADF statistics and *p*-values are reported for the original export series. Series with non-significant ADF test results ($p > 0.05$) were differenced until stationarity was achieved before ARIMA model estimation. Post-differencing ADF statistics are not reported.

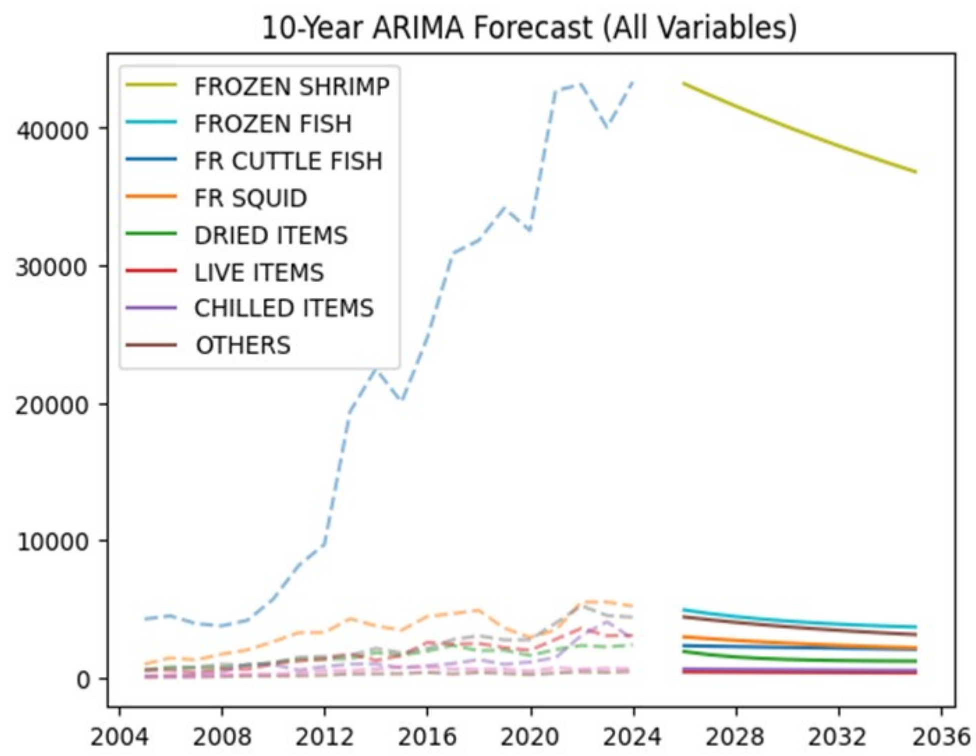

FIGURE 1 Predictive value trajectories and structural shifts in India’s marine export portfolio: ARIMA-based time-series forecasting.

4 | CONCLUSIONS

This study provides a comprehensive assessment of India's marine product exports by integrating growth, instability, concentration, market transition, and forecasting analyses. The findings indicate that although India's marine exports experienced substantial growth during the study period, the export structure has become increasingly concentrated, particularly in frozen shrimp, while notable changes have occurred in destination market retention patterns. The Markov chain analysis identified the USA as the most stable export destination during Phase II, whereas traditional markets such as Japan exhibited reduced market retention. Furthermore, the ARIMA forecasts project a gradual decline in export values across most product categories during 2026–2035, suggesting potential challenges for sustaining long-term export growth under existing trends.

The present study has several limitations. First, the ARIMA forecasts were developed using a relatively short annual time series and are presented as point forecasts without prediction intervals, which may increase forecast uncertainty over longer forecast horizons. Second, the Markov chain analysis assumes constant transition probabilities within each study phase, whereas trade relationships may evolve in response to changing economic conditions, trade policies, and geopolitical developments. Finally, the univariate ARIMA models rely solely on historical export values and do not explicitly account for external factors such as international prices, exchange rates, trade policies, climate variability, or consumer demand. Future research may employ multivariate forecasting approaches and time-varying transition probability models to provide more comprehensive assessments of India's marine export dynamics.

Overall, the findings suggest that the long-term competitiveness of India's marine exports can be strengthened through greater product diversification, expansion into emerging export markets, increased value addition, and continued investment in sustainable aquaculture and processing infrastructure. These measures may enhance export resilience and support the sustainable growth of India's marine export sector under evolving global market conditions

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CONFLICT OF INTEREST

The author declares no conflict of interest.

AUTHORS' CONTRIBUTION

M. Boopathi: Conceptualization, data collection, data analysis and writing – original draft preparation. N. Deepa: Methodology design, supervision and critical review of the manuscript. A. Rohini: Validation of analytical methods, interpretation of results and manuscript editing. S. Suganya: Data interpretation, literature review and technical inputs. R. Vasanthi: Statistical guidance, formal analysis support and review of results. T. Priyadharshan: Result writing and statistical guidance.

AI USE STATEMENT

The authors used an artificial intelligence (AI) language tool (Claude (Anthropic), Sonnet 5) solely to improve the readability, grammar, and language of the manuscript. The AI tool was not used to generate research data, perform analyses, interpret results, or develop the scientific content of this study. The authors take full responsibility for the accuracy and integrity of the manuscript.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available within the article. The secondary data used in this study were obtained from the published export statistics of the Marine Products Export Development Authority (MPEDA), Government of India, and are publicly available through the official MPEDA website [https://www.mpeda.gov.in].

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