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Original Article

Global shrimp market: examining how Indian vannamei changed the supply and market dynamics

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Abstract
India is the second largest contributor in the global shrimp export market with a 25 % share, Shrimps account for 75 % of India's seafood exports and *Penaeus vannamei* being the dominant commodity. The study analyzed the dynamics of the shrimp market by keeping the entry of *P. vannamei* as a reference point in India during 2009 and its impact on other primary shrimp producers over three decades (1988 to 2022). Results showed exports grew at a compound annual growth rate (CAGR) of only 4.5 % from 1988 to 2008, whereas they grew at 19.7 % after the introduction of *P. vannamei* (2009 to 2019). India's *P. vannamei* production affected the dominance of Thailand, China, and Indonesia in export markets. Further, Markov chain analysis was employed to assess market stability and estimate transition probabilities across export destinations, revealing instability in India's shrimp export markets during the post- *P. vannamei* period (2010–2019), along with the emergence of new markets in the post-COVID-19 phase (2010–2022). The decreasing international price of shrimp is alarming due to the supply surge and possible saturation in many export markets. Thus, India will need to strategize species diversification, commercial culture of native shrimp species to maintain the comparative advantage of India's shrimps in the international market as well as to ensure profitability for Indian shrimp farmers.

Keywords: Markov chain analysis; *Penaeus vannamei*; seafood export; shrimp market

1 | INTRODUCTION

Globally, 153 out of 195 countries trade in seafood fetching a value of US$ 128 billion in export earnings (2021–22). Crustaceans dominate the export basket, accounting for 26 % followed by fish fillets (19 %) and frozen fish (17 %). India is a predominant contributor in the global seafood export market with a 5.2% share, next only to Norway (10.4 %) and China (8.6 %). It exported 1.37 million tonnes and earned USD 7.76 billion (Rs. 57 thousand crores [Rs. 96 = 1 US$ approximately]) in foreign exchange during 2021–22 (UN Comtrade 2022). The share of seafood in agricultural exports stood at a significant 17% in 2021–22 (PIB 2022). The quantity rose by 19% while the value rose 32% over the previous year. In dollar terms, the export fetched $6.77 billion as against $6.73 billion a year ago with the frozen shrimp and fish category

continuing to dominate the export basket (MPEDA 2022). This growth indicates the potential of marine products export from India (Kumar 2004; Fathima *et al.* 2006; Sarada *et al.* 2006; Salim and Biradar 2009; Geethalakshmi 2010; Das *et al.* 2016; Rani and Kumar 2016; Singh and Krishnan 2019; Singh *et al.* 2022). The USA and South East Asia are the major import markets of India's seafood products.

Global shrimp aquaculture has evolved with region-specific species based on native availability and suitability. In Asia, shrimp farming was traditionally dominated by the giant tiger shrimp, *Penaeus monodon*, which is native to the tropical Indo-Pacific region (Fuller *et al.* 2014). In contrast, in Western countries, particularly along the Pacific coast of Latin America, aquaculture primarily focused on *Penaeus vannamei* (Pacific white shrimp or white leg shrimp), a species indigenous to the tropical eastern Pacific (Liao and Chien 2011). In the early 1990s, Asian shrimp farmers contributed more than 70 to 80% of total world production (Globefish 2018) while farmers in the West contributed less than 10% of the total. Development of SPF stocks of *P. vannamei* in the U.S. in the early 1990s (Wyban *et al.* 1992) boom the country's shrimp industry. The subsequent introduction of the domesticated non-native SPF *P. vannamei* to Asia in the late 1990s caused dramatic increases in shrimp production and rapid spread through Southeast Asia and it became the leading shrimp species contributed more than 50% of farmed shrimp production by 2004. By 2010, *P. vannamei* production accounted for 80% of total world production and was the dominant species farmed in India, China, Indonesia, and Vietnam the world's leading production countries supported with effective disease control measures in their culture farms (Wyban 2019).

Similarly, frozen shrimp continued to dominate the Indian seafood export basket, accounting for 53% in quantity and 75% in value. The total shrimp exports during 2021–22 reached 0.73 million tonnes. Among the cultured species, *P. vannamei* remained the major contributor, with exports increasing by 25% to 0.64 million tonnes, constituting about 88% of the total shrimp exports (MPEDA 2022). This was followed by *P. monodon*, whose exports grew significantly by 76% to 17,231 tonnes compared to the previous year. Japan was the primary market for black tiger shrimps. Frozen fish is the second largest export item, which contributed 16.5% in quantity and 6 % in earnings (MPEDA 2022). The entry of *P. vannamei* in the late 20s has begun to structurally transform Indian seafood production and exports. *Penaeus vannamei* dominates with 55% of all shrimp production while *P. monodon* has 9% of global share in 2019 (Fishstat 2019). Crustaceans account for 71.5% of India's total seafood export value of which shrimp alone contribute 97% (MPEDA 2022). Till the 1990s, *P. monodon* was a dominant species in culture. After WSSV disease in the late 1990s, shrimp farming declined. Since 2009, farmers have begun culturing *P. vannamei* due to its many advantages (CIBA 2022). Despite India's predominant position in the shrimp market is being eroded due to the rapid spurt in farmed shrimp production in other Asian countries *viz.*, China, Indonesia, Thailand, and Vietnam (Salim and Biradar 2009). Thus, using the 2009 entry of *P. vannamei* into India (Ashok *et al.* 2015) as the cut-off point for before-and-after analysis, the current study examines the growth pattern and dynamics of shrimp production and export of major shrimp producing countries for more than 30 years between 1988 and 2019, decade-by-decade. Further, the dynamism of Indian shrimp export in terms of gains and losses in export quantity by the major importing countries was also examined.

2 | METHODOLOGY

The trade scenario of the Indian shrimp market was compared with the global market by considering *P. vannamei* as the key species. Shrimp production in major producing countries, namely India, China, Ecuador, Thailand, Vietnam, and Indonesia, was analysed with specific reference to *P. vannamei*. Compound Annual Growth Rate (CAGR) and market share analyses were employed to assess growth trends and relative contributions across countries. Species wise shrimp production data were extracted from FAOSTAT for the period 1988–2019, while export and import data were obtained from UN Comtrade, International Trade Centre, and Marine Products Export Development Authority for the period 2000 to 2022. To ensure data reliability, values were cross-verified across these multiple sources, and only consistent figures were used for analysis.

2.1 Compound Annual Growth Rate (CAGR) analysis

The growth of Indian frozen shrimp export in terms of quantity, value, and unit value before and after the *P. vannamei* introduction to India in 2009 was estimated using Compound Annual Growth Rate (CGR) by fitting exponential trend distribution (Barrows 1996; Aswathy and Sathiadhas 2006; Salim and Biradar 2009; Sathiadhas *et al.* 2011; Anantharaju *et al.* 2016; Das *et al.* 2016; Anjum 2018; Qureshi and Krishnan 2018; Bandara *et al.* 2020; Geetha *et al.* 2020; Prabakar 2020; Nisar *et al.* 2021). Compound annual growth rate (CAGR) is a useful measure of growth over multiple periods. The growth rate accounts for the initial shrimp market price value to the ending price value in the assumption that the market price has been compounding over the period.

$$Y = ab^t e_t$$

where, Y = Quantity / value / unit value of Indian frozen shrimp export; a = Intercept; b = Regression coefficient; t = time period in years, and e = error term.

The compound growth rate was obtained for the loga-

rithmic form of the equation as:

$\ln Y = \ln a + t \ln b$

The compound growth rate (r) was computed by using the relationship:

$r = (\text{Anti Ln of } 'b' - 1) \times 100$

2.2 Market share analysis

The market share of exporters in total markets was obtained using the relation (Pavithra *et al.* 2014):

$\text{Market share} = X_{ij} / X_{wj} \times 100$

where X_{ij} is the share of i^{th} country's export in the world export of j^{th} commodity and X_{wj} is the world export of j^{th} commodity.

2.3 Markov chain analysis

In the present study, the dynamism of Indian shrimp export in terms of gains and losses in export quantity by the major importing countries from the period 2000 to 2022 was examined using the Markov chain model (Keane 1991; Kusuma and Basavaraja 2014; Qureshi and Krishnan 2018; Chandrasekar *et al.* 2020; Prabakar 2020). The transitional probability matrix obtained from Markov chain analysis would greatly explain the changes in the share of shrimp export to different countries from Indian markets. The matrix explains the market share of one that was grabbed by another competing country. It also explains the chances that the quantity of exports to a particular country gets maintained as in previous years. The higher the retention probability, the higher the loyalty of the importer. The transitional probability matrices were derived by using a new version called New Markov in Excel and by using the LPDE software version. In the study, the transitional probability matrix of shrimp trade was estimated for the period from 2000 to 2019 as evidence of market behaviour in pre-covid 19, with major importers of Indian frozen shrimp viz., USA, Viet Nam, China, Japan, United Arab Emirates (UAE), European Union (Belgium, Netherlands, and the United Kingdom), Canada and Russian Federation. Notably, the dynamics of markets for India's shrimp before (2000 to 2009) and after (2010 to 2019) the *P. vannamei* entry to India and post-covid-19 (2010 to 2022) were compared and analysed. The average export to a particular country would be considered random and following a first-order Markov model, it is given as,

$$E_{jt} = \sum_{i=1}^{r} E_{n-t} P_{ij} + e_{ij}$$

Where, E_{jt} = j^{th} country in t^{th} year, E_{it-1} = i^{th} country in (t–1) year; P_{ij} = Probable change of export share between countries i and j; e_{ij} = the error term; *n* = number of countries in trade.

The properties of the factors of the transitional probability matrix are:

$0 \le P_{ij} \le 1$

$$\sum_{i=1}^{r} P_{ij} = 1 \text{ for all i}$$

3 | RESULTS AND DISCUSSION

3.1 India's shrimp production and exports

India was the second largest exporter of shrimps with 25% share after Ecuador (45%) and is followed by Indonesia (6%), Argentina (5%), and Thailand (2.5%) during 2021-22. The USA was the most dominant crustacean import market with a 59% share followed by China (15%), EU (8%), and South East Asia (3%) during the same period. Shrimp are the most attractive crustaceans farmed around the world, and the Pacific white shrimp, *P. vannamei* is the most farmed among them in India and also globally. As the largest shellfish production system in India, shrimp farming is spread across nine maritime states and contributes more than 70% of the country's total seafood production (MPEDA 2018). Due to the availability of selectively bred, Specific Pathogen Free (SPF) seeds on the global market, the area under *P. vannamei* has expanded (FAO 2014). Studies by many (e.g. Moss 1995; Briggs *et al.* 2004; Ravichandran *et al.* 2009), the selectively bred *P. vannamei* shrimp is preferred to other shrimp species in farming since they can tolerate a wide range of salinities (0 to 45 ppt), can be stocked in large numbers, gains weight rapidly, feed on natural biofloc, has column feeding habitat, consume low levels of protein (30–35%), and they produce high meat yields (65–70%). Till the 1990s, *P. monodon* (tiger shrimp) was the dominant species of culture.

Due to frequent crop failures of black tiger shrimp, caused by the fatal white spot (WSSV) disease outbreak in the mid-1990s (CIBA 2016), India introduced SPF Pacific white shrimp in 2009 to revive the lapsing shrimp farming sector. *Penaeus vannamei*'s farming area has increased dramatically from 283 ha in 2009–10 to 100206 ha in 2019–20, and its production has also grown from 1731 tonnes to 0.7 million tonnes (Kumaran *et al.* 2017; MPEDA 2022). Also, the export-led production since 2009 has spurred the growth significantly. During past three decades, India has been exporting shrimps in frozen, chilled, and live conditions. The range of frozen shrimp exports from 1988 to 2009 was between 0.05 to 0.12 million tonnes. After the progressive *P. vannamei* entry, the quantity jumped to nearly 0.63 million tonnes during 2019 with steady growth (Figure 1).

The compound annual growth rate (CAGR) analysis showed that from 1988 to 2008 CAGR of Indian frozen shrimp exports to the world in terms of quantity, value, and unit price were only 4.68%, 4.46%, and 0.21% respectively. Further, during the decade (1998 to 2008) before *P. vannamei* entry, the CAGR in fact dropped to just 0.61%, 0.03%, and –0.57% respectively due to the disease effect. Thereafter, the entry of *P. vannamei* into India

transformed the sector with phenomenal growth in both production and export of shrimps. The CAGR of shrimp exports was 19.66 %, 16.50 %, and 2.71 % in quantity, value, and unit price terms respectively (Table 1). Thus, *P. vannamei* entry has structurally altered both supply side and demand side dynamics in shrimp markets.

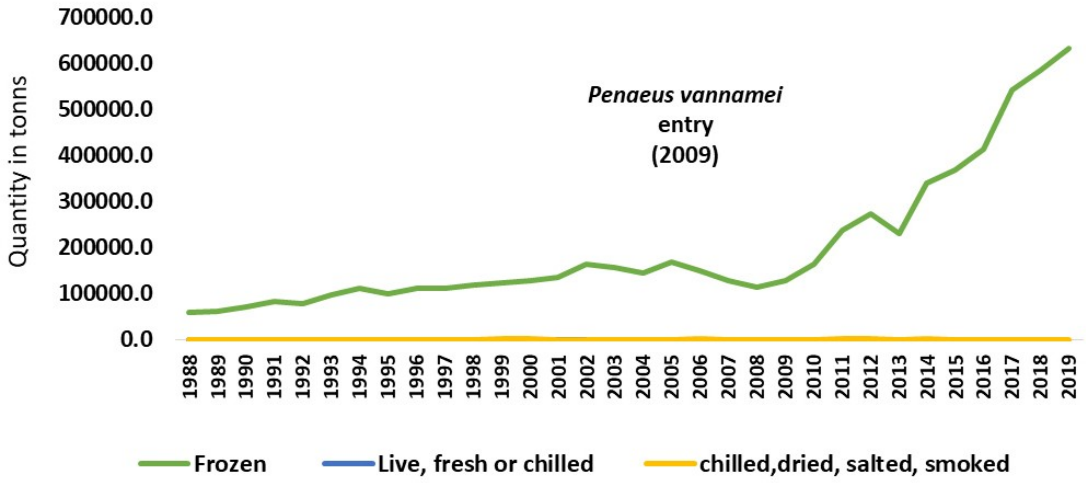

FIGURE 1 Frozen shrimp exports from India to World (1988 to 2019).

TABLE 1 Compound Growth Rate (CAGR) of Indian shrimp export to the World (1988 to 2019).

Category	Indian Shrimp exports to the world (CGR in %)		
	Quantity	Value	Unit price
Overall (1988 to 2019)	6.52	7.91	1.31
1988 to 2008	4.68	4.46	0.21
Before *Penaeus vannamei* (1998 to 2008)	0.61	0.03	–0.57
After *Penaeus vannamei* (2009 to 2019)	19.66	16.50	2.71

3.2 Global scenario of *Penaeus vannamei* and *Penaeus monodon* production

Global shrimp production was around 10 million tonnes (2019) of which *P. vannamei* alone contributed 55% (5.46 million tonnes) followed by *P. monodon* with 9.28% share (0.93 million tonnes). Among the six major shrimp producers, Ecuador had the maximum share of these two species (*P. vannamei* in particular) in total shrimp production. All major producers (India, Ecuador Thailand, China, Vietnam, and Indonesia) have witnessed increasing growth rates over the three decades, especially since 2002 when large-scale commercial *P. vannamei* production began in Asia (Figure 2). The share of *P. vannamei* in global farmed shrimp production has in creased from 0.6% in 1970 to 77.5% in 2019. Whereas, *P. monodon* had increasing growth up to the early 2000s contributing to nearly half the global shrimp production, but quickly declined thereafter resulting in only 15.5% production share by 2010 and 10.2% by 2019 as *P. vannamei* became the dominant shrimp species in almost all the major Asian shrimp producing countries (Figure 3).

3.3 Indian scenario of *Penaeus vannamei* production

In the year of introduction (2009), India produced just under 3% of global *P. vannamei*, but by the year 2019, the share had increased to 13%. Similarly, the production share of Vietnam and Indonesia have increased from 1% and 7% to 11% and 12% after a decade from 2009. During the same time, the shares of other major producers, especially the early entrants China in 1988 (Weimin 2005) and Thailand in 1998 (Panutrakul and Senanan 2021) declined from 48% and 24% to 33% and 7% (Figures 4 and 5) respectively due to disease problems. During the 1970s and 1980s *P. monodon* was the only farmed species in India, which had witnessed a drastic decline with a share of only 4.5% in 2019 due to the near total dominance of *P. vannamei* which had a 93% share by then (Figure 6).

3.4 Growth of major shrimp producers before and after the *Penaeus vannamei* entry into India

India: Although India has a long history of shrimp farming, commercial shrimp aquaculture gained only in the late 1980s. In the early 1990s, corporate firms also invested in the Indian shrimp farming sector, especially in the hatchery and feed mills. But sooner, many of these firms quit the sector unable sustain it in the wake of widespread WSSV disease outbreak in 1994 and 1995, followed by the verdict of the Supreme Court regulating the coastal aquaculture. Thereafter, the shrimp-farming recovered slowly with the area under culture increasing from 60000 ha to 145000 ha with the production of 40000 tonnes in 1991 to 100000 tonnes by early 2000's. This growth came despite the setback caused by WSSV (Chandrasekar *et al.* 2004). In the period between 1998 and 2008, *P. monodon*

production CAGR declined drastically to 0.8 % due to WSSV disease spread and low price due to consignment rejection (Geetha *et al.* 2020; Mohanty 2022), *Macrobrachium rosenbergii* production declined to 6.9% due to white muscle syndrome. During the next decade since 2009, CAGR increased tremendously to 29.8% due to the introduction of *P. vannamei*. This also has meant the decline in CAGR of the two other species namely *M. rosenbergii* (4.57%) and *P. monodon* (0.11%) during the same period. However, the production of Scampi was better from 2009 to 2019 than *P. monodon* due to the persistent demand for it in the international market (Table 2). This is supported by the study of Jayanthi and Gopal (2012) as India has emerged as the leader in the export of scampi.

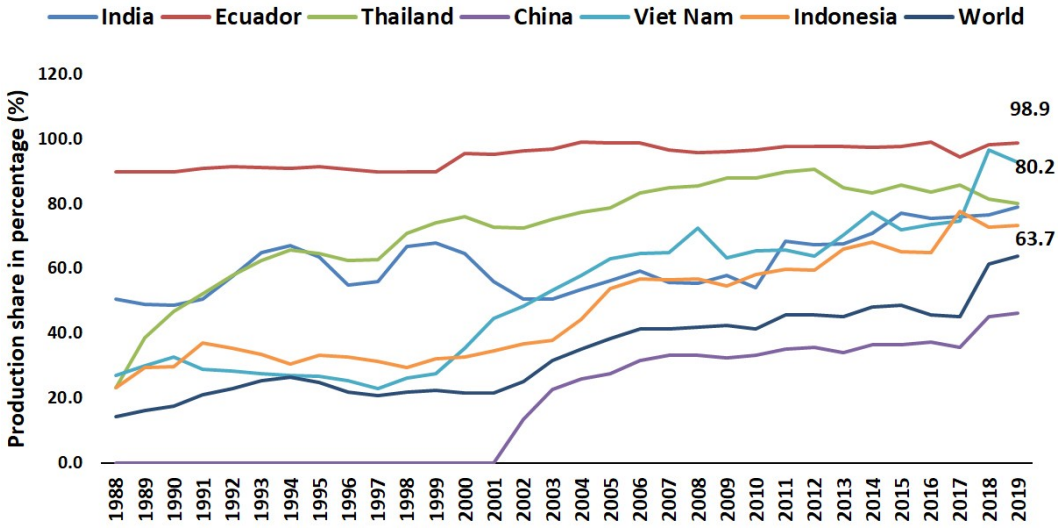

FIGURE 2 Share of *Penaeus vannamei* and *Penaeus monodon* in total shrimp production of the respective country (1988–2019).

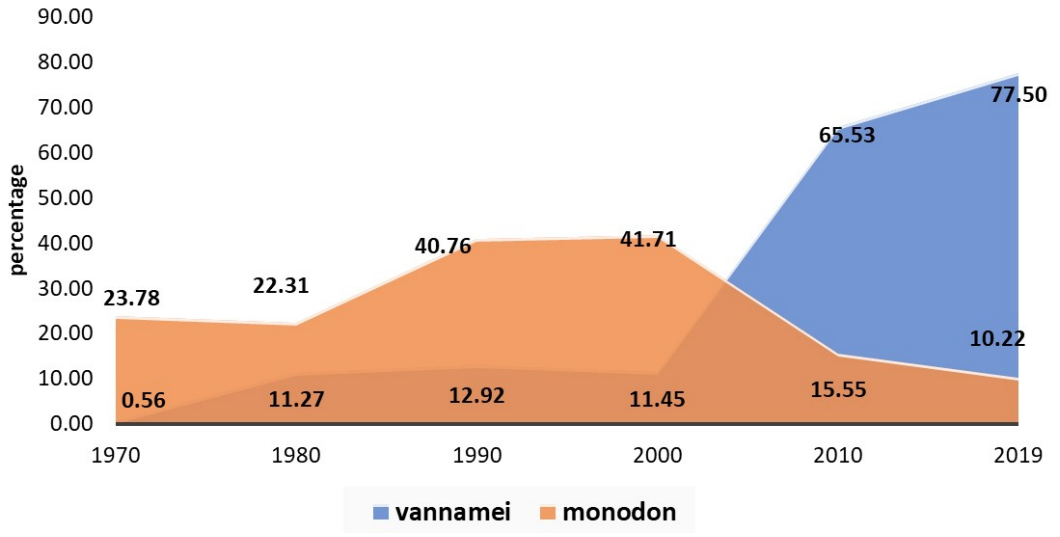

FIGURE 3 Share of *Penaeus vannamei* and *Penaeus monodon* in total cultured shrimp production in the world (1970 to 2019).

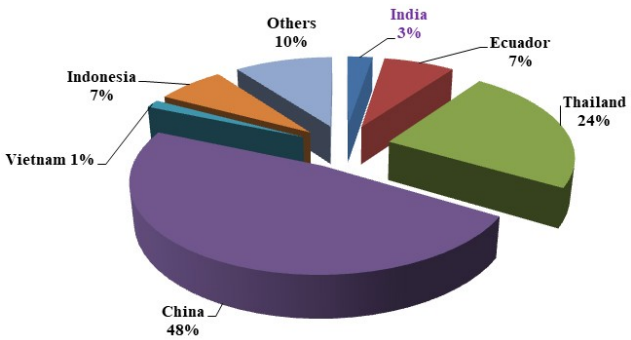

FIGURE 4 Global Share of major *Penaeus vannamei* producers in 2009.

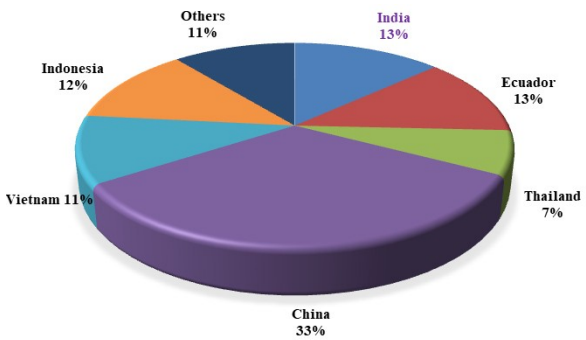

FIGURE 5 Global share of major *Penaeus vannamei* producers in 2019.

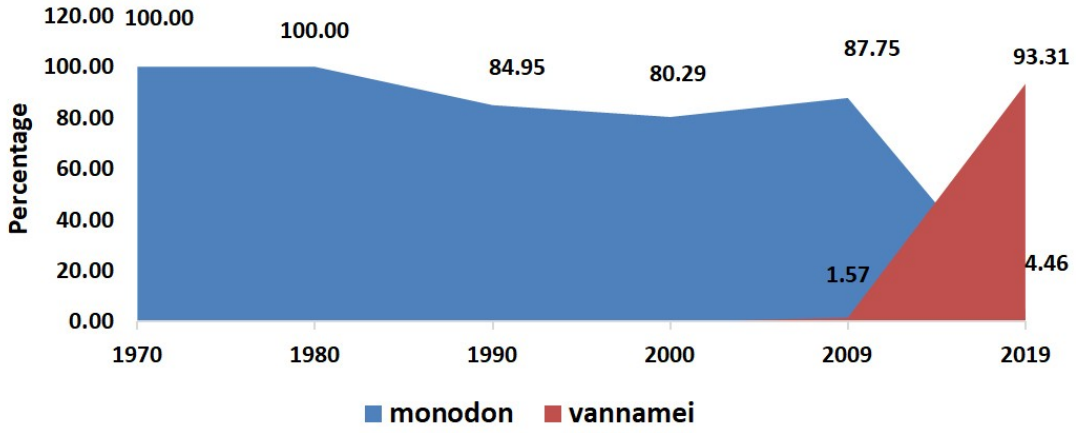

FIGURE 6 Share of *Penaeus vannamei* and *Penaeus monodon* to the total cultured shrimp production (decade wise 1970 to 2019) in India.

TABLE 2 Decade-wise compound growth rate (CGR) of major shrimp producers before and after the *Penaeus vannamei* entry into India.

Species / Years	Overall (1988 -2019)	1988-98	1999 to 2008	2009 to 2019
India				
Total shrimp production	4.58	6.99	2.15	10.83
Macrobrachium rosenbergii (Scampi)	15.21	28.76	6.95	4.57
Penaeus monodon	1.87	9.87	0.80	0.11
Penaeus vannamei				29.84
Ecuador				
Total shrimp production	6.27	5.15	11.32	12.40
Penaeus vannamei	6.62	5.21	11.94	12.54
Thailand				
Total shrimp production	2.22	7.41	6.68	–4.89
Penaeus monodon	-11.71	10.72	–38.84	6.56
Penaeus merguiencis	–3.62	–0.69	–11.12	–4.30
Penaeus vannamei			41.43	–4.97
Macrobrachium rosenbergii (Scampi)	4.90	–3.20	9.20	1.79
China				
Total shrimp production	9.08	5.35	15.53	1.94
Penaeus monodon	2.47	-	-	2.47
Penaeus chinensis	7.57	6.18	1.91	5.95
Penaeus vannamei			29.23	5.27
Vietnam				
Total shrimp production	9.22	7.26	14.39	7.30
Penaeus monodon	10.10	6.74	18.33	2.13
Penaeus merguiencis	2.04	6.73	3.06	–12.19
Penaeus vannamei			35.57	32.01
Indonesia				
Total shrimp production	5.05	4.31	5.97	6.38
Penaeus monodon	4.11	5.66	3.44	13.11
Penaeus merguiencis	1.07	4.26	0.96	-4.07
Penaeus vannamei			37.60	2.34
World				
Total shrimp production	5.00	4.99	6.86	3.10
Penaeus monodon	2.53	9.32	0.85	1.03
Penaeus vannamei	16.85	8.22	41.64	8.07

Ecuador: Ecuador started farming shrimp in 1969 (Marcillo 2017). *Penaeus vannamei* is the only shrimp species under commercial culture due to its nativity, geographical location, and climate (Wyban 2019). It has witnessed a persistent increase in its growth over all three decades with the decadal CGR ranging from 5.21% to 12.54%, taking advantage of the USA and European market demands, and the favourable climate that reduces disease incidence. Despite the country facing WSSV spread in 1999, it could revive the farming with the technological interventions especially the selective breeding program to produce a more tolerant strain. This has now come to be known as the Ecuador model (Wyban 2019). Another key factor for Ecuador's success was that unlike India, exporters are largely integrators rather than individual traders, and thus could obtain the economies of scale as well as efficient maintenance of quality standards. Ecuador also banned the export and import of *P. vannamei* brooders to ensure biosecurity and to maintain the competitive edge (Yellanki 2023). Thus, Ecuador's growth rate was not or could not be affected by India's entry into production and export of *P. vannamei* in a way it affected other Asian producers.

Thailand: Thailand started shrimp farming in the 1970s with the locally available *P. monodon* species (Rosenberry 2016). By the early 1990s, Thailand became the world's leading producer and exporter of *P. monodon*. The research and development as well as extension support provided by the Department of Fisheries on one hand, and the strong market focus of the export and processing industry kept the compound annual growth rate high at 10.72% during 1988 to 1998. However, during the late 1990s, as in India, disease problems increased the risks and slowed the shrimp industry's expansion in Thailand as well. Yellow head virus, WSSV, and Monodon Slow Growth Syndrome (MSGS) severely impacted the *P. monodon* industry (Wyban 2009) and led to its negative compound growth of –38.84%, while the CGR of *Penaeus merguiencis* also went down to –11.12% during 1998 to 2008. This perhaps produced the opportunity for the entry of SPF *P. vannamei* into Thailand. As the table above shows, the *P. vannamei* production witnessed a miracle growth with CGR of 41.43% during 1999 to 2008, propelling Thailand to become the largest supplier of white shrimp in Asia (Wyban 2007). The key factor of Thailand's success with *P. vannamei* was their controlled brood stock import to ensure true and quality stocks. In the subsequent years, however, India's entry and high CGR of *P. vannamei* dented Thailand's market share as its production grew at negative growth rate of –4.97% during 2009 to 2019. We could see Thailand's focus on reviving *P. monodon* (CGR 6.6%) to sustain its focus on export of high unit value products and counter loss in market share of *P. vannamei* to other countries especially India and Ecuador (Table 2).

China: China has been one of the world's largest shrimp producers since 1988 (Biao and Kaijin 2007) at the time of the *P. vannamei* introduction (Geetha *et al.* 2020). Before 1995, *P. chinensis* was the most important farmed shrimp species in China due to its nativity (Wang *et al.* 2006). After the outbreak of white spot syndrome in 1993 (Xianhong *et al.* 2015), the production of its native species *Penaeus chinensis* got affected severely. Thus, its CGR of 6.18% seen during 1988–98 declined to 1.91% during 1999–2008. As in Thailand, introduction of *P. vannamei* rescued the China's shrimp industry as its production witnessed a CGR of 29.23% during the same period. In the meantime, China attempted to develop new strains of native *P. chinensis* for faster growth and greater disease resistance on priority (Xianhong *et al.* 2015) and that seems to have paid off subsequently, as seen from its comeback with a growth rate of 5.95% during 2009 to 2019. However, *P. vannamei* production CGR declined to 5.27 %, owing mainly to the higher supply from India and Ecuador entering the export markets.

Vietnam: In Vietnam, shrimp seed production started in 1988 with the local species called *Penaeus merguiensis* and *Penaeus indicus*, and then shifted mostly to giant tiger shrimp by 1997 (Rosenberry 2015). This was evident from 18.33% compound growth rate of *P. monodon* during the decade of 1999 to 2008. The first WSSV outbreaks occurred in 1993 (Zwart *et al.* 2010) in Vietnam and affected *P. merguiensis* production the most. Interestingly, *P. monodon* production still grew at 15% during this decade unlike the other WSSV affected countries like India, Thailand and China. Vietnam also introduced the Pacific white shrimp in 2000, like China (Geetha *et al.* 2020). During the last two decades since then, Vietnam witnessed perhaps the highest growth rate in *P. vannamei* with a CGR of 35.57% during 1999 to 2008 and 32% during 2009–19. This shows that like Ecuador, Vietnam also was not affected by the rise in production and export of *P. vannamei* in India. However, this came at the cost of slower (3.06%) to negative CGR (–12.19%) of *P. merguiencis* during 1999 to 2008 and 2009 to 2019 respectively. *Penaeus monodon* production also saw a sluggish CGR of 2.13 % during 2009 to 2019 (Table 2). What contributed to the success and sustenance of *P. vannamei* industry in Vietnam post India's entry remains unexplained except that Vietnam created a very enabling policy and regulatory environment with a strong focus on FDI-led vertical integration from production to processing to export exports.

Indonesia: The shrimp-farming industry developed strongly in Indonesia in the late 1980s with two of its local species namely *P. monodon* and *P. merguiencis* (Taw 2015; Wiradana *et al.* 2020). Due to the WSSV outbreak in

1996 (Seafood Source 2010) production of native species dropped heavily almost by the year 2000 (Taukhid *et al.* 2008). Subsequently, the growth rate declined 0.96% during 1999 to 2008 for *P. merguiencis* and 3.44% for *P. monodon* from the earlier respective CGR of 4.26% and 5.66% obtained during 1988 to 1998. Pacific white shrimp was introduced in Indonesia in 2001 and the culture spread throughout the country by 2006 (Taukhid *et al.* 2008). This brought the troubled shrimp industry back with an impressive growth rate of 37.60% during the decade of 1999 to 2008. Indonesia, along with China and Vietnam, has witnessed tremendous growth in *P. vannamei* production during this decade. However, like China, the growth rate in *P. vannamei* could not be sustained during the last decade (2009–19) as its CGR slipped to 2.34% (Table 2), perhaps due to the increasing supply and competition from India and Ecuador. While the dominance of *P. vannamei* impacted negatively the production of native species especially the *P. merguiencis* (–4.07%). However, *P. monodon* showed a comeback during the last decade with the CGR of 13.11 % indicating a renewed focus on it that captured the space left by declining CGR of *P. vannamei* in recent years.

Whole World: Globally, the growth of *P. vannamei* production grew steeply during 1998 to 2008 with a CGR of 41.64%, it became more moderate and stable with an overall CGR of 8.07% during the last two decades from 2009–2017. On the contrary, the production of *P. monodon* attained a plateau and the growth become marginal with CGR of 1.03% after 2008 compared to the significant 9.3% CGR witnessed during the pre-*P. vannamei* period from 1988 to 1998. Given the production instability across many major Asian producers, the global growth was more stable as the decline in one country was met with an increased supply from the other country in the medium to long term, especially with the *P. vannamei*. It is supported by Ravisankar *et al.* (2005) which indicated higher growth rate in shrimp culture led to higher instability in production in many Asian countries due to risks associated with environmental complexities and disease incidences. At the same time, when the combined production of all shrimp species across the globe is concerned, the CGR has remained almost robust at 5% during each of the last three decades catering to the growing demand (Table 2). This also indicates that the global shrimp market demand remained robust to absorb the increased supply from the major producers or rather the increased supply was itself a result of increased demand.

3.5 Dynamics of the market before and after *Penaeus vannamei* into India through Markov Chain Analysis (MCA)

The dynamic nature of trade patterns *i.e.* the gains and losses in India's market share was examined using the Markov chain model. It provides the probability of the importing country continuing to import similar quantum of frozen shrimp from India in the future, considering the past trend in market share of competing suppliers (exporters) in a given import market. The major importers of India's shrimps namely USA, Vietnam, China, Japan, UAE, EU, Canada, and Russia were considered in the study. It is evident from the matrix (Table 3) that before *P. vannamei* came to India that is from 2000 to 2009 the USA and Japan were found to be the stable markets for Indian shrimp with a retention share of 83% and 80% respectively from the previous year. This is in conformity with earlier studies by Qureshi and Krishnan (2018) and Prabakar (2020). While European Union held a retention share of 30%, indicating the potential loss of market share for India in Europe, a higher retention rate at 55% for rest of the countries underscored the emergence of new markets for Indian shrimp.

TABLE 3 Markov's transitional probability matrix for market-wise shrimp export from India (2000 to 2009) before the introduction of *Penaeus vannamei*.

Countries	USA	Vietnam	China	Japan	UAE	EU	Canada	Russia	Others
USA	**0.826**	0.044	0.003	0.025	0	0.059	0.043	0	0
Vietnam	0	**0.018**	0.213	0.396	0.053	0.320	0	0.001	0
China	0.870	0	**0.130**	0	0	0	0	0	0
Japan	0.116	0	0.033	**0.799**	0.005	0	0	0	0.047
UAE	0	0	0	0.042	**0**	0	0	0	0.958
EU	0	0	0	0.174	0.147	**0.292**	0.126	0.005	0.255
Canada	0	0	0	0	0	1.000	**0**	0	0
Russia	0	0	0	0	0	1.000	0	**0**	0
Others	0	0	0	0	0.046	0.403	0	0	**0.551**

The entry of *P. vannamei* into India and its emergence as a major producer and exporter (Table 4), changed the international shrimp market dynamics considerably. During this decade (2010–2019), most of the major importing markets namely USA, Japan, and Vietnam, became unstable markets for Indian shrimp with retention share of 62%, 64%, and 55% respectively, raising a serious concern for India. The relatively minor mar-

kets like UAE, Canada, and Russia had no retention capacity for Indian shrimps showing that the supply of *P. vannamei* from other major Asian producers *viz.*, Indonesia, Thailand, and Ecuador created a competing environment for Indian producers. EU and China's retention behavior slightly improved to 36% and 17% respectively giving some relief.

In post-Covid-19 scenario (Table 5), China's retention share for Indian shrimp has improved to 89% while the conventional and major markets like USA (78%), Vietnam (69%), and Japan (58%) also showed improvements in retention rate. The share of the EU and other markets however declined to 30% and 41% respectively. Russia became an emerging importer of Indian shrimp with a share of 17% during the post Covid-19 period. And there is no assurance of import of India's shrimp by the markets *viz.*, UAE and Canada in coming years.

TABLE 4 Markov's transitional probability matrix for market-wise shrimp export from India (2010 to 2019) after the introduction of *Penaeus vannamei*.

Countries	USA	Vietnam	China	Japan	UAE	EU	Canada	Russia	Others
USA	**0.616**	0.068	0.013	0.052	0.070	0.085	0.025	0.026	0.045
Vietnam	0.351	**0.549**	0.083	0	0.010	0	0	0.007	0
China	0	0	**0.167**	0	0	0	0	0.079	0.754
Japan	0	0	0	**0.641**	0.026	0.127	0.075	0	0.131
UAE	1.000	0	0	0	**0**	0	0	0	0
EU	0.601	0	0	0	0.043	**0.357**	0	0	0
Canada	0	0	0	0	0	0	**0**	0	1.000
Russia	0.290	0.676	0	0	0	0.034	0	**0**	0
Others	0	0.207	0	0.038	0	0.125	0.072	0	**0.558**

TABLE 5 Markov's transitional probability matrix for market-wise shrimp export from India (2010 to 2022) during the post Covid-19 period.

Countries	USA	Vietnam	China	Japan	UAE	EU	Canada	Russia	Others
USA	**0.785**	0.013	0	0.038	0.029	0.052	0.032	0.027	0.024
Vietnam	0.182	**0.689**	0	0.023	0.071	0.035	0	0	0
China	0.075	0	**0.889**	0	0	0	0.003	0.033	0
Japan	0	0	0	**0.581**	0.081	0.167	0.078	0	0.093
UAE	1.000	0	0	0	**0.000**	0	0	0	0
EU	0.292	0.061	0	0	0	**0.298**	0	0	0.349
Canada	0	0	0	0	0	0	**0**	0	1.000
Russia	0	0	0.620	0	0	0	0	**0.170**	0.210
Others	0	0.233	0	0.102	0.029	0.172	0.056	0	**0.409**

The matrix from Table 6 indicates, although the USA is a primary importer of India's shrimp, its retention share decreased after the increased *P. vannamei* supply globally. USA has diversified its sources of supply that now includes Ecuador, Indonesia, Mexico, Vietnam, Argentina, Thailand, Peru, and Guyana other than India. In recent years, Ecuador has become the largest supplier of shrimp in the USA replacing India with a retention share of 94% as against India's 81%. Thailand, Argentina, Mexico, Peru, and Indonesia have become more competitive in USA with a retention share of 69%, 53%, 50%, 49%, and 46% respectively. Vietnam has a very minimal retention share of 21% since Japan and China are major importers of Vietnamese shrimp along with the USA. One of the major reasons that India is losing its retention share in USA to Ecuador, Peru, and Guyana could be the price advantage aided by shorter distance of USA market for these countries. These countries sold their shrimp at an average unit price (USD kg^{-1}) of 7.7, 8.6, and 5.8 respectively during 2010 to 2022 which was lower than India's unit price of USD 10 kg^{-1}.

4 | CONCLUSIONS

The study reveals that the introduction of *P. vannamei* in India led to a fourfold increase in shrimp production and exports, significantly transforming the country's position in the global shrimp market. However, its dominance resulted in a substantial decline in the export share of native species such as *P. monodon* and *M. rosenbergii*, indicating a structural shift toward monoculture-based production. India's rapid expansion reduced the relative dominance of traditional exporters like Thailand, China, and Indonesia, while Vietnam remained competitive due to its simultaneous adoption of *P. vannamei*. Meanwhile, Ecuador sustained consistent growth by strategically leveraging major markets such as the USA, China, and the EU. The findings further highlight increasing market instability, with shifts in major importing destinations and the

emergence of new markets such as China and Russia in the post-pandemic period. This volatility, coupled with supply surges, has contributed to declining international prices, posing significant economic risks for Indian shrimp farmers.

From a policy and industry perspective, the study emphasizes the need for a more resilient and diversified aquaculture strategy. Lessons from countries that mitigated disease impacts such as White Spot Syndrome Virus by promoting native species like *P. chinensis* and *P. monodon* highlight the importance of reducing monoculture risks. Accordingly, India should prioritize the strengthening of domestic seed production systems with SPF stocks of *P. monodon*, and reduce dependence on imported broodstock. Promoting the commercial culture of resilient native species such as *P. indicus* and *P. semisulcatus* can further enhance sustainability and farmer income stability. In addition, export diversification through value-added products and expansion into high-value finfish species like groupers, seabass, pompano, and snappers can improve trade resilience. Overall, a balanced strategy integrating species diversification, market expansion, and sustainability-oriented practices is essential to ensure the long-term stability and competitiveness of India's shrimp sector.

TABLE 6 Markov's transitional probability matrix for market-wise shrimp export to USA (2010 to 2022).

Countries	India	Ecuador	Indonesia	Mexico	Vietnam	Argentina	Thailand	Peru	Guyana	Others
India	**0.808**	0.012	0.127	0.020	0	0.033	0	0	0	0
Ecuador	0	**0.945**	0	0	0.055	0	0	0	0	0
Indonesia	0.418	0	**0.457**	0	0.124	0	0	0	0	0
Mexico	0	0.119	0.096	**0.505**	0	0	0.174	0.003	0.003	0.101
Vietnam	0	0	0.523	0.246	**0.212**	0	0.006	0.013	0	0
Argentina	0	0.472	0	0	0	**0.528**	0	0	0	0
Thailand	0	0.029	0.116	0	0	0	**0.689**	0.007	0.017	0.141
Peru	0.101	0	0	0	0	0	0	**0.490**	0.409	0
Guyana	0	0	0.405	0.258	0	0	0	0.337	**0.000**	0
Others	0	0	0	0	0.378	0	0	0.042	0	**0.580**

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CONFLICT OF INTEREST

The author declares no conflict of interest.

AUTHORS' CONTRIBUTION

V. Gomathy: data collection, methodology, visualisation, writing original draft; Ananthan P.S: conceptualisation, supervision, investigation and review and editing; C. Sundaramoorthy: methodology, data source; Nikita Gopal: review and editing.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on a reasonable request from the corresponding author.

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