International Journal of Education and Life Sciences (IJELS)
Vol. 3, No. 11 November, 2025: 3061-3084

From Capture Variability to Cultivation Necessity: A Systematic Review on Crustacean Diversity and Sustainable Penaeid Shrimp Aquaculture Development (2015–2025)

Yudiana Jasmanindar[1]*, Priyo Santoso[2], Immaria Fransira[3], Franchy Ch. Liufeto[4]
Nusa Cendana University
Corresponding Author: Yudiana Jasmanindar: yudiana@staf.undana.ac.id

A R T I C L E I N F O

Keywords: Market, Shrimp, Aquaculture, Crustacean, Production

Received : 20, September
Revised : 25, October
Accepted: 20, November

A B S T R A C T

Crustaceans are a highly economically valuable aquatic resource with important contributions to aquatic ecology, food security, and international trade. However, crustacean catches, especially penaeid shrimp, show high variability due to habitat degradation, catch pressure, and environmental changes. This condition is driving a shift from the exploitation of natural stocks to cultivation as a strategy to ensure the availability of supply and meet the growing demands of the global market. This article presents a *systematic literature review* (SLR) of scientific publications for the period 2015–2025, with reference to the PRISMA 2020 guidelines. Data were obtained from international databases (Scopus, Web of Science, Google Scholar) as well as additional literature from regional organizations (FAO, SEAFDEC, KKP). The results of the survey revealed that: (1) the diversity of crustaceans in the tropics is still high but the catch is unstable; (2) penaeid shrimp is the main commodity that has undergone a significant shift from capture to cultivation; (3) non-antibiotic strategies such as probiotics, biofloc, phytotherapy, and *integrated multi-trophic aquaculture* (IMTA) have been proven to support shrimp health and reduce environmental impacts. This study emphasizes the importance of integrating aspects of biodiversity, aquaculture technology, and ecosystem approaches in the development of sustainable penaeid shrimp aquaculture.

DOI: https://doi.org/10.59890/ijels.v3i11.212
https://ntlmultitechpublisher.my.id/index.php/ijels

INTRODUCTION

Crustaceans are one of the groups of aquatic biota that have high economic value and play an important role in maintaining the balance of aquatic ecosystems (Behringer & Duermit-Moreau, 2021). Types of crustaceans such as penaeid shrimp, crab (*Portunus pelagicus*), mangrove crab (*Scylla spp.*), and mantis shrimp (*Stomatopoda*) have long been used as a source of food and commodities for international trade (Emerenciano et al., 2022; FAO, 2022). In the last decade, global demand for crustaceans, particularly penaeid shrimp, has shown a significant increase in line with the growth of the human population and consumer preference for high-nutritional seafood (Apine et al., 2023; Lee et al., 2022; Monsalve & Quiroga, 2022; Syafaat et al., 2021).

Among the different types of crustaceans, the penaeid shrimp occupies a very strategic position. Species such as *Penaeus monodon* (tiger shrimp) and *Litopenaeus vannamei* (vannamei shrimp) are major commodities in both capture and aquaculture fisheries (Albalat et al., 2022; Asmild et al., 2024). Initially, the global supply of penaeid shrimp relied heavily on wild catches, but high variability of natural stocks, degradation of coastal habitats, and overfishing pressures caused catches to become unstable (Simtoe et al., 2025). This has led to the development of penaeid shrimp aquaculture since the end of the 20th century, which is now one of the fastest-growing subsectors in the global aquaculture industry (FAO, 2020; Pauly & Zeller, 2017).

As the human population increases and consumption patterns shift, the global market demand for penaeid shrimp continues to show a positive trend (Balmer, 2024; Grandviewresearch, 2023). According to FAO (2022) shrimp is one of the fishery products with the highest international trade value, accounting for more than 15% of the world's export value of fishery products. Southeast Asia is a major production hub, with countries such as Thailand, Vietnam, Indonesia, and the Philippines contributing significantly in both exports and domestic consumption. In Indonesia, shrimp ranks first in fishery export commodities with a foreign exchange contribution of more than USD 2 billion per year, making it a priority in sustainable production enhancement programs (KKP, 2023).

The trend of increasing market demand, both at the regional and global levels, presents both opportunities and challenges. On the one hand, this opportunity encourages the development of more intensive and standardized penaeid shrimp cultivation, but on the other hand, new problems arise, such as environmental degradation, price fluctuations, and the threat of recurrent diseases (Ahmed, 2025; Boonyawiwat et al., 2017; Purnomo et al., 2022). Therefore, it is important to understand the dynamics between crustacean diversity, aquaculture needs, and sustainable management strategies, so that the aquaculture industry can continue to meet market needs without sacrificing ecological and social aspects.

LITERATURE REVIEW

Crustacean Diversity and Its Significance

Crustaceans are one of the groups of aquatic invertebrates that play an important role in coastal and high-sea ecosystems. Ecologically, they play a role in maintaining the balance of the trophic chain, while economically, they are the main commodity in global fisheries trade (FAO, 2022) Various types of crustaceans have high commercial value, such as mangrove crabs (*Scylla* spp.), crabs (*Portunus pelagicus*), and mantis shrimp (Stomatopoda), but penaeid shrimp occupy a dominant position in both domestic consumption and export markets (Pauly & Zeller, 2017).

The biodiversity of crustaceans in the tropics, including Southeast Asia, is still relatively high. However, habitat degradation, such as mangrove conversion, pollution, and climate change, has an impact on the sustainability of wild populations. Some studies show a significant decline in catch yields in the last two decades, giving rise to the urgency to shift the focus from harvest exploitation to aquaculture development (Bogmans & van Soest, 2022; Costello et al., 2022; FAO, 2022; Gephart et al., 2020).

Variability of Penaeid Shrimp Catch

Historically, the world's supply of penaeid shrimp was mostly met through capture fisheries. However, population fluctuations due to overfishing, climatic variability, and natural reproductive cycles cause catch instability (Chen et al., 2025; Schlenker et al., 2023). In Indonesia, catches of tiger shrimp (*Penaeus monodon*) and crabs have shown a downward trend since the early 2000s (Badan Pusat Statistik, 2022; FAO (Food and Agriculture Organization), 2018; Wiyono & Ihsan, 2018; Yi et al., 2018). This variability of catches poses a risk to marine food security and global supply chains. Supply instability also has a direct impact on market prices, thus giving rise to the urgency to find a more controlled and sustainable production alternative, namely through aquaculture systems.

Studies have shown that variability in catches (due to environmental fluctuations, catch pressures, and habitat degradation) has a direct impact on marine food security and global supply chain stability. Globally, capture fisheries productivity tends to stagnate and even decline in some regions in line with historical ocean warming, so that the supply capacity of wild stocks becomes increasingly uncertain from year to year (Free et al., 2019). This uncertainty magnifies supply risks, both in volume, quality, and continuity of supply, which in turn disrupts the availability of aquatic proteins for domestic and export markets. The latest edition of the FAO report also confirms that, although the world's fisheries and aquaculture production reached new records, the contribution of catches is no longer the main engine of growth. This trend underscores the limitations of capturing resources to sustain the ever-increasing demand (FAO, 2024).

The downstream implication of supply variability is price volatility in the seafood market. The fisheries economics literature finds that supply uncertainty from capture fisheries tends to increase price volatility, while more stable aquaculture supplies have the potential to dampen such turmoil. A number of empirical analyses show lower volatility in cultivated commodities than in catches, and there is *a spillover* of volatility between market segments during supply shocks (Dahl & Jonsson, 2015). In shrimp commodities, the dynamics of global trade 2024–2025 also show adjustments in imports and trade values that are sensitive to changes in supply and demand, confirming the urgency of alternative production that is more controlled and sustainable through aquaculture systems (Dahl & Jonsson, 2018). Aquaculture development (including penitentiary) is a key strategy to stabilize supply while meeting long-term demand.

Transition from Capture Fisheries to Aquaculture

The shift from capture exploitation to penaeid shrimp farming is one of the important transformations in the global fisheries sector. The paradigm shift in global fisheries is reflected in the acceleration of aquaculture production growth, replacing stagnant growth in capture fisheries as the main source of aquatic food supply (Naylor et al., 2021). Sistem budidaya udang penaeid secara khusus diintroduksi untuk menjawab keterbatasan stok liar dengan menawarkan kontrol produksi yang lebih tinggi, efisiensi pertumbuhan, dan mitigasi risiko terhadap fluktuasi tangkapan (FAO, 2022). Several studies show that vannamei shrimp (*L. vannamei*) is the main commodity that is widely developed because it grows quickly, is tolerant of varied environmental conditions, and is more resistant to diseases (Shi et al., 2024; Z. Zhu et al., 2024).

In addition to penaeid shrimp cultivation, the opportunity to diversify crustacean cultivation is quite strong in the mangrove crab (*Scylla* spp.) commodity, which shows prospects through *fattening*, soft crab production, and improvement of hatchery techniques, latest on technical advances, as well as obstacles that need to be addressed to increase business scale (Liew et al., 2024). Meanwhile, tropical rock lobster (*Panulirus* spp.), the availability of puerulus (natural seeds), and market demand are of high value in Indonesia. This encourages the development of *marine cage-based grow-out* systems, supported by scientific evidence regarding potential seed sources and economic technical feasibility for aquaculture expansion (Priyambodo et al., 2020). Crab/blue swimming crab (*Portunus pelagicus*), a recent sectoral study in the Philippines shows room for strengthening value chains through seed management, product quality improvement, and upstream-downstream integration; these findings open up opportunities for hatchery-nursery innovation and integrated aquaculture schemes to complement capture fisheries (Yap et al., 2020)

Penaeid shrimp dominate crustacean cultivation activities. This is because, especially vannamei shrimp (*L. vannamei*) has the ability to tolerate a wide range of salinity (0–40‰), a faster growth rate, and a more stable performance in intensive production than tiger shrimp (*Penaeus monodon*) and other crustaceans (Emerenciano et al., 2022). At the global level, the production of penaeid shrimp cultivation continues to show rapid growth, one of which is revealed that the production of farmed shrimp has increased by more than 86% in the last decade (Emerenciano et al., 2022). In Indonesia, the government targets national shrimp production to reach 2 million tons by 2024 as part of a strategy to increase exports and marine food security (KKP, 2023).

Challenges in Penaeid Shrimp Culture.

Although the production of penaeid shrimp through aquaculture has soared, the sector continues to face major challenges in the form of viral diseases such as White Spot Syndrome Virus (WSSV) and *Early Mortality Syndrome* (EMS), which have led to mass deaths and significant economic losses in many aquaculture areas (Kim et al., 2023). Mass mortality in shrimp farming is often also associated with pathogenic bacterial infections, especially the genus *Vibrio*, which causes vibriosis disease and Acute Hepatopancreatic Necrosis Disease (AHPND), with mortality that can reach 70–100% within 20–30 days post-stocking (Bhassu et al., 2024; Herawati et al., 2025; V. Kumar et al., 2021). Microbial ecology studies on ponds show that when water quality deteriorates (e.g., decreased pH, excess organics), opportunistic communities such as *Vibrio*, *Alteromonas*, and *Pseudoalteromonas* can dominate and trigger disease outbreaks and mass mortality in farmed shrimp (Alfiansah et al., 2020).

In addition, the intensive use of antibiotics and chemicals in shrimp farming has triggered increased microbial resistance and contamination of resistance genes in aquaculture water systems, giving rise to long-term food security and ecological health issues (Thornber, Verner-Jeffreys, et al., 2020). The excessive use of antibiotics and chemicals in shrimp farming systems has the potential to trigger increased microbial resistance, making pathogenic bacteria difficult to control and affecting the effectiveness of therapy. Several studies show that the pollution of estuaries and oceans by antibiotics and the presence of antibiotic-resistant genes are caused by aquaculture activities that use antibiotics (Kemp et al., 2021; Zheng et al., 2021).

The environmental impacts of shrimp farming include eutrophication and organic pollution due to solid waste and nutrients, which worsen water quality, lower dissolved oxygen, and trigger overgrowth of algae (de Lacerda et al., 2021). The conversion of mangrove land into shrimp ponds has led to the loss of the ecological function of mangroves as pollutant filters and shoreline protection, as well as damaging coastal biodiversity (Macusi et al., 2022). Socially and economically, smallholder farmers often struggle to access modern technology and global markets, leaving them lagging in competition and facing economic risks due to aquaculture failures (Macusi et al., 2022). The impacts and obstacles of shrimp farming activities indicate the need for more sustainable aquaculture innovation and management (Villarreal, 2023).

Sustainable Strategy in Penaeid Shrimp Farming

A variety of non-antibiotic strategies have been developed to strengthen the health resilience of shrimp while minimizing negative environmental impacts. Research on the application of probiotics and prebiotics has been shown to stabilize the gut microbiota of shrimp and increase the immune response to pathogens (Amiin et al., 2023). Biofloc systems utilize nutrient recycling and reduce organic waste by streamlining water and feed use (Raza et al., 2024).

The phytotherapy and natural immunostimulant approach, as well as multi-trophic integration (IMTA*)*, expands the diversification of the aquaculture ecosystem through the use of bioactive compounds and synergies between organisms in the cultivation system (Jasmanindar et al., 2018; Li et al., 2023).

The implementation of this strategy has shown positive results in reducing mortality, improving growth performance, and improving production efficiency, although scalability and adoption by smallholder farmers remain a challenge. One of the implementations of non-antibiotic strategies in the form of the use of bioflocs and probiotics has been shown to reduce mortality in *L. vannamei* when challenging the pathogen *Vibrio parahaemolyticus*, compared to conventional systems (V. Kumar et al., 2020). Meta-analyses of various probiotic studies showed improved survival rates and growth performance (e.g., increased SGR and feed efficiency) in penaeid shrimp farming with beneficial microbial supplementation. However, widespread adoption is still hampered by the challenges of small business scale and lack of access to financing or technology, although the benefits of more efficient production have been identified as a major attraction (Ghosh et al., 2024; Raza et al., 2024).

Research Gaps and the Urgency of Systematic Studies

Although local and experimental studies have extensively discussed crustacean diversity and innovation in penaeid shrimp farming, methodological gaps are still evident in the lack of a systematic review linking catch variability to the transition to aquaculture and the effectiveness of sustainable strategies. Many studies have focused only on one intervention, such as probiotics or bioflocs, or focused on one local area, so they are less able to describe cross-country patterns and different ecological contexts (Emerenciano et al., 2021; Iber et al., 2025; Sha et al., 2025). These limitations limit understanding of moderation factors such as environmental conditions, policies, and regional technical capacity—particularly in Southeast Asia—which are critical in formulating a truly adaptive and sustainable penaeid cultivation strategy (SEAFDEC, 2021).

Thus, *a systematic literature review* (SLR) is needed to summarize the latest findings, identify patterns, and decipher knowledge gaps. This study is important to strengthen the scientific basis for fisheries policy formulation and the sustainable development of penaeid shrimp farming. The following is the framework or *framework* that can be described in Figure 1.

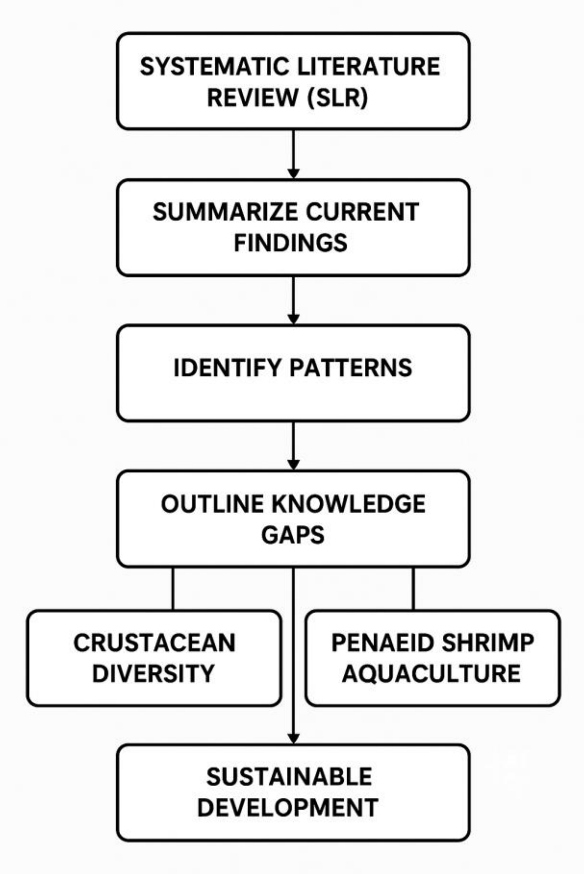

Figure 1. Conceptual Framework

The framework in Figure 1 illustrates the conceptual relationship between crustacean catch variability, transition to a penaeid cultivation system, and implementation of sustainability strategies. The process begins with a capture variability analysis, which highlights production fluctuations due to environmental factors, climate change, and fishing pressures on natural stocks. Furthermore, the results of the analysis became the basis for the transition to a more controlled and efficient penaeid cultivation system, through the application of technological innovations such as biofloc, probiotics, phytotherapy, and *the Integrated Multi-Trophic Aquaculture* (IMTA) system. The final stage focuses on the integration of sustainability strategies that include environmental, social, and economic aspects, to produce scientific synthesis and policy recommendations that support the sustainable management of aquatic resources at the regional and global levels.

METHODOLOGY

Research Design

This study uses the *Systematic Literature Review* (SLR) approach with reference to the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. This approach was chosen to compile, evaluate, and synthesize scientific evidence related to crustacean diversity, catch dynamics, and the transition to sustainable penaeid shrimp farming.

Data Sources and Search Strategies
The literature search process is carried out on major international databases i.e:
- Scopus
- Web of Science
- ScienceDirect
- Google Scholar

In addition, additional literature was obtained from the reports of international and regional organizations, such as FAO, SEAFDEC, and the Indonesian Ministry of Maritime Affairs and Fisheries.
The keywords used in the search incorporate Boolean terms, among other things:
- *"crustacean diversity" OR "penaeid shrimp" OR "capture fisheries"*
- *"aquaculture development" OR "sustainability" OR "disease management"*
- *"non-antibiotic strategies" OR "probiotics" OR "biofloc" OR "integrated aquaculture"*

The search was limited to the time range 2015–2025, English and Indonesian publication languages, and articles published in reputable journals and scientific proceedings.
Inclusion and Exclusion Criteria
Criteria included:
1. Articles on the diversity of crustaceans or penaeid shrimp.
2. Articles discuss capture fisheries, aquaculture, or the transition from capture to aquaculture.
3. Study highlighting sustainable shrimp health management strategies.
4. Articles with relevant primary data, reviews, or technical reports.

Exclusion criteria:
1. Articles that do not provide relevant empirical data or analysis.
2. Studies that focus only on non-economic crustaceans.
3. Opinion articles, editorials, or publications without *peer review*.

Literature Selection Process
The stages of article selection are carried out as follows:
1. Identification – all articles from the database are collected (n = X).
2. Initial screening – titles and abstracts are checked to rule out duplication and inconsistencies.
3. Eligibility – the full text is reviewed according to the inclusion-exclusion criteria.
4. Final inclusion – articles that meet the criteria are included in the analysis (n = Y).

This process is illustrated using the PRISMA 2020 flowchart.
Article Quality Assessment
To ensure reliability, each article is assessed with a Quality Appraisal Checklist, which includes the following aspects:
1. Clarity of the purpose of the research.
2. Relevance of the methodology.
3. Data validity.
4. Contribution to the theme of sustainability of penaeid shrimp farming.

Articles are scored, and only articles of "good" to "excellent" quality are used in the final synthesis.

Data Analysis Techniques

The analysis is carried out in two approaches:

1. Descriptive Analysis
   - Distribution of publications by year, country, and journal.
   - Research trends on crustacean diversity, capture fisheries, and penaeid shrimp cultivation.
2. Thematic Synthesis Articles that passed were analyzed based on themes:
   - Crustacean diversity and catch conditions.
   - Transition from capture fisheries to aquaculture.
   - Non-antibiotic strategies in shrimp health management.
   - Concept of sustainability and application of environmentally friendly technology.

The results of the analysis are presented in the form of tables, graphs, and comparative narratives to highlight research gaps and recommendations for the sustainable development of penaeid shrimp cultivation. The quality of the article was evaluated using a CASP (Critical Appraisal Skills Programme) checklist to ensure methodological validity and data clarity.

RESEARCH RESULT

Publication Distribution and Study Characteristics

A total of *120 publications* met the inclusion criteria, with a consistent increase in the number of articles since 2018, especially after 2020 when the issue of the sustainability of penaeid shrimp farming became more prominent in the Southeast Asian region. Indonesia (n = 38), Vietnam (n = 27), Thailand (n = 19), and the Philippines (n = 11) are the countries with the highest number of publications, in line with their dominance in global penaeid shrimp production. Most studies use experimental approaches (56%), followed by field survey studies (22%), policy and socio-economic reviews (14%), and scientific reviews (8%). In general, the trend of research is moving towards *intensification with sustainability safeguards*, especially related to bioflocs, probiotics, integrated systems, and environmental impact analysis.

Crustacean Diversity and Catch Dynamics in Southeast Asia

The SLR results show that the Southeast Asian region has a high diversity of economic crustaceans, especially in the families Penaeidae, Portunidae, and Scyllaridae. Molecular taxonomy research in Malaysia, Vietnam, and Indonesia, conducted since 2018, has identified both stability and genetic fragmentation in wild penaeid shrimp populations as a result of environmental pressures and exploitation. Most national reports (FAO, SEAFDEC) show a decline in the stability of crustacean catches, especially penaeid shrimp, red shrimp, crabs, and mangrove crabs since 2015–2022. This variability is triggered by climate change, degradation of coastal habitats, the intensification of fishing catches, and the declining health of estuarine ecosystems. The change reinforces the scientific rationale that wild stocks are no longer able to support market demand, and makes the transition to aquaculture an inevitable structural change.

Transition from Catching to Penaeid Shrimp Farming

Most publications conclude that the increasing global demand for *vannamei* shrimp is directly accelerating the shift from capture exploitation to intensive aquaculture. Indonesia and Vietnam are the most prominent examples, taking advantage of fluctuations in catches as a momentum to expand pond industrialization programs. The 2018–2023 study confirms that *L. vannamei* was chosen as the main commodity because of its rapid growth, feed conversion efficiency, tolerance to variable salinity, as well as its resistance to several diseases when compared to local species. Nonetheless, some studies underscore the risk of genetic homogenization due to the use of uniform seed strains, which has the potential to reduce long-term resistance to new diseases.

Sustainability Challenges in Penaeid Cultivation

The SLR identified four main groups of challenges in the sustainability of penaeid cultivation in Southeast Asia:

(1) Aquaculture Diseases (WSSV, AHPND/EMS, EHP)

WSSV and AHPND are reported to be the largest causes of economic losses in Indonesia, Vietnam, and Thailand. Molecular studies 2018–2023 showed that the virulence variation of *Vibrio parahaemolyticus* and the presence of toxin plasmids were the main factors in the EMS outbreak, while WSSV remained highly contagious and able to survive in the pond environment.

(2) Antibiotic Dependence and AMR (Antimicrobial Resistance)

About 45% of studies reported non-standard use of antibiotics in small-scale farming. Strong evidence suggests increased bacterial resistance to oxytetracycline, florfenicol, and enrofloxacin, which has an impact on food safety and environmental health.

(3) Environmental Impact

Several studies have found that intensive ponds contribute to eutrophication, increased organic load, and mangrove degradation—especially in coastal areas of Indonesia and Vietnam. Traditional ponds without modern waste management have greater pollution potential.

(4) Socio-Economic Barriers

Smallholder farmers face limited access to biofloc technology, commercial probiotics, SPF (Specific Pathogen Free) seeds, and highly competitive market access. The inequality of production capacity leads to an income gap between traditional farmers and industrial farmers.

Non-Antibiotic Strategy and Sustainable Technology

The SLR identified four dominant groups of strategies that were considered effective in reducing mortality and improving the health and productivity of penaeid shrimp:

(1) Bioflok Technology (BFT)

BFT was reported in 31% of the total studies as the most effective method for improving growth, biosecurity, and water quality. BFT has been proven to reduce feed costs by 20–35% through the use of floc as a natural additional feed.

(2) Probiotic, Prebiotic, dan Sinbiotic

Experimental studies in Indonesia, Vietnam, and Thailand showed an increase in non-specific immunity, feed efficiency, and survival by 10–40% when using *Bacillus*, *Lactobacillus*, and *Pseudomonas probiotics*.

(3) Integrated Multi-Trophic Aquaculture (IMTA)

IMTA systems that integrate shrimp with fish, seaweeds, or mollusks have been shown to reduce organic waste accumulation by more than 50% and improve water quality, based on studies conducted in the Philippines and Thailand.

(4) Natural Phytotherapy and Immunostimulants

Plant extracts such as *Gracilaria*, *Ulva*, and terrestrial spices have been shown to increase the immune response of shrimp at certain doses, although their scalability is still a question.

Thematic Summary and Gap Analysis

Based on the results of thematic mapping in the SLR, several key research gaps were successfully identified and summarized in **Table 1** to provide a comprehensive picture of areas that still require scientific deepening. The SLR results reveal several key patterns:

1. The intensification of penaeid production has increased significantly, but has not been fully followed by an increase in health management capacity.
2. Sustainability technologies (BFT, probiotics, IMTA) are widely researched at the laboratory level, but field adoption is still low.
3. The availability of wild crustacean biodiversity data is limited and tends to be fragmentary between countries.
4. The Ecosystem Approach to Aquaculture (EAA) has only been adopted in a small number of studies in Southeast Asia.
5. Lack of integration of socio-economic studies in the design of cultivation technical strategies.

A summary of the research gaps identified in the SLR is presented in Table 1. Therefore, future studies need to integrate sustainable aquaculture technologies with ecological, social, and governance dimensions to develop a penaeid shrimp production system that is genuinely resilient to environmental fluctuations and market dynamics

DISCUSSION

Crustaceans, especially penaeid shrimp, have a vital role in the global fisheries and aquaculture sector. From an economic perspective, penaeid shrimp accounts for more than 50% of the export value of fishery products in the Southeast Asian region, making it a major commodity in international trade. From an ecological perspective, the presence of crustaceans in nature contributes to the food chain and the balance of coastal ecosystems, especially in mangrove, seagrass, and coral reef ecosystems. However, dependence on wild-caught stocks can no longer guarantee supply stability, due to overfishing, habitat degradation, and climate change factors.

Table 1. Research Gaps Summary

Research Category	SLR Findings	Research Gaps
Shrimp Health Management	Limited implementation of standardized biosecurity protocols; pathogen-focused studies dominate research.	Lack of long-term field evaluations on integrated health management systems.
Sustainable Aquaculture Technologies	Biofloc, probiotics, synbiotics, and IMTA are widely studied at the laboratory scale but poorly adopted at the farm level.	Absence of national-scale implementation models and limited assessment of socio-economic feasibility.
Crustacean Biodiversity Data	Biodiversity information of wild crustaceans is fragmented and inconsistent across Southeast Asian countries.	No regionally standardized biodiversity database or genomic monitoring programs.
Ecosystem Approach to Aquaculture (EAA)	Only a small proportion of studies apply EAA in penaeid shrimp production.	Lack of evidence-based EAA frameworks tailored for Southeast Asian aquaculture systems.
Socio-economic Integration	Socio-economic dimensions are generally excluded from the design and testing of technical innovations.	Limited interdisciplinary research linking social, economic, and technical aspects of shrimp farming.

The Southeast Asian region has a high diversity of economic crustaceans, especially from the families Penaeidae, Portunidae, and Scyllaridae, which are important components of coastal fisheries. Regional biodiversity studies show that the high diversity of crustacean species in this region is influenced by tropical oceanographic conditions, primary productivity, and the complexity of coastal habitats such as mangroves and seagrass beds. Molecular taxonomy research conducted in Malaysia, Vietnam, and Indonesia since 2018 has revealed that wild penaeid shrimp populations show patterns of genetic stability at the macro level, but also show genetic fragmentation in some locations due to environmental degradation and intensive fishing pressure. These findings confirm that the genetic integrity of wild penaeid shrimp in Southeast Asia is increasingly vulnerable to environmental changes and overexploitation (FAO, 2022; Naylor et al., 2021; SEAFDEC, 2021).

Most national reports published by FAO and SEAFDEC show a decline in the stability of crustacean catches in Southeast Asia since 2015–2022, especially for penaeid shrimp (*Litopenaeus vannamei*, *Penaeus monodon*), red shrimp, crab (*Portunus pelagicus*), and mangrove crab (*Scylla spp.*). The decline in catches is related to increasingly extreme environmental variability, including ocean warming, changes in salinity, and storm events that affect the life cycle of crustaceans. In addition, the degradation of coastal ecosystems due to mangrove conversion, sedimentation, and pollution has resulted in the decline of habitats important for spawning and the development of crustacean larvae. Regional fisheries reports also show that intensification of catches, especially in shallow waters and estuaries, has contributed significantly to the depletion of wild crustacean stocks in the past decade (FAO, 2022; Pauly & Zeller, 2017; SEAFDEC, 2021).

The variability in wild crustacean production triggered by climate change, coastal degradation, intensification of catches, and declining ecosystem health reinforces the scientific rationale that wild stocks are no longer able to meet market demand consistently. This condition has triggered a structural shift towards penaeid shrimp farming as the main source of supply, especially in countries such as Indonesia and Vietnam, which have experienced increased investment and pond expansion since 2018 (Mustafa et al., 2023). Regional production modelling studies show that aquaculture's contribution to the supply of penaeid shrimp now exceeds marine catch, marking a fundamental change in crustacean-based food security systems. Thus, the transition to aquaculture is not only a response to fluctuations in catches but also a structural need to provide commodities with more controlled standards of quality, quantity, and continuity (Rubel et al., 2019).

Most publications conclude that the increasing global demand for vannamei shrimp is directly accelerating the shift from capture exploitation to intensive aquaculture. For example, a review by Naser et al., (2022) mentions that *L. vannamei* has become a major commodity due to its strong export potential and its ability to be produced on a large scale with international standards. Southeast Asia, Indonesia, and Vietnam are the most prominent examples; The two countries are using fluctuations in wild-caught yields as a momentum to expand the pond industrialization program supported by national policies and foreign investment.

Studies published between 2018 and 2023 confirm that *L. vannamei* was chosen as the main cultivated species due to its superior biological characteristics, including its rapid growth, high feed conversion efficiency, its tolerance to wide salinity variations from 0.5 ppt to 40 ppt, as well as its resistance to several diseases when compared to local species such as *Penaeus monodon*. For example, Luo et al., (2022) report that *L. vannamei* can grow well at low and high salinity, demonstrating ecological flexibility that is well-suited for intensive cultivation systems.

Nonetheless, some studies underscore the risk of genetic homogenization arising from the widespread use of uniform seed strains, which could reduce long-term resistance to new diseases and diminish genetic diversity. The review of Naser et al., (2022) highlights that the production of *L. vannamei* monocultures with high commercial seed stocks can lead to genetic dependencies and increase susceptibility to emerging pathogens. Therefore, while intensive aquaculture offers an alternative to the global shrimp supply, sustainability strategies require seed management, genetic diversification, and strict biosecurity monitoring.

Aquaculture diseases are still the most critical challenge in the sustainability of penaeid shrimp farming in Southeast Asia, especially White Spot Syndrome

Virus (WSSV), Acute Hepatopancreatic Necrosis Disease/Early Mortality Syndrome (AHPND/EMS), and *Enterocytozoon hepatopenaei* (EHP) (World Organisation for Animal Health, 2023). Various studies show that WSSV is one of the most destructive pathogens in shrimp farming, with a potential mortality of 70–100% in a short period of time, and has spread widely in major production centers, including Southeast Asian countries (Islam et al., 2023) AHPND/EMS caused by the PirA/PirB toxin-producing *strain of Vibrio parahaemolyticus* has also been reported to cause acute mortality in the early phases of rearing and is a major cause of intensive aquaculture failures in many shrimp-producing countries (Kumar et al., 2020). Meanwhile, EHP contributes to chronic growth decline and "growth retardation" syndrome, thereby lowering productivity, even though mortality rates are not always high (Dhar & Mai, 2021) These findings confirm that without strengthening biosecurity, early detection, and integrated health management, these diseases will continue to be a major inhibitor to the sustainability of penaeid production.

Dependence on antibiotics and the emergence of Antimicrobial Resistance (AMR) are serious issues that threaten the sustainability of shrimp farming, food security, and the health of coastal ecosystems. A global study of the shrimp industry shows that uncontrolled use of antibiotics can encourage the selection of resistant bacteria, which are then spread through pond wastewater, coastal sediments, and food chains (Thornber, et al., 2020). A recent review of AMR in Asian and Southeast Asian aquaculture noted that hotspots of antimicrobial resistance are found in various intensive aquaculture systems, including shrimp ponds, although quantitative data on drug use are still limited (Milijasevic et al., 2024). Policy studies have emphasized the need for *a One Health* approach to reduce antibiotic use, through the promotion of probiotics, vaccines (where available), improved feed management, and stricter regulatory regulation of the distribution and use of antimicrobials in the aquaculture sector (Ibarra et al., 2020).

The environmental impacts of intensified penaeid cultivation have been extensively documented, including eutrophication, increased organic waste loads, degradation of water quality, and loss of mangrove ecosystems and seagrass meadows around pond areas. A synthesis study in the Philippines shows that shrimp pond expansion contributes to increased soil and groundwater salinity, changes in coastal land use, and increased risk of organic pollution in recipient waters (Macusi et al., 2022). Another study on the impacts of aquaculture in Southeast Asia highlights that the conversion of mangroves to ponds has reduced the buffer capacity of coastal ecosystems against waves, tidal floods, and seawater intrusion, while degrading the ecosystem function as an important habitat for larval and juvenile stadia of various organisms (Tahiluddin et al., 2025). In the long term, the accumulation of organic waste and nutrients around poorly managed aquaculture areas can increase the vulnerability of the ponds themselves to disease and production failures (FAO, 2022; Hemati et al., 2025).

Socio-economic barriers are also a pillar of challenges that are no less important, especially for smallholder farmers in the Southeast Asian region.

Studies have shown that small-scale farmers often face limited access to capital, technology, information, and markets, making it difficult to adopt innovations such as bioflocs, probiotics, or ecolabel certifications that require initial investment and compliance with strict standards (Belton et al., 2018). Socio-economic analyses in the Philippines and Indonesia reveal that the intensification of shrimp farms can give rise to inequality, including the marginalization of smallholder fishers, changes in coastal livelihood structures, and the risk of income vulnerability when commodity prices fluctuate (Macusi et al., 2022). On the other hand, medium- and large-scale pond companies are better able to meet international certification standards such as the Aquaculture Stewardship Council (ASC) and Best Aquaculture Practices (BAP), thereby gaining better access to premium export markets, while smallholder farmers are lagging in the process of "upgrading" sustainability (Vo et al., 2024). This condition shows that efforts to strengthen sustainability are not only a technological issue, but also involve inclusive policy design, institutional support, and financing schemes that favor small-scale producers.

SLR shows that Biofloc Technology (BFT) is one of the most effective non-antibiotic strategies in improving the health and productivity of penaeid shrimp, especially through the mechanism of reducing ammonia load, stabilizing the aquatic microbiome, and providing natural feed from microbial flocs. Various experimental studies in Southeast Asia prove that BFT is able to improve shrimp growth, feed conversion efficiency (FCR), as well as survival through improved water quality and pathogen suppression based on microbial competition. In addition, the use of BFT can reduce dependence on antibiotics because the system supports better biosecurity conditions than conventional systems. Overall, BFT is considered a key pillar of sustainable aquaculture technology due to its impact on nutrient efficiency and the reduction of organic waste (El-Sayed, 2020; Emerenciano et al., 2021).

The use of probiotics, prebiotics, and synbiotics has also been identified as a key strategy in increasing the physiological resilience of penaeid shrimp. The results of the analysis show that probiotics based on *Bacillus*, *Lactobacillus*, and *Pseudomonas have* been shown to increase non-specific immune responses, improve nutrient absorption, and suppress the growth of pathogens such as *Vibrio parahaemolyticus,* which causes AHPND (Amiin et al., 2023). Prebiotics such as β-glucan and mannan-oligosaccharides also act as immunostimulants that can enhance shrimp's innate defense mechanisms, while synbiotics offer a dual approach by combining the benefits of probiotics and prebiotics (Khanjani et al., 2024). The implementation of this strategy is an important solution in reducing antibiotic dependence in intensive ponds, while supporting food security and environmental health.

Integrated Multi-Trophic Aquaculture (IMTA) is seen as an ecosystem-based strategy that is able to reduce environmental impact while increasing productivity through the integration of shrimp with other species such as fish, bivalves, or seaweed (*Gracilaria* or *Ulva*). Recent studies in the Philippines, Thailand, and Indonesia show that IMTA is able to reduce the accumulation of organic waste, stabilize water quality, and provide additional economic value through the harvesting of companion organisms (Biswas et al., 2020). In addition, the integration of filter feeders and photosynthetic organisms has been shown to suppress pathogen growth through nutrient competition and natural bioremediation capacity enhancement (Holanda et al., 2023). Thus, IMTA offers a holistic approach that is aligned with the principles of ecological and economic sustainability.

Phytotherapies and natural immunostimulants are emerging as increasingly researched non-antibiotic alternatives, utilizing extracts of marine and terrestrial plants to increase the immune resistance of penaeid shrimp. Bioactive compounds such as phenolics, flavonoids, sulfate polysaccharides, and terpenoids in plants such as *Gracilaria*, *Ulva*, turmeric, and garlic have been shown to increase phagocytic activity, immune enzyme production, as well as resistance to WSSV and AHPND infections (Dadras et al., 2023; Jasmanindar et al., 2018; Zhu, 2020). In addition, this approach is considered environmentally friendly and relatively accessible to smallholder farmers, although more consistent scalability research and dosage guidance are still needed. Phytotherapy has the potential to be an important component in an integrated shrimp health management strategy based on EAA (Ecosystem Approach to Aquaculture) (Chong et al., 2020; Cortez-Mago et al., 2025; Hassan et al., 2025).

The intensification of penaeid shrimp production has increased significantly in Southeast Asia in the past decade, but this increase has not been fully followed by the strengthening of health management and biosecurity. A global study by (Naylor et al., 2021) shows that the rapid expansion of the shrimp industry is causing a gap between the production capacity and readiness of aquaculture health systems, especially in developing countries. This is reinforced by a report (FAO, 2022) which highlights the high prevalence of WSSV, AHPND, and EHP diseases in areas with pond intensification that is not balanced with adequate health governance. As a result, many intensive production systems in Southeast Asia remain vulnerable to disease outbreaks despite increased productivity.

Sustainability technologies such as biofloc (BFT), probiotics, synbiotics, and Integrated Multi-Trophic Aquaculture (IMTA) are widely researched on a laboratory scale and small trials, but their adoption rate in the field is still low. El-Sayed (2020) and Emerenciano et al., (2021) emphasized the gap between scientific evidence and implementation, caused by capital barriers, lack of technical training, and low infrastructure readiness for smallholder farmers. In addition, wild crustacean biodiversity data to support stock management and conservation is still limited and fragmented between countries, as reported by SEAFDEC (2021), making it difficult to formulate an ecology-based regional strategy. This data limitation also affects the accuracy of monitoring wild penaeid shrimp stocks and their habitats on the coast of Southeast Asia.

Ecosystem-based approaches such as the Ecosystem Approach to Aquaculture (EAA) have only been adopted in a small number of aquaculture management studies and policies in Southeast Asia. In fact, according to FAO (2021), the implementation of EAA is important to integrate ecological, governance, and socio-economic dimensions to ensure long-term sustainability.

Many technical studies still focus on the biological and technological aspects of intensification, without linking them to the socio-economic conditions of coastal communities, which actually greatly influence the successful implementation of the technology. In line with this, other opinions emphasize that the non-involvement of socio-economic aspects in the design of aquaculture technologies has led to low adoption, production inequality, and market vulnerability. As such, future research needs to create an interdisciplinary approach that connects sustainable technologies with ecological, social, and governance contexts (Belton et al., 2018, 2020; Garlock et al., 2024; Gephart et al., 2021; Henriksson et al., 2021).

CONCLUSIONS AND RECOMMENDATIONS

The results of the systematic review indicate that the high variability in crustacean catch yields in tropical regions is driven by habitat degradation, climate change, and fishing pressure, which have collectively triggered a structural shift from reliance on wild stocks toward aquaculture systems, particularly for *L. vannamei*. While penaeid aquaculture has expanded rapidly due to its biological efficiency and production stability, the sector's sustainability remains constrained by disease challenges (WSSV, AHPND, EHP), antibiotic dependence, ecological impacts, and the limited capacity of small-scale farmers to adopt modern technologies.

The review also highlights that various non-antibiotic strategies, such as biofloc, probiotics, IMTA, and phytotherapy, have been shown to effectively enhance shrimp health and production performance, yet their adoption at the farm level remains uneven. Therefore, the successful development of sustainable penaeid shrimp aquaculture requires the integration of environmentally friendly technologies, ecosystem-based approaches, strengthened biosecurity, and policy support that ensures farmers' access to innovation, resources, and improved health management.

Based on the findings of the study, efforts are needed to strengthen biosecurity and shrimp health management through the implementation of early disease detection, the use of pathogen-free larvae, and the use of non-antibiotic strategies such as biofloc, probiotics, IMTA, and phytotherapy as sustainable alternatives that can reduce antibiotic dependence and increase aquaculture resilience. The implementation of this technology needs to be expanded through policy support, the provision of financing and technical training for smallholder farmers, as well as the development of environmentally friendly production infrastructure based on the Ecosystem Approach to Aquaculture (EAA), so that ecological impacts can be minimized. In addition, it is necessary to develop a crustacean biodiversity database and monitor population genetics as the basis for natural broodstock management, as well as the harmonization of national regulations related to the use of antibiotics, sustainability certification, and management of aquaculture areas to ensure an adaptive, competitive, and sustainable penaeid shrimp production system.

ADVANCED RESEARCH

This study still has some limitations that open up space for further research, especially since most of the studies are still laboratory-based, so long-term field data is needed to test the sustainability of the technology under real conditions. The integration of socio-economic aspects also needs to be strengthened by including social variables, gender, capital structure, and market dynamics to understand the adoption of technology by farmers. In addition, the availability of local genomic and physiological data is still limited, so research on genetic diversity and the domestication potential of local shrimp needs to be improved. Long-term evaluation of the effectiveness of interstate non-antibiotic strategies is also important to assess their consistency across different aquaculture ecosystems. On the other hand, the development of climate-based disease prediction models is an urgent need, considering that climate change contributes directly to the emergence of outbreaks.

ACKNOWLEDGMENT

Thank you to all those who have helped in the creation of this article.

REFERENCES

Ahmed, R. (2025). Eco-Friendly Shrimp Farming: Balancing Economic Growth and Environmental Sustainability in Agriculture. *International Journal of Science Education and Science*, *2*(1), 61–68. https://doi.org/10.56566/ijses.v2i1.326

Albalat, A., Zacarias, S., Coates, C. J., Neil, D. M., & Planellas, S. R. (2022). Welfare in Farmed Decapod Crustaceans, With Particular Reference to Penaeus vannamei. *Frontiers in Marine Science*, *9*, 1–19. https://doi.org/10.3389/fmars.2022.886024

Alfiansah, Y. R., Peters, S., Harder, J., Hassenrück, C., & Gärdes, A. (2020). Structure and co-occurrence patterns of bacterial communities associated with white faeces disease outbreaks in Pacific white-leg shrimp Penaeus vannamei aquaculture. *Scientific Reports*, *10*, 11980. https://doi.org/10.1038/s41598-020-68891-6

Amiin, M. K., Lahay, A. F., Putriani, R. B., Reza, M., Putri, S. M. E., Sumon, M. A. A., Jamal, M. T., & Santanumurti, M. B. (2023). The role of probiotics in vannamei shrimp aquaculture performance - A review. *Veterinary World*, *16*(3), 638–649. https://doi.org/10.14202/vetworld.2023.638-649

Badan Pusat Statistik. (2022). *Produksi Perikanan Tangkap Menurut Provinsi dan Jenis Penangkapan, 2000-2020*. Https://Www.Bps.Go.Id/. https://www.bps.go.id/id/statistics-table

Balmer, C. (2024). *Aquafarming becomes main global source for fish, U.N. food agency says*. Reuters.Com.

Behringer, D. C., & Duermit-Moreau, E. (2021). Crustaceans, One Health and the changing ocean. *Journal of Invertebrate Pathology*, *186*, 107500. https://doi.org/10.1016/j.jip.2020.107500

Belton, B., Bush, S. R., & C, L. D. (2018). Not just for the wealthy : Rethinking farmed fish consumption in the Global. *Global Food Security*, *16*, 85–92.

https://doi.org/10.1016/j.gfs.2017.10.005

Belton, B., Little, D. C., Zhang, W., Skladany, M., Thilsted, S. H., & Edwards, P. (2020). Farming fi sh in the sea will not nourish the world. *Nature Communications*, *11*, 1–8. https://doi.org/10.1038/s41467-020-19679-9

Bogmans, C. W. J., & van Soest, D. (2022). Can global aquaculture growth help to conserve wild fish stocks? Theory and empirical analysis. *Natural Resource Modeling*, *35*(1). https://doi.org/10.1111/nrm.12323

Boonyawiwat, V., Patanasatienkul, T., Kasornchandra, J., Poolkhet, C., Yaemkasem, S., Hammell, L., & Davidson, J. (2017). Impact of farm management on expression of early mortality syndrome/acute hepatopancreatic necrosis disease (EMS/AHPND) on penaeid shrimp farms in Thailand. *Journal of Fish Diseases*, *40*(5), 649–659. https://doi.org/10.1111/jfd.12545

Chen, Z., Chen, J., Feng, Y., Yuan, M., Li, G., & Li, Z. (2025). Spatial and temporal evolution of shrimp farming in coastal provinces of China over the past 20 years and its driving mechanisms. *Anthropocene Coasts*, *8*(25), 1–22. https://doi.org/10.1007/s44218-025-00078-w

Chong, C. M., Murthy, A. V. S. G., Choy, C. ., & Lai, K. S. (2020). Phytotherapy in aquaculture: Integration of endogenous application with science. *Journal of Environmental Biology*, *41*, 1204–1214. https://doi.org/http://doi.org/10.22438/jeb/41/5(SI)/MS_12

Cortez-Mago, R., Borges, L., & Wasielesky, W. (2025). Medicinal plants and their applications in shrimp culture. *Latin American Journal of Aquatic Research*, *53*(1), 22–38. https://doi.org/10.3856/vol53-issue1-fulltext-3251

Dahl, R. E., & Jonsson, E. (2018). Volatility spillover in seafood markets. *Journal of Commodity Markets*, *12*, 44–59. https://doi.org/https://doi.org/10.1016/j.jcomm.2017.12.005

de Lacerda, L. D., Ward, R. D., Godoy, M. D. P., Meireles, A. J. de A., Borges, R., & Ferreira, A. C. (2021). 20-Years Cumulative Impact From Shrimp Farming on Mangroves of Northeast Brazil. *Frontiers in Forests and Global Change*, *4*, 653096. https://doi.org/10.3389/ffgc.2021.653096

Dhar, A. K., & Mai, H. N. (2021). Acute Hepatopancreatic Necrosis Disease (AHPND) and Hepatopancreatic Microsporidiosis (HPM): two threats to sustainable shrimp aquaculture Necrosis Disease (AHPND). *Promotion of Sustainable Aquaculture, Aquatic Animal Health and Resource Enhancement in Southeast Asia*, 200–216.

El-Sayed, A.-F. M. (2020). Use of biofloc technology in shrimp aquaculture : a comprehensive review , with emphasis on the last decade. *Review in Aquaculture*, 1–30. https://doi.org/10.1111/raq.12494

Emerenciano, M. G. C., Miranda-Baeza, A., Martínez-Porchas, M., Poli, M. A., & Vieira, F. do N. (2021). Biofloc Technology (BFT) in Shrimp Farming: Past and Present Shaping the Future. *Frontiers in Marine Science*, *8*, 813091. https://doi.org/10.3389/fmars.2021.813091

Emerenciano, M. G. C., Rombenso, A. N., Vieira, F. D. N., Martins, M. A., Coman, G. J., Truong, H. H., Noble, T. H., & Simon, C. J. (2022). Intensification of Penaeid Shrimp Culture: An Applied Review of Advances in Production

Systems, Nutrition and Breeding. *Animals*, *12*(236), 1–39. https://doi.org/10.3390/ani12030236

FAO (Food and Agriculture Organization). (2020). The State of Food and Agriculture 2020. In *The State of Food and Agriculture 2020*. https://doi.org/10.4060/cb1447en

Garlock, T. M., Asche, F., Anderson, J. L., Eggert, H., Anderson, T. M., Che, B., Chávez, C. A., Chu, J., Chukwuone, N., Dey, M. M., Fitzsimmons, K., Flores, J., Guillen, J., Kumar, G., Liu, L., Llorente, I., Nguyen, L., Rasmus, N., Pincinato, R. B. ., … Tveteras, R. (2024). Environmental , economic , and social sustainability in aquaculture : the aquaculture performance indicators. *Nature Communications*, *15*, 5274. https://doi.org/10.1038/s41467-024-49556-8

Gephart, J. A., Golden, C. D., Asche, F., Belton, B., Froehlich, H. E., Fry, J. P., Halpern, B. S., Christina, C., Jones, R. C., Klinger, D. H., Little, D. C., Mccauley, D. J., Thilsted, S. H., Troell, M., Allison, E. H., Gephart, J. A., Golden, C. D., Asche, F., Belton, B., … Allison, E. H. (2021). Scenarios for Global Aquaculture and Its Role in Human Nutrition. *Reviews in Fisheries Science & Aquaculture*, *29*(1), 122–138. https://doi.org/10.1080/23308249.2020.1782342

Ghosh, A. K., Hasanuzzaman, A. F. M., Sarower, M. G., Islam, M. R., & Huq, K. A. (2024). Unveiling the biofloc culture potential: Harnessing immune functions for resilience of shrimp and resistance against AHPND -causing Vibrio parahaemolyticus infection. *Fish & Shellfish Immunology*, *151*, 109710. https://doi.org/https://doi.org/10.1016/j.fsi.2024.109710

Grandviewresearch. (2023). Shrimp Market Size, Share & Trends Analysis Report By Species (L. Vannamei, Trachipenaeus Curvirostris), By Source (Wild, Aquaculture), By Form (Green/ Head-off, Green/ Head-on), By Distribution Channel (B2B, B2C), By Region, And Segment Forecasts, 2025 -. In *https://www.grandviewresearch.com/*.

Hassan, H. U., Ali, A., Sulivany, B. S. A. Al, Bilal, M., Kanwal, R., Raza, M. A., Arslan, A., & Ijaz, M. Z. (2025). Investigation of the effects of phytogenic dietary additives on growth performance , nutrient utilization , economic efficiency and health of Pangasius hypophthalmus : implications for sustainable aquaculture development. *Scientific Reports*, *15*, 22661. https://doi.org/https://doi.org/10.1038/s41598-025-03658-5 3

Hemati, A., Kakoolaki, S., Ghaednia, B., & Pourbaba, H. (2025). Biology , pathogenesis and management approaches of White Spot Disease in shrimp aquaculture : A review. *Iranian Journal of Fisheries Science*, *24*(6), 1523–1567. https://doi.org/10.22092/ijfs.2025.134677

Henriksson, P. J. G., Troell, M., Banks, L. K., Belton, B., Beveridge, M. C. M., Klinger, D. H., Pelletier, N., Phillips, M. J., & Tran, N. (2021). Perspective Interventions for improving the productivity and environmental performance of global aquaculture for future food security. *One Earth*, *4*(9), 1220–1232. https://doi.org/10.1016/j.oneear.2021.08.009

Herawati, T., Rahayu, I., Aisyah, A., Untung, M., & Agung, K. (2025). Report on Vibrio Species Contamination in Shrimp From the Coast of Pangandaran , West Java , Indonesia. *Environmental Microbiology Reports*, *17*, e70210. https://doi.org/10.1111/1758-2229.70210

Holanda, M., Ravagnan, E., Lara, G., Santana, G., Furtado, P., Cardozo, A., Wasielesky, W., & Poersch, L. H. (2023). Integrated multitrophic culture of shrimp Litopenaeus vannamei and Tilapia oreochromis niloticus in biofloc system: A pilot scale study. *Frontiers in Marine Science*, *10*, 1060846. https://doi.org/10.3389/fmars.2023.1060846

Ibarra, R., Norden, W., Jimenez, D., Farias, D. R., Canales, A., & Isaac, T. (2020). *Review of global antibiotic use , impacts , solutions , and gaps in Aquaculture*. Seafood Watch/World Bank,.

Iber, B. T., Ikyo, B. C., Nor, M. N. M., Abdullah, S. R. S., Shafie, M. S. Bin, Manan, H., Abdullah, M. I., & Kasan, N. A. (2025). Application of Biofloc technology in shrimp aquaculture: A review on current practices, challenges, and future perspectives. *Journal of Agriculture and Food Research*, *19*(January), 101675. https://doi.org/10.1016/j.jafr.2025.101675

Islam, S. I., Mou, M. J., Sanjida, S., & Mahfuj, S. (2023). A review on molecular detection techniques of white spot syndrome virus: Perspectives of problems and solutions in shrimp farming. *Veterinary Medicine Adn Science*, *9*, 778–801. https://doi.org/10.1002/vms3.979

Jasmanindar, Y., Sukenda, S., Alimuddin, A., Junior, M. Z., & Utomo, N. B. P. (2018). The Chemical Composition of Gracilaria verrucosa Extract and its Utilization on Survival and Growth Litopenaeus vannamei. *Omni-Akuatika*, *14*(3), 1–9. https://doi.org/10.20884/1.oa.2018.14.3.508

Jasmanindar, Y., Sukenda, S., Zairin Jr, M., & P, U. N. B. (2018). Dietary administration of Gracilaria verrucosa extract on Litopenaeus vannamei immune response, growth, and resistance to Vibrio harveyi. *Aquaculture, Aquarium, Conservation & Legislation*, *11*(4), 1069–1080.

Kemp, J. O. G., Taylor, J. J., Kelly, L. A., Larocque, R., Heriazon, A., Tiessen, K. H. D., & Cooke, S. J. (2021). Antibiotic resistance genes in the aquaculture sector: Global reports and research gaps. *Environmental Reviews*, *29*(2), 300–314. https://doi.org/10.1139/er-2020-0087

Khanjani, M. H., Mozanzadeh, M. T., Gisbert, E., & Hoseinifar, S. H. (2024). Probiotics, prebiotics, and synbiotics in shrimp aquaculture: Their effects on growth performance, immune responses, and gut microbiome. *Aquaculture Reports*, *38*, 102362. https://doi.org/10.1016/j.aqrep.2024.102362

Kim, M. J., Kim, S. H., Kim, J. O., Lee, T. K., Jang, I. K., & Choi, T. J. (2023). Efficacy of White Spot Syndrome Virus Protein VP28-Expressing Chlorella vulgaris as an Oral Vaccine for Shrimp. *Viruses*, *15*, 1–15. https://doi.org/10.3390/v15102010

KKP (Kementerian Kelautan dan Perikanan) (2023). Laporan Kinerja Kementerian Kelautan dan Perikanan Tahun 2024. In *Kementerian Kelautan dan Perikanan* (Vol. 1). https://kkp.go.id/an-component/media/upload-gambar-pendukung/kkp/LAPORAN/Laporan Kinerja KKP/2022/20230316_Laporan Kinerja KKP 2022.pdf

KKP (Kementerian Kelautan dan Perikanan) (2023). *CBIB wujud semangat konsep blue economy*. Direktorat Jenderal Perikanan Budi Daya.

Kumar, R., Ng, T. H., & Wang, H. (2020). Acute hepatopancreatic necrosis disease in penaeid shrimp. *Review in Aquaculture*, *12*, 1867–1880. https://doi.org/10.1111/raq.12414

Kumar, V., Roy, S., Behera, B. K., Bossier, P., & Das, B. K. (2021). Pathogenesis and Mitigation Strategies in Shrimp Aquaculture. *Toxin*, *13*(524), 1–28.

Kumar, V., Wille, M., Lourenço, T. M., & Bossier, P. (2020). Biofloc-Based Enhanced Survival of Litopenaeus vannamei Upon AHPND-Causing Vibrio parahaemolyticus Challenge Is Partially Mediated by Reduced Expression of Its Virulence Genes. *Frontiers in Microbiology*, *11*, 1270. https://doi.org/10.3389/fmicb.2020.01270

Lee, D., Yu, Y. Bin, Choi, J. H., Jo, A. H., Hong, S. M., Kang, J. C., & Kim, J. H. (2022). Viral Shrimp Diseases Listed by the OIE: A Review. *Viruses*, *14*(3), 1–62. https://doi.org/10.3390/v14030585

Li, C., Zhang, X., Chen, Y., Zhang, S., Dai, L., Zhu, W., & Chen, Y. (2023). Optimized Utilization of Organic Carbon in Aquaculture Biofloc Systems: A Review. *Fishes*, *8*, 465. https://doi.org/10.3390/fishes8090465

Liew, K. S., Yong, F. K. Bin, & Lim, L. S. (2024). An Overview of the Major Constraints in Scylla Mud Crabs Grow-out Culture and Its Mitigation Methods. *Aquaculture Studies*, *24*(1), 1–9. https://doi.org/10.4194/AQUAST993

Luo, Z., Yu, Y., Bao, Z., Xiang, J., & Li, F. (2022). Evaluation of genomic selection for high salinity tolerance traits in Pacific white shrimp Litopenaeus vannamei. *Aquaculture*, *557*, 738320. https://doi.org/https://doi.org/10.1016/j.aquaculture.2022.738320

Macusi, E. D., Estor, D. E. P., Borazon, E. Q., Clapano, M. B., & Santos, M. D. (2022). Environmental and Socioeconomic Impacts of Shrimp Farming in the Philippines: A Critical Analysis Using PRISMA. *Sustainability*, *14*, 2977. https://doi.org/10.3390/su14052977

Milijasevic, M., Veskovic-moracanin, S., Milijasevic, J. B., Petrovic, J., & Nastasijevic, I. (2024). Antimicrobial Resistance in Aquaculture : Risk Mitigation within the One Health Context. *Foods*, *13*, 2448.

Monsalve, E. R., & Quiroga, E. (2022). Farmed shrimp aquaculture in coastal wetlands of Latin America — A review of environmental issues. *Marine Pollution Bulletin*, *183*, 113956. https://doi.org/https://doi.org/10.1016/j.marpolbul.2022.113956

Mustafa, A., Syah, R., Paena, M., Sugama, K., Kontara, E. K., Muliawan, I., Suwoyo, H. S., Asaad, Andi Indra Jaya, Asaf, R., Ratnawati, E., Athirah, A., Makmur, M., Suwardi, S., & Taukhid, I. (2023). Strategy for Developing Whiteleg Shrimp (Litopenaeus vannamei) Culture Using Intensive / Super-Intensive Technology in Indonesia. *Sustainability*, *15*, 1753.

Naser, M. N., Nath, S. M., & Hosain, M. E. (2022). Whiteleg shrimp Litopenaeus vennamei : Current status , future prospects and opportunities for Bangladesh Aquaculture. *Bangladesh Journal of Zoology*, *50*(2), 143–184. https://doi.org/10.3329/bjz.v50i2.62051

Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H., Little, D. C., Lubchenco, J., Shumway, S. E., & Troell, M. (2021). A 20-year retrospective review of global aquaculture. *Nature*, *591*, 551–563. https://doi.org/10.1038/s41586-021-03308-6

Pauly, D., & Zeller, D. (2017). Comments on FAOs State of World Fisheries and Aquaculture (SOFIA 2016). *Marine Policy*, *77*, 176–181. https://doi.org/10.1016/j.marpol.2017.01.006

Priyambodo, B., Jones, C. M., & Sammut, J. (2020). Assessment of the lobster puerulus (Panulirus homarus and Panulirus ornatus, Decapoda: Palinuridae) resource of Indonesia and its potential for sustainable harvest for aquaculture. *Aquaculture*, *528*, 735563. https://doi.org/10.1016/j.aquaculture.2020.735563

Purnomo, A. R., Patria, M. P., Takarina, N. D., & Karuniasa, M. (2022). Environmental Impact of the Intensive System of Vannamei Shrimp (Litopenaeus vannamei) Farming on the Karimunjawa-Jepara-Muria Biosphere Reserve, Indonesia. *International Journal on Advanced Science, Engineering and Information Technology*, *12*(3), 873–880. https://doi.org/10.18517/ijaseit.12.3.14181

Raza, B., Zheng, Z., & Yang, W. (2024). A Review on Biofloc System Technology, History, Types, and Future Economical Perceptions in Aquaculture. *Animals*, *14*, 1489. https://doi.org/10.3390/ani14101489

Rubel, H., Wooda, W., Perez, D., Unnikrishnan, S., Felde, A. M. Zum, Zielcke, S., Lidy, C., & Lanfer, C. (2019). *A Strategic Approach to Sustainable Shrimp Production in Vietnam The Case for Improved Economics and Sustainability*. Https://Media-Publications.Bcg.Com. https://media-publications.bcg.com

Schlenker, L. S., Stewart, C., Rock, J., Heck, N., & Morley, J. W. (2023). Environmental and climate variability drive population size of annual penaeid shrimp in a large lagoonal estuary. *PLoS ONE*, *18*(5), 1–26. https://doi.org/10.1371/journal.pone.0285498

SEAFDEC. (2021). SEAFDEC annual report. In *SEAFDEC Regional Report*. www.seafdec.org

Sha, H. N., Lu, Y. M., Zhan, P. P., Chen, J., Qiu, Q. F., & Xiong, J. B. (2025). Beneficial effects of probiotics on Litopenaeus vannamei growth and immune function via the recruitment of gut Rhodobacteraceae symbionts. *Zoological Research*, *46*(2), 388–400. https://doi.org/10.24272/j.issn.2095-8137.2024.364

Shi, M., Jiang, S., Shi, J., Yang, Q., Huang, J., Li, Y., Yang, L., & Zhou, F. (2024). Evaluation of Genetic Parameters and Comparison of Stress Tolerance Traits in Different Strains of Litopenaeus vannamei. *Animals*, *14*, 1–11. https://doi.org/10.3390/ani14040600

Simtoe, A. P., Lugendo, B. R., & Mgaya, Y. D. (2025). Assessment of Food Sources for Juvenile and Adult Penaeus monodon in Tanzania Coastal Waters . *Aquaculture, Fish and Fisheries*, *5*(1), 1–14. https://doi.org/10.1002/aff2.70041

Syafaat, M. N., Azra, M. N., Waiho, K., Fazhan, H., Abol-Munafi, A. B., Ishak, S. D., Syahnon, M., Ghazali, A., Ma, H., & Ikhwanuddin, M. (2021). A review of the nursery culture of mud crabs, genus scylla: Current progress and future directions. *Animals*, *11*(7), 1–15. https://doi.org/10.3390/ani11072034

Tahiluddin, A. B., Bornales, J. C., Limbaro, G. R. A., Paudac, M. A. U., Amarille, R. K., Sirad, N. R., Kabirun, M. C., Ujing, R. A., Gonzaga-Torino, F. M., Sabdani, M. H., Bacla-an, R. E., Hairal, M. A. S., Magcanta-mortos, M. L. M., & Esguerra, J. P. (2025). Environmental Impacts of Aquaculture in the Philippines. *Israeli Journal of Aquaculture*, *77*(2), 51–81. https://doi.org/10.46989/001c.133778

Thornber, K., Verner-jeffreys, D., Hinchliffe, S., Rahman, M. M., Bass, D., & Tyler, C. R. (2020). Evaluating antimicrobial resistance in the global shrimp industry. *Reviews in Aquaculture*, *12*, 966–986. https://doi.org/10.1111/raq.12367

Villarreal, H. (2023). Shrimp farming advances, challenges, and opportunities. *Journal of the World Aquaculture Society*, *54*(5), 1092–1095. https://doi.org/10.1111/jwas.13027

Vo, T., Le, H., Phan, D., Tran, A., Nguyen, Y., Nguyen, H., & Pham, T. (2024). Towards sustainable mangrove-shrimp aquaculture through capacity building and partnership in the Mekong River Delta. *APN Science Bulletin*, *14*(1), 28–37. https://doi.org/10.30852/sb.2024.2491

Wiyono, E. S., & Ihsan. (2018). Abundance, fishing season and management strategy for blue swimming crab (Portunus pelagicus) in pangkajene kepulauan, South Sulawesi, Indonesia. *Tropical Life Sciences Research*, *29*(1), 1–15. https://doi.org/10.21315/tlsr2018.29.1.1

World Organisation for Animal Health, W. (2023). Infection with white spot syndrome virus. In *WOAH Aquatic Manual* (pp. 1–17).

Yap, E. E. S., V, M. S., Napata, R. P., & Ledesma, A. B. B. (2020). *The Philippines' Blue Swimming Crab (Portunus pelagicus) Fishery Root Cause Analysis Report | UNDP in Philippines*. https://www.ph.undp.org/content/philippines/en/home/library/environment_energy/the-philippines_-blue-swimming-crab--portunus-pelagicus--fishery.html

Zheng, D., Yin, G., Liu, M., Chen, C., Jiang, Y., Hou, L., & Zheng, Y. (2021). A systematic review of antibiotics and antibiotic resistance genes in estuarine and coastal environments. *Science of the Total Environment*, *777*, 146009. https://doi.org/10.1016/j.scitotenv.2021.146009

Zhu, F. (2020). A review on the application of herbal medicines in the disease control of aquatic animals. *Aquaculture*, *526*, 735422. https://doi.org/https://doi.org/10.1016/j.aquaculture.2020.735422

Zhu, Z., Shi, W., Li, F., Zhang, M., Luo, K., Tong, D., Yu, Y., Zhang, X., Lu, L., & Yan, M. (2024). Studies on immunological characteristics and transcriptomic analysis of Litopenaeus vannamei low salt-tolerance family. *Developmental & Comparative Immunology*, *161*, 105265. https://doi.org/https://doi.org/10.1016/j.dci.2024.105265