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A SYSTEMATIC REVIEW OF COST-RELATED ISSUES IN SHRIMP FARMING

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ABSTRACT

Aquaculture is considered as the fastest-growing food production sector globally, expanding rapidly across all regions (FAO, 2022). However, high operational costs including feed, labour, disease prevention, and water management are major challenges facing shrimp farming. These challenges threaten industry growth and sustainability. Although the topic is critical, only a limited number of systematic reviews, less than five as of 2024, have addressed cost-related issues in this field. Comparatively, few articles have systematically reviewed the available literature in this area, hence the current study, which aims to develop a systematic review of the practice of cost adjustment in aquaculture communities. This systematic review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement in its systematic search strategy, employing five electronic abstract and citation databases: (1) Emerald Insight; (2) IEEE Xplore; (3) ScienceDirect; (4) Scopus; and (5) Taylor & Francis Online, to research existing studies, leading to the selection of 41 related research papers. The selected articles were evaluated using the search terms “shrimp farming” AND “cost”. Three significant issues arose—environmental, feeding, and disease, which are the most essential cost-related issues in most shrimp farms. Based on the pattern of previous studies, the review presents several recommendations for scientists, agencies, and communities to consider going forward.

Introduction

The aquaculture industry currently provides half the global seafood production and is one of the fastest-growing food production sectors in the world (Aanesen & Mikkelsen, 2020). Global aquaculture production hit a record 122.6 million tons in 2020, including 87.5 million tons of aquatic animals worth US $264.8 billion and 35.1 million tons of seaweed worth US $16.5 billion (The State of World Fisheries and Aquaculture, 2022). According to the report, Asian countries made the most significant contribution to aquaculture production, with China being the largest producer of aquaculture.

One of the most significant aquatic animals in aquaculture is shrimp. Shrimp farming contributes significantly to national economies through job creation and foreign exchange earnings, especially in countries such as China, Thailand, Indonesia, and Vietnam (Primavera, 1997; Bhattacharya & Ninan, 2011). Most shrimp aquaculture occurs in China, Thailand, Indonesia, India, Vietnam, Brazil, Ecuador, and Bangladesh, and it has generated significant revenue in these developing countries. Increasing demand from developed regions, such as Europe, the United States, and Japan has attracted investors to the industry, leading to the adoption of intensified farming techniques that can lead to environmental degradation (Dierberg & Kiattisimkul, 1996; Cao, 2012).

Similar to other sectors, aquaculture is increasingly affected by rising input costs, particularly related to feed, energy and disease management. These rising costs threaten the sustainability and profitability of the industry (Sanchez-Zazueta & Martinez-Cordero, 2009; Asche *et al*., 2018). Increases in aquaculture production require control of environmental and sanitary conditions (Asche *et al*., 2018). Disease outbreaks have hit shrimp production worldwide (Kasan *et al*., 2019), with twenty viral, four bacterial, three fungal, and several protozoal diseases having been identified in shrimp or crustaceans (Amatul-Samahah *et al*., 2020). Notable shrimp diseases include White Spot Syndrome Virus (WSSV), Taura Syndrome Virus (TSV), and Acute Hepatopancreatic Necrosis Disease (AHPND), all of which have been linked to substantial production losses worldwide (Zorriehzahra, 2015; Patil *et al*., 2021).

The economic losses arising from diseases being reported around the world are now a major problem, costing the industry billions in USD each year (Patil *et al*., 2021). Additionally, while environmental issues have become a concern for shrimp aquaculture, the industry has also faced criticism for contributing to mangrove deforestation, water pollution, and saltwater intrusion, especially in coastal regions (Dierberg & Kiattisimkul, 1996; Cao, 2012). According to Dierberg and Kiattisimkul (1996), environmental issues, including Mangrove destruction, saltwater intrusion, land subsidence, water quality degradation, sediment deposition, abandoned shrimp farms, and displacement of traditional livelihoods are among the problems commonly faced in shrimp aquaculture.

The above-mentioned obstacles often relate to the costs involved in overcoming shrimp farm management problems, thus there is a need to recognise these cost-related obstacles as they determine the ultimate profitability of shrimp aquaculture. Despite the volume of literature on shrimp farming, there has been a lack of systematic reviews specifically focused on cost-related issues, which this paper aims to address. This paper adopts a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach for 41 shrimp farming studies to investigate the cost-related issues in shrimp aquaculture. This paper aims to make suggestions for future studies by gathering information from existing studies and summarising them accordingly.

Methodology

This systematic review was conducted and reported based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach as introduced by Moher *et al*. (2009). PRISMA is a writing guide for creating an excellent systematic review report, mainly used in health sector studies. The research objective of this systematic review is to identify the most common cost-related problems in shrimp farm management and, in particular, the costliest problems, and recommend cost-effective ways to overcome them. According to the PRISMA checklist, several items need to be addressed in a systematic review report.

Eligibility Criteria

In addition to the inclusion criteria (full-text, English), studies were excluded if they; (i) did not directly discuss cost-related aspects of shrimp farming; (ii) were non-peer-reviewed (e.g., editorials, reports); or (iii) were irrelevant to the research aim based on title or abstract screening. Any title or abstract that mentioned or discussed cost-related aspects of shrimp farming were considered relevant for review.

Information Sources

Five well-known electronic abstract and citation databases were used to collect existing studies: (1) Emerald Insight; (2) IEEE Xplore; (3) ScienceDirect; (4) Scopus; and (5) Taylor & Francis Online.

Search Strategy

The following search terms were used in the five electronic abstract and citation databases: "Shrimp farming" and "cost".

Studies Selection

The studies selection process was performed using Mendeley Desktop and Microsoft Excel, with Mendeley Desktop being used to check for duplicates of papers, and Microsoft Excel to facilitate management and indexing of the findings of the systematic literature review. The PRISMA flow chart is presented to show the complete study selection process.

Data and Information

The following data and information were extracted from the full text paper: (1) Operational location, (2) shrimp species, (3) research highlights, and (4) research findings. The collected data and information were managed within an Excel sheet and presented in tabular form.

Results

Studies Selection

The PRISMA flow chart as in Figure 1 depicts the study selection procedure, which involves four phases: Identification, screening, eligibility, and inclusion. In the first identification phase, a total of 321 studies were identified in Emerald Insight, IEEE Xplore, ScienceDirect, Scopus, and Taylor & Francis Online. These sources of information were chosen due to their accessibility and relevance to aquaculture economics, management, and technical sciences. These sources are recognised for their high-quality publications in agriculture and aquaculture disciplines. The exclusion of other databases may present a risk of missing some relevant literature, which is acknowledged as a limitation. Relevance was determined by whether the title or abstract indicated a focus on cost elements such as feed, disease, environment, and technology or economic returns in shrimp aquaculture operations. Any duplicated papers were excluded using the Check for Duplicates tool in Mendeley Desktop, and only reputable and fully reviewed journal articles and conference proceedings were included.

At the beginning of the screening process, 73 papers were excluded where the papers were either duplicates, book chapters, editorials, reports, or not in English. The titles and abstracts of 248 articles were then screened, resulting in the exclusion of a further 163 papers due to their unsuitability to the aims and objectives of the current research. In the stage of eligibility, 85 full-text papers were downloaded and read, out of which a further 44 were excluded due to the absence of any explicit discussion on the cost of shrimp farming, this being a primary focus for the current study. Finally, 41 articles (studies) were included in the review for qualitative analysis.

Study Characteristics

Following the analysis of 41 studies related to this research, a descriptive analysis of the types of papers included in this work is presented in Figure 2, and the geographical locations of studies in Figure 3. Figure 2 reveals that 92.5% of the total number of papers are journal articles with the remaining being conference proceedings. In Figure 3, it is observed that Vietnam had the most studies on cost-related issues in shrimp farming, with a total of 11 papers. Honduras, Indonesia, and Japan had only one paper respectively. The location of two papers was unspecified as the studies were general and not location specific, and three papers concentrated on multiple Asian countries.

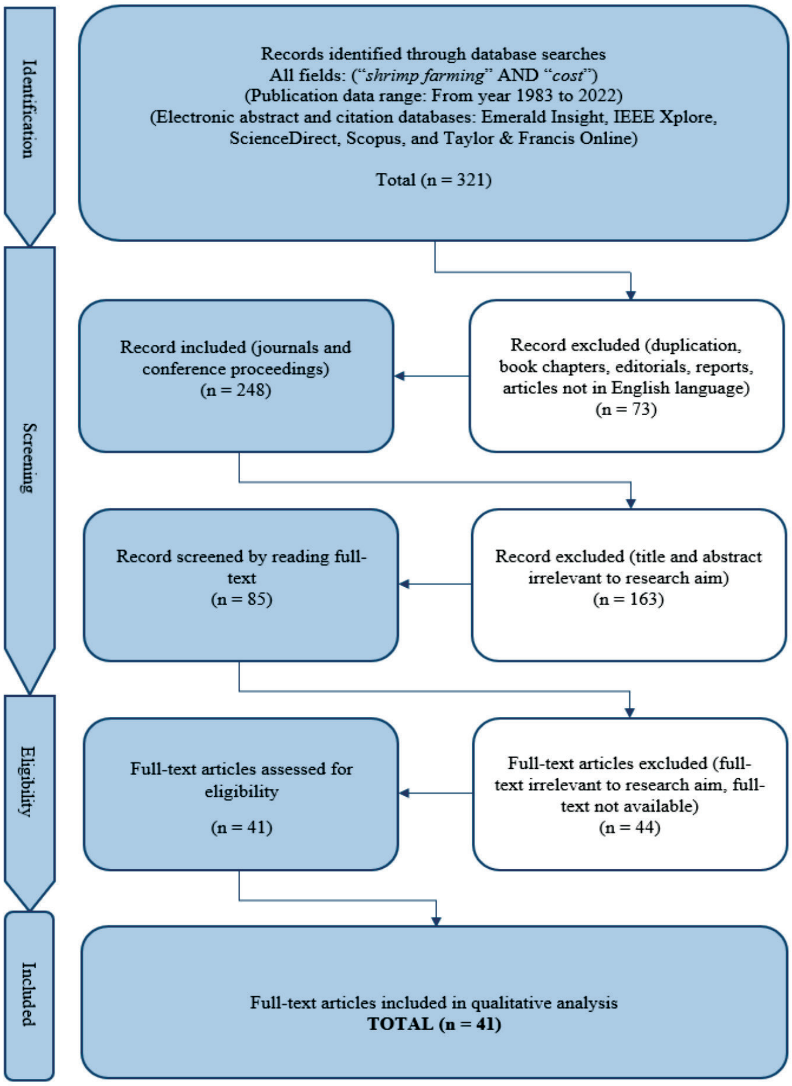

Figure 1: PRISMA flow chart for studies selection

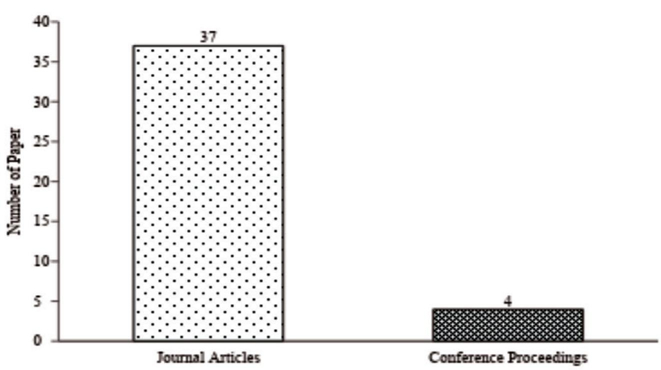

Figure 2: Type of paper

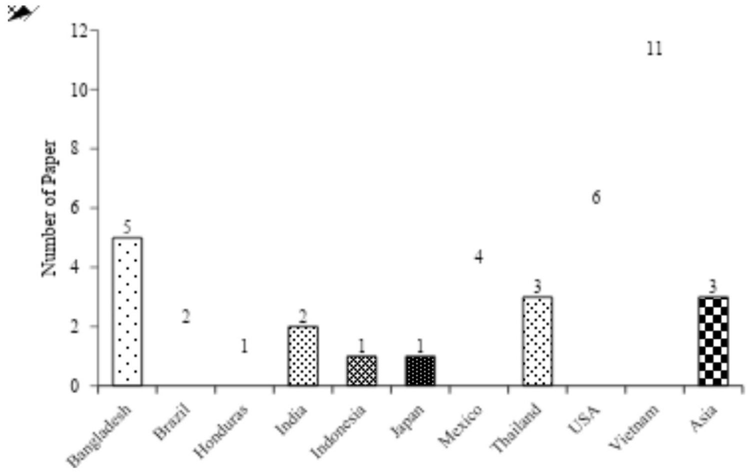

Figure 3: Geographical location of study

Data and Information from Selected Studies

Table 1 summarises the data and information extracted from the selected studies in ascending order by year, from 1983 to 2022. The nearly four-decade period emphasises the extent to which cost-related issues in shrimp farming are relevant. The collected information includes location, species, highlights, and findings for each selected study.

Table 1: Summary of data and information from selected studies

Sources	Location	Species	Highlights and Findings
Bauer *et al*. (1983)	United States of America	Freshwater prawn	Estimated costs and returns of freshwater prawn, *Macrobrachium rosenbergii* farming. The findings are that the construction of paddle wheel aerator sites for low oxygen levels and the lower-cost feed can help reduce production costs.
Griffin *et al*. (1984)	United States of America	Penaeid shrimp	Analysed the connection between facility design, environmental and management issues, and factors impacting production costs and profit for shrimp. The mean cost was $1450 per acre.
McKee *et al*. (1989)	United States of America	*Penaeus setiferus*	Conducted an economic and investment analysis. The highest cost item is labour, followed by production and harvest costs, which are post larvae and feed costs. The feeding rate can be reduced significantly without reducing shrimp growth by maximising natural productivity in ponds.
Miller (1990)	Mexico	Species not specified	Presented the shrimp aquaculture management in Mexico, including the operating costs.

Lambregts *et al*. (1993)	United States of America	*Penaeus vannamei*	Economies of scale and comparison of semi-intensive, intensive and very-intensive shrimp farms. Feed was the most critical cost item and energy the least important.
Kongkeo (1997)	Indonesia, Philippines, Taiwan, and Thailand	*Penaeus monodon*	Compared the shrimp farming management in 4 countries: Indonesia, Philippines, Taiwan, and Thailand. The total annual cost in Thailand is the highest among the four countries with $44.87 per hectare of pond due to high feed cost.
Shang *et al*. (1998)	Indonesia, Philippines, Malaysia, Vietnam, India, Bangladesh, Sri Lanka, and China	Hatchery and grow-out shrimp Asia	Analysed the costs and returns of shrimp grow-out in Asian countries with three stages of farms (intensive, semi-intensive, and extensive). Feed and seed are significant costs.
Paquotte *et al*. (1998)	Brazil	*Penaeus vannamei*	Examines a new technology of floating cages shrimp aquaculture. The result showed $4.7 per kg of production cost.
Ling *et al*. (1999)	Thailand, Indonesia, Philippines, Malaysia, Vietnam, India, Bangladesh, Sri Lanka, China, and Taiwan	*Penaeus monodon*, *Penaeus orientalis*, *Penaeus indicus* Asia	Comparison of shrimp farming cost in three farm systems in Asia. Domestic resource cost method was used to compare the benefits of the systems.
Be *et al*. (1999)	Vietnam	Species not specified	Discussed the severe saline intrusion in Mekong Delta and thus the costs of salinisation and sedimentation are estimated.
Hazarika *et al*. (2000)	Thailand	Species not specified	Examined the situation of shrimp farms before full-scale intensive shrimp farming was introduced. They found that shrimp farms located in the Mangrove area require high environmental cost.
Valderrama and Engle (2001)	Honduras	Species not specified	Conducted a financial risk analysis and identified the costs of a shrimp farm.
Mathis and Baker (2002)	United States of America	Species not specified	Examined the use of environmental assurance bonds to manage shrimp farms' environmental costs.
Islam *et al*. (2005)	Bangladesh	*Penaeus monodon*	Conducted a study at nine shrimp farms of different sizes. The findings showed that small farms spend more on inputs and labour. Thus, high net returns are expected compared to large farms that cost mostly on the size of ponds rather than focusing on the quality.

Bluffstone *et al*. (2006)	Thailand	Species not specified	Presented the economic instruments for managing environmental factors in shrimp farming as it caused a degradation of the environment.
Alam *et al*. (2007)	Bangladesh	*Penaeus monodon*	Cost and returns of 102 shrimp farms in 2002 were analysed. The average total cost of shrimp farming is $1084.40 per hectare.
Lan (2009)	Vietnam	Six shrimp species (*P. monodon*, *Macro branchium*, *Panulirus ornatus*, *P. homarus*, *P. longines*, and *P. timsoni*)	Estimated the environmental costs of coastal shrimp farms. The environmental cost increased by 0.39% for every unit of shrimp yield increased.
Sanchez-Zazueta and Martinez-Cordero (2009)	Mexico	Species not specified	Designed a stochastic bioeconomic model to analyse the management taken by the farm in combatting shrimp disease. Marketing the product directly would increase the operating costs by 33%.
Joffre and Bosma (2009)	Vietnam	Species not specified	Analysed technical and economic characteristics of 170 farms that were categorised into four systems (intensive commercial, intensive family farms, more extensive brackish water polyculture, and rice-shrimp farms). The costs of intensive commercial farms are 25 to 45 times higher than brackish water polyculture.
Bhattacharya and Ninan (2011)	India	Species not specified	Conducted a cost-benefit analysis of shrimp farms and compared between intensive and traditional farm systems. The result showed that intensive farms may have high returns but have high risk when environmental costs are considered.
Ponce-Palafox *et al*. (2011)	Mexico	*Litopenaeus vannamei*	Discussed the technical, economic, production, and environment variables of semi-intensive commercial farms. Findings revealed that investment in equipment and technology can help increase the farm yields.
Sanchez-Zazueta *et al*. (2013)	Mexico	Species not specified	Analysed credit management using a bioeconomic model. The result showed that the minimum cost was $15,710 for the operation of a farm.
Jatobá *et al*. (2014)	Brazil	*Litopenaeus vannamei*	Analysed the zootechnical performance and dietary costs for marine shrimp in a super-intensive biofloc system. Shrimp that has the most weight gain and crude protein contents of 32.9% costs the lowest in the semi-intensive farms.

Duy *et al*. (2015)	Vietnam	Species not specified	Presented a solution to manage the environmental conditions and lessen manpower that can lower the labour cost and the use of electricity.
Haider (2015)	Bangladesh	*Penaeus monodon*	Conducted a cost-benefit analysis of shrimp farms by including indirect and unaccounted costs.
Khac *et al*. (2016)	Vietnam	*Penaeus monodon*	Conducted costs and returns analysis on tiger shrimp farms. The result found that net revenue increased when the fixed, seed and feed costs were higher.
Akber *et al*. (2017)	Bangladesh	*Penaeus monodon*	Presented phased changes of shrimp farming, including the cost changes.
Seekao and Pharino (2018)	Thailand	*Penaeus vannamei*	Conducted flood risk mapping and a cost-benefit analysis to analyse the damage and measures taken for managing flood risk. The result showed a damage cost of $9,375 per flood.
Long *et al*. (2020)	Vietnam	*Penaeus vannamei*	Performed a data envelopment analysis to evaluate the cost and technical efficiency of shrimp farms. The result showed that the efficiencies were negatively influenced by credit constraints for operational cost.
Dhar *et al*. (2020)	Bangladesh	Species not specified	Presented the economic, environmental, and sustainability problems of shrimp farms.
Reis *et al*. (2020)	United States of America	*Litopenaeus vannamei*	Developed a better feeding protocol for automated systems, and stated that labour costs determine a farm's performance.
Quyen *et al*. (2021)	Vietnam	Species not specified	Presented the cost-benefit of farms with VietGAP. Farms with VietGAP were found to be more practical with maximum costs of $2,000 compared to farms without VietGAP with $10,000.
Emerenciano *et al*. (2021)	Location not specified	*Litopenaeus vannamei*	Described the past, present, and future Biofloc Technology (BFT) in shrimp farming. BFT optimises nutrients but has high production costs compared to the normal system due to high energy cost.
Nisar *et al.* (2021)	India	*Penaeus monodon* and *Litopenaeus vannamei*	Profitability and production function analysis of intensified shrimp farms were presented. The result showed that feed and labour are the most significant factor in production.
Wijaya *et al*. (2021)	Indonesia	*Litopenaeus vannamei*	40 shrimp farmers were interviewed to perform an economic analysis of shrimp farms. The land shrimp pond is the largest asset cost while feed and shrimp seeds cost the most operationally.

Folorunso *et al*. (2021)	Vietnam	Species not specified	Examined the technical efficiency of semi-intensive and intensive shrimp farms. The cost of shrimp seeds, feed, and lime were found to be important variables in determining the farm's efficiency.
Schwabe *et al*. (2021)	Vietnam	*Litopenaeus vannamei*	Discussed the relationship of input agents and farmers, highlighting that feed and fry make up to 60% to 80% of the cost.
Asche *et al*. (2021)	Location not specified	Species not specified	Presented a basic economic model to analyse the impact of disease on a shrimp farm.
Long (2022)	Vietnam	*Litopenaeus vannamei*	Analysed the cost efficiency of intensive white-leg shrimp farms using data envelopment analysis. Their findings showed that reducing chemicals/drugs and fry while increasing feed per ha can increase cost efficiency.
Hashiro and Yasueda (2022)	Japan	Species not specified	Discussed the use of RNAi-based pesticide in shrimp farming. Many issues of the reliability and safety of farm production can be solved using RNAi-based products.
Phu and Nguyen (2022)	Vietnam	Species not specified	Examined the use of oxygen aerators using solar energy for farms in areas without electricity. Twice or more of the costs can be saved when gas and oil-powered oxygen aerators are changed to solar energy.

Discussions

Feed Costs

When managing shrimp farms, costs can vary depending on area, shrimp size, shrimp stages, and farm types (intensive, semi-intensive, and extensive). Alam *et al*. (2007) emphasised that shrimp production costs depend on the level of management effort and the type of facilities. Annual fixed costs are independent of production levels such as ponds, wells, and equipment, while variable costs represent costs that change with production levels such as labour, fertiliser, and electricity costs, with many of the studies discussing the issue of feed being the most significant operating cost in a shrimp aquaculture (Sanchez-Zazueta & Martinez-Cordero, 2009). Among the 41 reviewed studies, feed consistently emerged as the dominant cost factor, often accounting for 60% to 80% of operating costs (Sanchez-Zazueta & Martinez-Cordero, 2009; Schwabe *et al*., 2021). This finding aligns with global aquaculture trends, where feed prices are increasingly volatile due to dependence on imported raw materials.

Environmental Factors

Of the 41 selected studies, the issue discussed most frequently was that of the farming environment, because this is an important determinant of the performance and yield of shrimp farms, affecting the profitability of farmers. One of the most important environmental issues is water quality, which includes water temperature, salinity, pH, and dissolved oxygen levels, with temperature and salinity having a major impact on shrimp growth (Griffin *et al*., 1984). On the Texas coast, salinity is typically between 30 and 32 parts per thousand (ppt), but varies from 7 to 50 parts per thousand (ppt) depending on the area. In Taiwan, however, salinities of 10 to 15 ppt in ponds cause many problems, including high costs for underground water pumping, land subsidence, an increase in pathogens, and heavily polluted soil (Kongkeo, 1997).

Kongkeo (1997) discussed that, as a result of this problem, the bacteria which attack the organic matter at the floor of the pond multiply rapidly, causing both the pond to degrade faster and the feed to decompose faster, resulting in higher feed costs. The poor operating environment leads to a higher likelihood of disease infestation and stress symptoms in shrimp, which in turn increases mortality (Alam *et al*., 2007). Pale discoloration of the body and rotting tails are the symptoms in shrimp that indicate poor environmental quality, while when the oxygen content in the water is low, lubrication pumps are needed to reoxygenate the water to an adequate level, resulting in higher operating costs (Griffin *et al*., 1984). Shrimp farming in mangrove areas cost more than other regions due to the environmental impact on the nearby area resulting from shrimp farming activities (Hazarika *et al*., 2000).

Disease-Related Costs

A further issue that is often the focus of shrimp farming studies is viral and disease infections in shrimp. Common shrimp viruses include White Spot Syndrome, Yellowhead, Taura Syndrome, and Infectious Hypodermal and Hematopoietic Necrosis (IHHN), such infections posing the risk of damage to the marine ecosystem where populations of wild shrimp species can be harmed. The viruses can also be spread to markets as they can survive freezing. Frequent disease outbreaks can be caused by high shrimp density and low water quality of the shrimp farm, a condition that results in the release of toxic gases that can harm the shrimp by causing stress and reducing their resistance to disease (Kongkeo, 1997).

Technological Investment

Joffre and Bosma (2009) discussed that intensifying technological investment and increasing biodiversity can help reduce disease outbreaks, but the cost of maintaining the farming environment increases proportionately as preventive measures are taken by farmers to combat disease problems, that can cause large losses if left unattended. The previously referred oxygen aerators for environments with low water oxygen levels are a case in point. However, certain technologies such as solar powered aerators, as discussed by Phu and Nguyen (2022), can potentially mitigate operating costs being cheaper than fossil fuels, although there is the initial investment cost to consider. Another measure to keep water quality at a satisfactory level to prevent disease with less cost is to reduce the stocking density of shrimp as this can prevent overcrowding and oxygen starvation (Sanchez-Zazueta & Martinez-Cordero, 2009).

Recommendations

The world has been in recovery since the World Health Organization (WHO) declared the coronavirus disease 2019 (COVID-19) a global pandemic in March 2020, a disease which has killed millions and caused sickness among tens of millions. As a result of urgent measures taken to prevent the virus from spreading, the global economy plummeted, severely impacting sectors heavily dependent on trade, including fisheries and aquaculture.

The aquaculture industry has felt the effects of the pandemic particularly severely, having been impacted by import and export restrictions put in place by certain countries in a bid to contain the virus. Aside from this, labour issues are also hampering the industry in many countries that rely on foreign workers to run their farms. Immigration restrictions during the pandemic seriously impacted workforce availability, and even now, while still in recovery mode, the fluctuating input to aquaculture represents a serious threat to the industry. Further research on the unique characteristics and exchange patterns of shrimp farming and how it can adapt to the global scenario needs to be done. Many countries still rely heavily on imported feed for their shrimp industry, and although feed issues have been discussed in most papers, there is no economic study dealing with feed price increases and its consequences. The variation in feed prices needs to be estimated or extrapolated into the analysis to obtain a clearer picture of the profitability of shrimp farming in the long run.

Aside from feed prices, the quality of broodstock and brood must also be considered in any economic analysis as it is one of the main factors in determining the profitability of shrimp farms. Broodstock and brood are imported by certain countries, but problems have manifested during growth in some cases of broodstock and brood, demonstrating poor resistance against disease. Thus, the costs associated with poor quality broodstock need to be included in any cost-analysis study.

Regarding new technologies, there is a need to further investigate the suitability or of solar power and Recirculating Aquaculture Systems (RAS) for small, medium, and large farms. Currently, the aquaculture industry is still heavily reliant on conventional power such as fossil fuel and natural resources. Therefore, appropriate studies should be conducted to gain insights into the application of these new technologies.

Finally, it is rare to find studies that calculate losses at the farm level related to disease, with available information focusing on national losses rather than those at the operational level. It is essential to understand the potential losses shrimp farmers might bear so that relevant authorities can develop appropriate policies to provide sustainable economic support to those in need. In addition, such support could provide shrimp farmers with information on how best to manage their farms based on relevant scenarios simulated in future studies.

To summarise, the sustainability of shrimp industry would benefit from a more comprehensive analysis related to the following themes:

(a) The impact of the latest technologies on shrimp farm profits.

(b) The impact of brood stock or fry on a broader range of shrimp species.

(c) The current currency exchange rate affecting the prices of feed and brood stock.

(d) The impact of alternative treatments to combat disease.

(e) The costs associated with disease at the farm level.

Conclusions

In conclusion, this paper reviewed 41 studies using the PRISMA guide to examine the cost-related issues in shrimp farming. The results show that environment and disease are the most important cost-related issues in shrimp farming, these two issues being closely related to the increased costs associated with feeding and the use of new technologies. A limitation of the current study, however, is that as a systematic literature review, while this review synthesises findings from 41 studies, it must be noted that many studies did not quantify cost categories in detail. The review thus draws qualitative trends rather than statistical generalisations.

Therefore, recommendations for future research include the exploration of all the other factors and costs associated with shrimp farming, herein only mentioned but not directly researched. This analysis provides some useful insights into the associated fixed and operational costs of shrimp farming and the effects on profitability of even minor variations in costs. In many ways, the shrimp farming industry is unique compared to other segments of aquaculture because of its susceptibility to diseases and variations in farm practice management. However, owing to shrimp remaining a high value commodity and high demand species, shrimp farming has the capacity to provide a significant contribution to a nation’s income.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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