

Sustainable Aquaculture Practices for Milkfish (*Chanos chanos*): An Integrated Analysis of Environmental, Economic, and Policy Dimensions in Asia

Jane Mar L. Alimorin^{1,2}

¹Department of Basic Agricultural Sciences, College of Agriculture, University of Science and Technology of Southern Philippines, Claveria, Misamis Oriental, Philippines

²Open University, Visayas State University, Visca, Baybay City, Leyte, Philippines

Corresponding Author: Jane Mar L. Alimorin

DOI: <https://doi.org/10.52403/ijrr.20250749>

ABSTRACT

This paper provides a comprehensive analysis of sustainable milkfish aquaculture in Asia, focusing on the environmental, economic, and policy dimensions. The importance of milkfish farming, particularly in Southeast Asia, is examined in light of its contribution to food security, rural livelihoods, and the broader economy. The review highlights the need for integrated approaches that combine technological advancements, efficient resource management, and improved governance to ensure sustainability. Key trends, such as the adoption of Multitrophic Recirculating Aquaculture Systems (MRAS), integrated farming systems, and genetic improvements in hatchery technologies, are explored. These practices enhance water quality, reduce the environmental footprint, and promote long-term viability. Additionally, the role of policy frameworks, including regulatory measures, certification systems, and public-private partnerships, is emphasized as essential in supporting sustainable milkfish production. The review also identifies emerging challenges, such as the effects of climate change on water quality and production rates, the impact of waste management practices on ecosystems, and the need for better stakeholder participation

and governance frameworks. The findings stress the importance of coordinated efforts across countries and sectors to achieve sustainable milkfish aquaculture. By bridging the environmental, economic, and policy aspects, this paper offers valuable insights for policymakers, researchers, and practitioners aiming to advance sustainable practices in the aquaculture industry. Ultimately, it underscores the necessity of a holistic approach to address the multidimensional challenges faced by milkfish farming in Asia and ensure its sustainability for future generations.

Keywords: Milkfish aquaculture, sustainability, environmental impacts, economic viability, policy frameworks, Southeast Asia, technological innovation, governance.

INTRODUCTION

Milkfish (*Chanos chanos*) has long been a cornerstone of aquaculture in Asia, particularly in the Philippines, Indonesia, and Taiwan, where it has been cultivated for centuries in brackish water ponds and fish pens (Smith & Chong, 1984). These countries collectively account for the majority of global milkfish production, with Indonesia and the Philippines being especially prominent due to their extensive

coastal and pond resources (Smith & Chong, 1984; Troell, 2009; Henriksson et al., 2017). The cultivation of milkfish is deeply embedded in the socioeconomic fabric of coastal communities across Southeast Asia. It provides not only a vital source of affordable animal protein but also supports the livelihoods of thousands of smallholder farmers, fish workers, and their families (Smith & Chong, 1984). In Indonesia, for example, traditional tambak (pond) aquaculture has sustained rural economies since at least the 15th century, underpinning food security and rural employment (Troell, 2009; Henriksson et al., 2017; Partelow et al., 2018).

Despite its importance, the sustainability of milkfish aquaculture is increasingly challenged by environmental, economic, and governance pressures. Environmental issues such as habitat degradation, overuse of shared resources, and declining water quality threaten long-term productivity (Partelow et al., 2021; Bush et al., 2019). Economically, producers in Taiwan and the Philippines face declining profitability due to rising input costs, stagnant market prices, and shifting consumer preferences toward alternative species like tilapia (Smith & Chong, 1984). Governance gaps further complicate the sector, with limited institutional capacity, ineffective policy implementation, and inadequate support for collective action among stakeholders (Partelow et al., 2023; Hishamunda et al., 2014; Bush et al., 2019). The information on milkfish farming is disconnected, as it usually deals with one issue at a time, such as installation or market trends without consolidating the environmental, economic as well as the policy perspective. This lack of an integrated approach is the root of the unsustainability of the same. A systematic review that bridges these dimensions is therefore essential to inform policy, guide future research, and support the transition toward more sustainable milkfish aquaculture in Asia (Smith & Chong, 1984; Partelow et al., 2023).

The absence of a comprehensive review that discusses the environmental, social, and economic context of sustainability when it comes to the production of milkfish is particularly noticeable. This review is not only necessary for reaching the balance between benefits, efficient methods, and research voids but also for understanding the situation better as a whole. By addressing this need, the present review aims to contribute to the development of integrated policy approaches and sustainable farming strategies in the Asia-Pacific region.

METHODS

This study employed a systematic review approach to comprehensively examine the environmental, economic, and policy dimensions that influence the sustainability of milkfish aquaculture across selected Asian countries. These countries include major producers and innovators in milkfish farming such as the Philippines, Indonesia, Taiwan, Singapore, as well as other nations within the broader Asia-Pacific region where aquaculture plays a vital role in food security and economic development. The methodological framework of this study draws from established systematic review protocols commonly used in environmental science and aquaculture research, ensuring a rigorous and transparent process for data selection, analysis, and synthesis. Through this approach, the study aims not only to consolidate existing knowledge but also to identify emerging trends, critical gaps, and challenges that may hinder the advancement of sustainable practices (Travero et al., 2025). The findings are intended to inform evidence-based policy recommendations, guide future research directions, and support the development of management strategies that promote ecological resilience, economic viability, and regulatory effectiveness within the milkfish aquaculture sector.

1. Literature Search Strategy

The review followed a structured and reproducible search process, employing a combination of academic databases and

institutional repositories to ensure comprehensive coverage of relevant literature. Primary databases included Scopus, ScienceDirect, Web of Science, JSTOR, and Google Scholar, which provided access to peer-reviewed journal articles, conference papers, and other scholarly works. To supplement these academic sources, additional materials were gathered from reports and publications produced by reputable international agencies such as the Food and Agriculture Organization (FAO), the Bureau of Fisheries and Aquatic Resources (BFAR) in the Philippines, and the Asian Development Bank (ADB). National aquaculture development plans and policy documents from selected Asian countries were also reviewed to capture practical insights and policy directions (Nagal et al., 2024). This multi-source approach ensured that the review integrated both scientific evidence and grey literature, offering a balanced and contextually grounded understanding of sustainable milkfish aquaculture.

Search terms included combinations of the following keywords: “milkfish aquaculture,” “sustainable aquaculture,” “*Chanos chanos*,” “environmental impacts,” “economic viability,” “aquaculture policy,” “Asia,” “integrated aquaculture systems,” and “recirculating aquaculture systems.” Boolean operators (AND, OR) were applied to refine and filter results.

2. Inclusion and Exclusion Criteria

To ensure rigor and relevance, only peer-reviewed articles, agency reports, and published technical documents from 2000 to 2024 were considered. Inclusion criteria were:

- Studies focusing on milkfish aquaculture in Asia;
- Literature addressing at least one of the following dimensions: environmental sustainability, economic efficiency, or policy frameworks;
- English-language publications;
- Empirical, theoretical, or review-based articles.

- Excluded materials comprised non-peer-reviewed blog articles, media opinion pieces, and grey literature lacking sufficient methodological transparency.

3. Data Extraction and Synthesis

Each selected document was systematically reviewed and coded using a data extraction matrix designed to capture key variables, including:

- Country of origin;
- Type of aquaculture practice (e.g., pond culture, MRAS, offshore cage systems);
- Environmental impacts and management (e.g., water quality parameters, effluent control, biodiversity effects);
- Economic indicators (e.g., feed conversion ratio, profitability, market access);
- Policy and governance features (e.g., regulatory frameworks, stakeholder participation, co-management models).

A thematic analysis was conducted to systematically organize the findings into three major domains: environmental sustainability, economic viability, and policy and governance. This analytical approach enabled a structured examination of the literature while maintaining flexibility to capture the complexity and interconnections among these domains (Nagal, 2025). Thematic coding employed both inductive and deductive strategies—drawing on existing theoretical frameworks while remaining open to new insights and patterns emerging from the data (Abao et al., 2024). This dual approach facilitated the identification of cross-cutting themes, recurrent issues, and emerging challenges that shape the sustainability of milkfish aquaculture in the Asian context. By synthesizing these patterns, the study provides a nuanced understanding of the multi-dimensional factors influencing sustainable aquaculture development and highlights priority areas for future research, policy intervention, and industry practice.

4. Quality Assessment

To ensure the credibility and reliability of sources, each document was appraised using

an adapted version of the Critical Appraisal Skills Programme (CASP) checklist for reviews. Studies were evaluated on criteria such as clarity of objectives, methodological soundness, data transparency, and analytical depth. Only sources meeting at least 70% of the quality criteria were retained in the final synthesis.

5. Limitations

This review was limited to publications in English, which may have excluded relevant studies published in local Asian languages. Furthermore, while every effort was made to access the most recent and credible data, there may be publication lags in government or institutional reports that influence the currency of economic or policy data.

ADVANCEMENTS IN SUSTAINABLE MILKFISH CULTIVATION IN ASIA

Sustainable milkfish farming has gained increasing attention across Asia as countries strive to balance aquaculture productivity with environmental responsibility and economic viability. The following table presents a comprehensive overview of current trends shaping sustainable milkfish farming in the region. These trends highlight significant advancements in production practices, alongside efforts to address ecological impacts, integrate new technologies, and strengthen economic

resilience. Together, they underscore the critical role of innovation and cross-sector collaboration in ensuring the long-term sustainability of milkfish aquaculture.

One significant trend is the increasing demand for milkfish seeds in the Philippines, which is driven by the growing milkfish production and the need for expanding seed production facilities such as Integrated Breeding and Hatcheries (IBH) (Table 1). This growth necessitates coordinated investments in seed production infrastructure to ensure self-sufficiency and sustainability within the milkfish industry (Salayo et al., 2020). The establishment of robust seed production facilities is essential for meeting the increasing demand for high-quality seeds, which are critical for maintaining a steady supply chain in the aquaculture sector. In response to the challenges posed by high-investment and low-profit ventures like IBHs, the Philippines has also focused on promoting public-private partnerships. This collaboration encourages balanced, sustainable growth by efficiently utilizing capital and workforce, which secures the upstream milkfish value chain (Salayo et al., 2020). By integrating public and private efforts, this approach streamlines resource management and ensures the long-term sustainability of the industry, thus enhancing overall production efficiency.

Table 1: Current Trends in Sustainable Milkfish Farming in Asia

Current Trend	Country of Origin	Implications	References
Increasing demand for milkfish seeds driven by growth in milkfish production and the need to expand seed production facilities such as Integrated Breeding and Hatchery (IBH)	Philippines	Necessitates coordinated investments in seed production infrastructure to secure self-sufficiency and sustainability of the milkfish industry	Salayo et al. (2020)
Promotion of public-private partnerships to fund high-investment but low-profit IBHs alongside profitable hatcheries, nurseries, and cage culture		Encourages balanced sustainable growth through efficient utilization of capital and workforce, securing the upstream milkfish value chain	
Integration of Multitrophic Recirculating Aquaculture Systems (MRAS) with Photosynthetic Bacteria (<i>Rhodovulum sulfidophilum</i>)	Taiwan	Enhances water quality by reducing ammonia and nutrient concentrations, thereby preventing harmful cyanobacteria blooms.	Chang et al. (2019)

		<p>Promotes beneficial microbial communities (including nitrogen cycle bacteria and anoxygenic phototrophs) that improve ecosystem function and health.</p> <p>Reduces water resource consumption and minimizes wastewater discharge and marine pollution.</p> <p>Supports co-culture of multiple species (milkfish, shrimp, clams, seaweed) for efficient resource utilization and enhanced production sustainability.</p>	
Application of Beneficial Microbial Communities for Water Quality and Disease Management in Coastal Aquaculture		<p>Use of beneficial bacteria such as <i>Rhodovulum sulfidophilum</i> reduces pathogenic bacteria (e.g., <i>Vibrio</i>, <i>Escherichia</i>), enhancing animal health and survival.</p> <p>Promotes a stable and healthy microbial environment in aquaculture ponds, reducing reliance on chemical treatments.</p> <p>Helps maintain low ammonia and nutrient levels, mitigating eutrophication risks and environmental impacts.</p> <p>Supports sustainable intensification of aquaculture by maintaining ecosystem balance.</p>	
Transition from low-tech to high-tech aquaculture systems including Recirculating Aquaculture Systems (RAS) and offshore cages with automation	Singapore	Enhances productivity, sustainability, and biosecurity; reduces manpower and operational costs through automation and monitoring; promotes environmentally friendly practices by reducing pollution and integrating filter feeders	Shen et al. (2020)
Focus on genetic improvement and hatchery technologies for producing genetically improved milkfish fry		Ensures consistent supply of high-quality fry, which is critical to expanding local milkfish aquaculture; supports food security by producing superior and disease-resistant stocks suitable for local and regional markets	
Utilization of simple, environmentally friendly technology for milkfish cultivation in coastal ponds	Indonesia (Sumbawa Island)	Supports continuation of milkfish farming with minimal environmental impact; allows high survival rates and low production costs; promotes sustainability without needing complex technology upgrades.	Asrial et al. (2020)
Emphasis on extensification and technological improvement including reuse of abandoned pond lands and continuous modification of culturing techniques (Rapmilkfish)		Addresses weaknesses in technology and economic sustainability dimensions; aims to improve management sustainability through optimizing pond conditions and operational methods; targets enhancing farmer resilience and market integration.	
Development and utilization of hatchery-produced milkfish seeds	Indonesia	Shift from reliance on limited wild seeds from natural mangrove areas to sustainable hatchery production (~800 kg/MT/Ha), ensuring continuous seed availability and reducing pressure on natural resources.	Rahmah (2022)
Implementation of site and environmental criteria for sustainable cultivation		Emphasis on selecting cultivation sites free from pollution, with optimal water quality parameters (salinity, temperature, pH, dissolved oxygen), and protection from storms and human activity; this ensures fish health, environmental sustainability, and reduces risks of disease/outbreaks.	

Taiwan's adoption of Multitrophic Recirculating Aquaculture Systems (MRAS) with photosynthetic bacteria (*Rhodovulum sulfidophilum*) is another important trend that has proven beneficial for improving water quality. These systems help reduce ammonia and nutrient levels in the water, thus preventing harmful cyanobacteria blooms and promoting healthier ecosystems for milkfish farming (Chang et al., 2019). Furthermore, MRAS minimizes water consumption and wastewater discharge, which mitigates environmental pollution. The integration of multiple species, such as milkfish, shrimp, clams, and seaweed, optimizes resource utilization and enhances the sustainability of the production system (Chang et al., 2019).

Another innovation in Taiwan's aquaculture practices involves the application of beneficial microbial communities, such as *Rhodovulum sulfidophilum*, to improve water quality and manage diseases. The use of these microbial communities helps reduce pathogenic bacteria like *Vibrio* and *Escherichia*, which are harmful to fish health. This sustainable approach decreases reliance on chemical treatments, supporting healthier aquaculture environments and reducing the risks associated with eutrophication (Chang et al., 2019). By maintaining a balanced microbial ecosystem, this method also facilitates the sustainable intensification of aquaculture practices.

In Singapore, the transition from low-tech to high-tech aquaculture systems, including Recirculating Aquaculture Systems (RAS) and offshore cages with automation, represents a significant shift toward enhanced productivity, sustainability, and biosecurity. These systems reduce operational costs through automation, promote environmentally friendly practices by minimizing pollution, and ensure greater efficiency in milkfish farming (Shen, Ma, & Yue, 2020). High-tech systems also reduce manpower requirements, which makes them more scalable and less resource intensive. As such, this transition is crucial for ensuring the

long-term sustainability and profitability of the milkfish farming industry in Singapore.

The focus on genetic improvement and hatchery technologies is also pivotal in ensuring the consistent supply of high-quality milkfish fry. In Singapore, genetic advancements in hatcheries aim to produce disease-resistant, high-quality fry, which is critical for expanding local aquaculture operations. By producing superior and more resilient stocks, these technologies help enhance food security and increase the economic viability of the milkfish industry (Shen et al., 2020). Consistently producing healthy fry is a key component in addressing challenges such as disease outbreaks and ensuring a reliable supply of milkfish for local and regional markets.

In contrast, Indonesia, particularly on Sumbawa Island, has focused on utilizing simple, environmentally friendly technologies in coastal ponds. These methods ensure high survival rates and low environmental impact, allowing for continued milkfish farming without the need for complex technological upgrades. This approach is especially important in regions where advanced technologies may not be easily accessible, as it offers a cost-effective and sustainable solution to milkfish cultivation (Asrial et al., 2020). The use of low-tech methods ensures that farmers can continue to engage in aquaculture practices while minimizing their environmental footprint.

Additionally, Indonesia emphasizes the importance of selecting optimal sites for milkfish cultivation to ensure long-term sustainability. By choosing locations with favorable water quality parameters—such as salinity, temperature, pH, and dissolved oxygen—farmers can reduce the risks of disease outbreaks and improve fish health. Protecting cultivation sites from pollution, human activity, and extreme weather events further enhances the sustainability and success of milkfish farming in the region (Asrial et al., 2020). This approach ensures that environmental factors conducive to healthy fish farming are prioritized, thus

supporting both productivity and sustainability.

With this, the trends highlighted in the table reflect the continuous evolution of sustainable practices in milkfish farming across Asia. From the genetic improvements and high-tech systems in Singapore to environmentally friendly practices in Indonesia, these developments demonstrate the importance of research, technological innovation, and environmental stewardship in achieving a sustainable and profitable milkfish farming industry. Addressing the technological, economic, and environmental challenges that come with milkfish farming is essential to ensuring that the industry remains viable and continues to meet global demands for this important aquaculture species.

GAPS AND EMERGING CHALLENGES IN ENVIRONMENTAL, ECONOMIC, AND POLICY DIMENSIONS ENVIRONMENTAL ASPECTS

Water quality is a key determinant of fish health and productivity in aquaculture. Parameters such as dissolved oxygen (DO), pH, nutrients, temperature, and organic matter significantly influence fish growth, health, and survival rates. Poor water quality can lead to disease outbreaks, increased mortality, and lower yields, which in turn, severely impact production efficiency and economic returns. As the table illustrates, monitoring and managing water quality are essential practices across various regions, particularly Southeast Asia, including countries such as China, Vietnam, and Indonesia (Yusoff et al., 2024; Razman et al., 2023). The need for rigorous water quality management systems in these regions is critical in maintaining sustainable aquaculture practices. Efforts to monitor parameters like oxygen levels, temperature, and nutrient concentrations are necessary to

mitigate risks associated with poor water quality, which can lead to disease outbreaks and production losses (Ohagan et al., 2023). The discharge of untreated effluents from aquaculture operations poses a serious environmental threat, particularly in regions such as China and Southeast Asia. These effluents often contain excess nutrients and organic matter, which, when released into nearby water bodies, contribute to eutrophication—an environmental process that depletes oxygen levels in aquatic ecosystems and leads to the deterioration of water quality. This environmental degradation can harm biodiversity and the health of surrounding ecosystems. The need for improved waste and effluent management systems is vital for minimizing the ecological footprint of aquaculture activities (Yusoff et al., 2024; Razman et al., 2023). By implementing more effective effluent treatment and waste management practices, aquaculture industries can reduce the negative impacts on water bodies and promote a healthier environment.

Countries like Indonesia and China are increasingly utilizing integrated aquaculture systems, including aquaponics and the addition of polylactic acid (PLA), to enhance water quality and reduce the reliance on chemical inputs. Aquaponics, a system that integrates fish farming with plant cultivation, provides a natural biofiltration process that improves water quality by removing excess nutrients (Table 2). This approach not only reduces the need for chemical fertilizers but also promotes a circular economy within the aquaculture industry, where waste products from fish farming are used to nourish plants, creating a symbiotic relationship between the two systems. The use of PLA, a biodegradable polymer, further enhances the sustainability of aquaculture practices by promoting eco-friendly materials that minimize environmental impact.

Table 2: Environmental Implications of Sustainable Aquaculture in Asia

Environmental Dimension	Country of Origin	Implications
Water Quality (DO, pH, nutrients, temperature, organic matter)	Various, incl. Southeast Asia (China, Vietnam, Indonesia)	Significant influence on fish growth, health, mortality, and yields; Poor quality leads to disease and production loss; Need for monitoring and management
Waste and Effluent Management	China, Southeast Asia	Discharge of untreated effluents affects nearby water bodies, ecosystem health, causing eutrophication
Use of Integrated Systems (Aquaponics, Polylactic acid addition)	Indonesia, China	Enhances water quality by biofiltration; reduces use of chemical inputs; promotes circular economy in aquaculture
Environmental Governance & Licensing	UK, Asia	Lack of clear frameworks hinders sustainable development; Certification encourages good practices, especially for export markets
Climate Change Effects	Southeast Asia	Influences physical and chemical water parameters causing fluctuations which raise disease risk and decrease productivity
Ecosystem Health & Biodiversity Considerations	UK, China	Macroalgae aquaculture considerations show importance of ecosystem services; Coastal policy effectiveness impacts sustainability
Use of Intelligent and Unmanned Equipment for Monitoring	China	Improves precision in environmental monitoring, early disease detection and resource optimization
Feed Production and Usage Impact	Global	Feed sourcing and usage relates closely to environmental footprint; lifecycle assessments crucial for sustainability
Scale of Farming and Collective Impact	UK, Asia	Single smallholder farms have limited effect, but conglomerates impact environment significantly; landscape-scale governance needed

The effectiveness of environmental governance is a crucial factor in the sustainable development of the aquaculture industry. In regions such as the UK and parts of Asia, the lack of clear environmental governance frameworks and licensing systems can hinder the progress toward sustainable aquaculture practices. The establishment of comprehensive frameworks and the use of certification systems can encourage good practices and ensure that aquaculture activities are conducted responsibly, especially in export markets where sustainability is becoming an increasingly important factor. Certification systems not only promote environmental sustainability but also help aquaculture products meet international standards, thereby increasing their marketability. Climate change is expected to have significant implications for aquaculture practices, particularly in Southeast Asia, where changes in physical and chemical water parameters are already being observed.

Fluctuations in water temperature, salinity, and other variables may increase the risk of diseases and decrease overall productivity. As water parameters become more volatile, aquaculture systems may face challenges in maintaining optimal conditions for fish growth, leading to reduced yields and higher mortality rates. Therefore, understanding and mitigating the effects of climate change is a key area of focus for the aquaculture industry. Adaptation strategies that include improving infrastructure and investing in climate-resilient practices are crucial for sustaining the industry in the face of climate-related challenges.

Ecosystem health and biodiversity are vital components of sustainable aquaculture practices. The inclusion of macroalgae in aquaculture systems, as seen in the UK and China, underscores the importance of considering ecosystem services when designing aquaculture operations. Macroalgae not only enhance water quality by absorbing excess nutrients but also

contribute to overall ecosystem health by providing habitat for marine life and supporting biodiversity. Effective coastal policies and governance frameworks are essential for ensuring the sustainability of these practices, as they help safeguard ecosystem services and promote the long-term health of aquatic environments (Yusoff et al., 2024).

Technological advancements in monitoring and management are increasingly being adopted in China, where intelligent and unmanned equipment is used to improve the precision of environmental monitoring. These tools enable real-time data collection on water quality, disease outbreaks, and resource optimization, enhancing the ability to detect problems early and respond quickly. The use of unmanned equipment, such as drones and automated sensors, has the potential to revolutionize aquaculture monitoring by providing more accurate and timely information, leading to more efficient and sustainable farming practices (Yusoff et al., 2024).

Feed production and usage are critical factors in the environmental footprint of aquaculture operations. The sourcing of ingredients for fish feed and the efficiency of feed utilization directly impact the sustainability of the industry. Global efforts to assess the lifecycle of feed products are important for understanding their environmental impact. By optimizing feed production and reducing waste, aquaculture operations can significantly reduce their environmental footprint and improve sustainability. Sustainable feed practices not only benefit the environment but also enhance the economic viability of the industry by reducing feed costs and improving resource efficiency (Yusoff et al., 2024).

The scale of farming operations plays a significant role in determining the environmental impact of aquaculture activities. While smallholder farms may have a limited effect on the environment, large conglomerates operating on a landscape scale can cause significant ecological damage. Therefore, landscape-scale

governance and management frameworks are needed to address the collective impact of large-scale aquaculture operations. Effective regulation and coordination across farms of varying sizes can help minimize environmental degradation and ensure that aquaculture activities contribute to sustainable development goals.

ECONOMIC ASPECTS

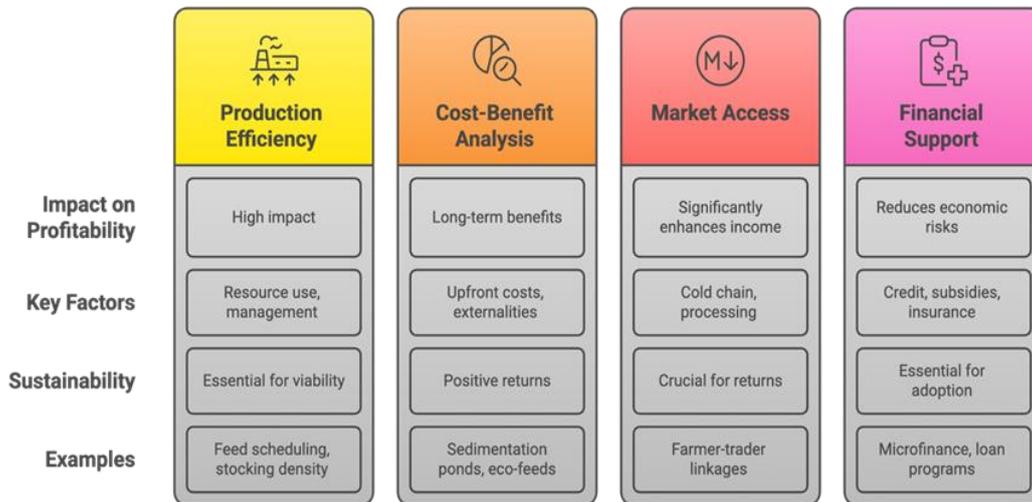
Production Efficiency and Profitability

Sustainable aquaculture practices for milkfish in Asia demonstrate variable production efficiencies and profitability, contingent upon environmental conditions, management practices, and technological adoption. In Taiwan, Sonvisen and Standal (2019) employing stochastic frontier analysis suggest that environmental variables such as pond depth, fish fry size, and shrimp density significantly influence technical efficiency, with smaller ponds and optimized farming parameters enhancing productivity. Similarly, Yustika (2008, 2012) emphasizes that water quality management is crucial; monitoring efforts in West Java, Indonesia, indicate that maintaining parameters such as pH, dissolved oxygen, and salinity contributes to higher survival rates and better growth performance, thus positively impacting profitability. The economic analyses incorporating cost-benefit evaluations in Indonesia, as discussed by Asfi Manzilati et al. and further supported by Yustika (2012), demonstrate that aquaculture systems, when aligned with environmental standards and optimized resource use, are financially feasible and can sustain production efficiency. The findings of Sodikin (2016) and Rostika et al. (2018) reinforce the importance of environmental and infrastructural factors in effective aquaculture development, which directly influence productivity outcomes. Implications of these results underscore the necessity for integrated environmental and economic management strategies to enhance productivity and ensure sustainability. Countries like Taiwan and Indonesia exemplify how technological improvements,

water quality regulation, and adaptive strategies can lead to more efficient and profitable milkfish aquaculture, thereby contributing significantly to local livelihoods and food security in Asia. These insights

consolidate the importance of tailored management practices and environmental considerations for sustainable milkfish farming across Asian regions.

Figure 1: Economic Aspects of Milkfish Aquaculture, Highlighting Key Factors and Their Impact on Profitability



Cost-Benefit Analyses of Sustainable Practices

Recent studies in Asia, particularly from the Philippines and Indonesia, have underscored the economic and sustainability potential of alternative feeding strategies in milkfish aquaculture. Research by Macusi et al. (2024) and Macusi et al. (n.d.) in the Philippines demonstrated that integrating indigenous feed materials such as taro (*Colocasia esculenta*) and bloodmeal can achieve similar growth rates compared to commercial feeds, with bloodmeal producing a notably low feed conversion ratio (FCR) of 1.60. These interventions yielded promising financial metrics, as diets combining taro with commercial feeds resulted in a gross profit margin of 42% and a cost-benefit ratio of 1.37, indicating tangible economic benefits for milkfish farmers (Macusi et al., 2024; Macusi et al., n.d.).

On a broader socio-economic scale, research by Shalli et al. (2023) and Macusi et al. (2023) highlight that milkfish farming remains crucial for the livelihoods and food security of coastal communities; however, ongoing challenges such as high feed costs

and limited resources diminish profitability. Asrial et al. (2020) and Macusi et al. (2023) further point out that environmental and economic vulnerabilities—including the impacts of climate change and resource limitations—necessitate the adoption of innovative, sustainable practices to ensure the long-term viability of the industry.

While the use of alternative feeds holds substantial promise for enhanced profitability and environmental sustainability, the feasibility of these approaches relies on the consistent quality and availability of indigenous feed resources, as discussed by the aforementioned authors. Thus, evidence from Macusi et al., Shalli et al., and Asrial et al. collectively suggests that cost-effective and sustainable aquaculture practices in milkfish farming in the Philippines and Indonesia can be achieved through adaptive feed strategies, though they require further support in supply chain and resource management to overcome practical implementation barriers.

Market Access and Value Chain Improvements

The pivotal role of market access and value chain enhancements in fostering greater sustainability and economic success in the Asian milkfish industry plays a significant role. Zapata and Cruz (2023), focusing on the Philippines, emphasize that the adoption of smart food value chain models—encompassing technological integration and improved information flows—can substantially strengthen stakeholder collaboration and efficiency along the milkfish supply chain. Complementing this, Saclauso et al. (2016) describe how "The Philippines Recommends for Milkfish," a comprehensive set of updated methodologies for fry production, grow-out culture, and postharvest management, aims not only to optimize production but also to minimize dependency on imported fry, thus strengthening local industry resilience.

Parallel challenges are reported in Indonesia, where Fadjar and Putri (2024) identify systemic barriers such as low-quality seed, insufficient capital, and deficient support services as key impediments hindering farmer productivity and welfare. Their findings highlight the necessity for targeted interventions to improve market linkages and the broader value chain environment. Further, Marlana and Sholekhuddin (n.d.) illustrate that, for micro, small, and medium enterprises (MSMEs) engaged in milkfish processing, advances in product innovation and supply chain management are directly correlated with enhanced market performance and access, pointing to the strategic importance of innovation throughout the value chain.

Across the region, Randolph (2013) positions improved market access to animal-source foods—including milkfish—as a means to bolster nutritional outcomes and reduce rural poverty among smallholder producers. Hence, these studies from the Philippines and Indonesia demonstrate that value chain modernization through technological innovation, institutional support, and market system development is

essential for advancing sustainability and economic viability in milkfish aquaculture. Nonetheless, these opportunities must be balanced against continued risks such as environmental constraints and market fluctuations, signaling the ongoing need for adaptive strategies and collaborative research in the sector.

Financial Support and Insurance Schemes

Significant progress in financial support mechanisms and sectoral modernization for milkfish aquaculture in Asia, particularly in the Philippines as reported by Baliao et al. (2020), the Bangus Fry Sufficiency Program was implemented by the Department of Agriculture–Bureau of Fisheries and Aquatic Resources (DA-BFAR), establishing community-based larval rearing facilities that directly addressed the challenge of imported fry dependency and ensured local fry availability for growers. SEAFDEC/AQD (2020) notes that this public investment, together with multi-agency collaboration and technical training, has notably improved farmers' access to quality fry, reduced production costs, and fostered the adaptation of environmental best practices. Furthermore, Chingcuanco and Borromeo (2021) emphasize, in the Philippine Milkfish Industry Roadmap, the strategic integration of financial support, input provision, and sectoral capacity-building in achieving climate-resilient and economically stable aquaculture.

Concurrently, value chain modernization and improved market access have been propelled by both technological and organizational advances. Marlana and Sholekhuddin (2021) demonstrate that product innovation and targeted supply chain upgrading among micro, small, and medium enterprises in milkfish processing significantly enhance market reach and performance. Additionally, updated methodologies in fry production, grow-out, and postharvest care—developed by DA-BFAR and SEAFDEC/AQD—have streamlined the supply chain and increased the competitiveness of the local milkfish industry (SEAFDEC/AQD, 2020).

In Indonesia, Fadjar and Putri (2024) highlight the necessity of institutional support to overcome productivity constraints such as low-quality seed and insufficient access to capital. Marlana and Sholekhuddin (2021) underscores that continued improvement in credit and insurance access is crucial for the sector's inclusiveness and long-term growth, ensuring that financial and value chain advancements benefit a broad base of smallholder producers. With this, these contributions illustrate that multidimensional support from government initiatives to technological integration and institutional innovation is central to the ongoing sustainability and transformation of milkfish aquaculture in Asia, Tang (n.d.).

POLICY ASPECTS

Regulatory Frameworks and Compliance

Sustainable aquaculture practices for milkfish in Asia are guided by comprehensive and multi-tiered regulatory systems that are continually evolving to address environmental, economic, and social challenges. The study by Bigeyo N. Kuboja et al. (2024) focuses on the legal and regulatory framework for small-scale fisheries in mainland Tanzania, highlighting that while such frameworks recognize and protect certain rights of small-scale fishers, significant challenges remain. Key issues include limited access to resources, inadequate labor rights, insufficient financial benefits, and a lack of formal social protection. Kuboja and colleagues argue that robust regulatory frameworks must not only legitimize productive activities but also actively support implementation, enforcement, and review to improve access, tenure, and labor conditions in the sector. Although this analysis primarily references Tanzania, the findings echo similar institutional challenges faced by aquaculture sectors across Asia.

Expanding the scope to a global and Asian context, the work of Rajesh Sharma (2024) examines the impact of regulatory frameworks such as Business Responsibility and Sustainability Reporting (BRSR) on

sustainable supply chains. Sharma underscores the increasing importance of structured compliance and transparent disclosures in environmental, social, and governance (ESG) criteria, which extend into the aquaculture industry in Asia. The adoption of frameworks like BRSR compels companies to report and align their practices with sustainability standards, ultimately enhancing innovation, risk management, and stakeholder relationships.

Bigeyo N. Kuboja et al. (2024) demonstrate that improving legal frameworks for small-scale fisheries in Tanzania (and by extension, similar Asian contexts) involves strengthening enforcement, access rights, and social protections. Rajesh Sharma (2024) shows that global and regional compliance requirements such as BRSR are driving aquaculture industries toward supply chain transparency and ESG integration. Gutsulyak, Magzanova, and Sokolskaya (2023) provide an in-depth perspective on the Russian experience with legal reform, demonstrating the advantages of targeted government support, digitalization, and cross-level coordination for sustainable aquaculture. Together, these authors illustrate that while significant progress has been made in regulatory approaches to sustainable aquaculture for milkfish in Asia, continued evolution, stakeholder involvement, and enforcement are essential to meeting the sector's environmental and socio-economic goals.

Co-Management and Community-Based Approaches

Recent research underscores the significance of co-management and community-based approaches in guiding sustainable aquaculture practices for milkfish within tropical Asia, notably in countries such as Sri Lanka, Thailand, and the Philippines. Schiemer et al. (2024) highlight the transition from conventional centralized fisheries management to more integrated, transdisciplinary strategies that actively engage multiple stakeholders, including local fishers, scientists, and policy-makers. This

integrated approach is rooted in the findings of the EU-funded FISHSTRAT project, which emphasized lakes and reservoirs as social-ecological systems where diverse, sometimes conflicting, uses require negotiated, locally appropriate solutions. Key components include combining ecological knowledge—such as trophic interactions and the promotion of small indigenous fish species—with local and experiential insights to devise co-management strategies that improve ecological sustainability and socio-economic outcomes.

Further, evidence from comparative studies in Tonga indicates that community management structures—specifically, dual systems combining no-take reserves with areas of exclusive community fishing rights—can yield measurable biodiversity gains and support sustainable resource access for local communities, helping to reduce overexploitation and conflict. In broader terms, the literature posits that the success of co-management and community-based management depends on decentralizing decision-making power, fostering local stewardship, and involving fisher communities directly in governance and conservation activities. These studies advocate for participatory models in milkfish aquaculture that strengthen community involvement, promote sustainable production, and conserve aquatic biodiversity, referencing the works of Charles (2023), Smallhorn-West et al. (2020), and recent theoretical syntheses on fisheries governance.

Support Programs and Subsidies

A growing body of research highlights how targeted support programs and subsidies are central to the sustainability and socio-economic impact of milkfish aquaculture across diverse contexts. In the Philippines, government initiatives to commercialize hatchery-bred milkfish fry have yielded substantial welfare gains for the industry (Garcia et al., 2020). The establishment of local hatcheries—supported technically and

financially through programs like the GAINEX project spearheaded by DOST-PCAARRD—enabled a strategic shift away from dependency on fry imports from Indonesia and Taiwan. This import substitution translated to reduced production costs and increased sector-wide welfare, with significant consumer surplus accruing to milkfish grow-out operators, who act as both the primary consumers in the fry industry and producers in the grow-out sector (Garcia et al., 2020). The study underscores that such targeted assistance through local hatchery support effectively lowers enterprise risks and enhances sectoral welfare; replicating these localized solutions, coupled with robust government technical and financial backing, is likely to benefit other aquaculture species as well (Garcia et al., 2020).

In Tanzania, milkfish pond farming contributes to livelihoods and the local blue economy, yet substantial constraints remain due to a lack of critical support. Major challenges faced by farmers include inadequate feeds and seeds, insufficient funds, and limited technical support—factors that significantly restrict both profitability and productivity (Shalli et al., 2023). The absence of formal subsidies or consistent empowerment programs continues to hamper the sector's socio-economic impact, despite its vital role in food supply, income generation, and employment for coastal communities. These results highlight that addressing these gaps through enhanced support mechanisms—such as targeted training, credit access, and reliable input supply chains—is essential for amplifying socio-economic outcomes and sustaining local aquaculture livelihoods (Shalli et al., 2023).

At a broader policy level, Sinan et al. (2022) draw attention to the role of subsidies in shaping the competitive landscape of fisheries, particularly in transnational contexts like the Indian Ocean Tuna Commission. Their analysis—while focused on tuna—serves as a cautionary reference point, emphasizing that while subsidies can empower domestic aquaculture and

strengthen coastal communities, poorly designed or insufficiently transparent subsidy regimes may perpetuate structural disadvantages and resource inequities, ultimately compromising long-term sector viability (Sinan et al., 2022).

Generally, these studies indicate that the success of sustainable milkfish aquaculture hinges on accessible and well-governed support programs. Strategic government interventions in the Philippines demonstrate the potential for subsidies and technical assistance to unlock welfare gains (Garcia et al., 2020), while experiences in Tanzania highlight the necessity of comprehensive empowerment and resource distribution (Shalli et al., 2023), and global analyses reinforce the need for fair, transparent, and context-adapted subsidy strategies to support sector resilience and lasting benefits (Sinan et al., 2022).

Integration with National Fisheries Policies and SDGs

A review of recent scholarship underscores the growing importance of integrating milkfish aquaculture into national fisheries policies and broader frameworks aligned with the United Nations Sustainable Development Goals (SDGs), particularly in Asian countries such as the Philippines, Vietnam, and Indonesia. Empirical findings indicate that milkfish aquaculture significantly enhances food security and livelihoods by generating employment and income for millions of small-scale fishers and providing a crucial protein source within coastal communities (Lynch et al., 2020). Alignment with the SDGs is increasingly recognized in the policy discourse: for example, milkfish production directly advances SDG 1 (No Poverty) and SDG 2 (Zero Hunger) by improving economic stability and nutritional outcomes, while sustainable aquaculture practices contribute to SDG 14 (Life Below Water) through the promotion of resource stewardship and environmental health (Elliott et al., 2022; Phan et al., 2024).

Policy analyses further recommend that national fisheries strategies should embed milkfish aquaculture within overarching sustainable development agendas. This includes a focus on climate-resilient farming systems and disease management, which are critical for mitigating the vulnerabilities intensified by climate change and biosecurity threats (Virapat, 2022). Collaborative regional frameworks—particularly those fostered in the Asia-Pacific—are emphasized for promoting best practices, ensuring safety and quality standards, and facilitating knowledge exchange to optimize production efficiency and sustainability. Despite these advancements, ongoing challenges such as overfishing, environmental degradation, and restricted market access persist, signalling the continued necessity for adaptive policy measures and inclusive growth strategies. The literature recommends a holistic, multi-sectoral approach to integrating milkfish aquaculture into national and regional policy, grounded in the SDGs for enduring environmental, social, and economic benefits (Lynch et al., 2020; Elliott et al., 2022; Phan et al., 2024).

CROSS-CUTTING ISSUES

Stakeholder Participation

Stakeholder participation is widely recognized as a critical determinant of sustainability in aquaculture systems, yet in the context of milkfish aquaculture in Asia, participation remains uneven and constrained by multifaceted governance challenges. A synthesis of recent studies reveals that barriers to effective stakeholder engagement are rooted in institutional, financial, and socio-technical dimensions that vary across national contexts but share common underlying themes.

In Indonesia, smallholder operators and community-based producers face persistent obstacles such as limited access to capital, the absence or weakness of localized governing institutions, and repeated failures in the implementation of national government programs (Riany et al., 2023). These governance gaps have often led to

fragmented production networks, underutilization of aquaculture potential, and low adaptive capacity among farmers. Scholars argue that overcoming these constraints requires not only targeted funding mechanisms—such as microfinance schemes, revolving credit lines, or public–private investment programs—but also deliberate capacity-building initiatives that empower local producers to participate actively in decision-making processes. The experience in Central Java underscores this point: community empowerment programs that coupled technical training with infrastructure investments significantly enhanced knowledge transfer, increased adoption of improved farming practices, and built trust among stakeholders (Setyono et al., 2023).

In the Philippines, a different governance model has emerged as a potential pathway for sustainable management: co-management systems. Under these arrangements, national and local governments collaborate with fishers, private business operators, and non-governmental organizations to design and implement aquaculture policies (Sugimoto et al., 2016). This model recognizes that fishers and local operators are not merely beneficiaries of policy but are also key actors with contextual knowledge, whose participation ensures policies are locally appropriate and socially equitable. Co-management frameworks have shown promise in balancing production goals with ecosystem stewardship by embedding participatory monitoring, resource-use negotiations, and shared accountability into the governance structure.

A broader regional analysis spanning nine Asian countries further highlights that inclusive stakeholder participation must be coupled with robust policy analysis and socioeconomic profiling to maximize its impact (Galparsoro et al., 2020). Policymakers are urged to integrate demand-supply projections and livelihood assessments into national action plans so that interventions are not only technically sound but also responsive to the needs of poorer

household's dependent on aquaculture for income and food security. This approach moves beyond technocratic solutions by embedding social justice considerations—ensuring that benefits are equitably distributed along the value chain and that vulnerable groups are not left behind.

A critical enabler of sustained stakeholder engagement lies in strengthening upstream production inputs. For instance, the development of local hatcheries and the commercialization of hatchery-bred fry represent transformative interventions that reduce reliance on wild seedstock and ensure a more reliable supply chain (Garcia et al., 2020). These measures directly enhance the bargaining position and operational efficiency of grow-out operators, who are often marginalized in policy dialogues despite their pivotal role in the value chain. Complementary community-based strategies—such as coordinated distribution of quality fingerlings, farmer field schools, and cooperative-led technical advisory services—have further demonstrated their effectiveness in driving collective action and innovation adoption (Setyono et al., 2023).

To elevate participation from a reactive to a proactive and strategic level, recent scholarship and development projects advocate for the creation of a “smart” milkfish value chain (Zapata et al., 2023). This entails establishing regional seedstock command centers to centralize and standardize genetic resources, implementing science-based community farms that function as living laboratories for adaptive management, and supporting processing enterprise hubs that anchor value addition and market access. These interventions not only foster technological innovation and information sharing but also institutionalize the involvement of multiple stakeholders—farmers, researchers, extension agents, processors, and policymakers—in co-designing solutions.

Taken together, these experiences underscore that stakeholder participation in milkfish aquaculture in Asia is not merely a procedural formality but a structural

necessity for achieving sustainability. Meaningful engagement requires addressing power asymmetries, investing in human and social capital, and embedding participatory mechanisms within governance frameworks. By integrating localized empowerment initiatives with broader policy reforms and value-chain innovations, Asian milkfish aquaculture can move toward a resilient and inclusive future—one where environmental stewardship, economic viability, and social equity are jointly pursued through active and informed participation at all levels of the industry.

Technology and Innovation Uptake

Technological innovation has become a cornerstone for advancing milkfish aquaculture in Asia, driving improvements in production efficiency, environmental sustainability, and value-chain integration. A growing body of literature highlights how targeted innovations—both at the production and governance levels—can address long-standing constraints in the industry while enabling more equitable and resilient growth. Historical breakthroughs, such as the deep-water pond culture systems developed in the 1970s, demonstrated the transformative potential of technical interventions. By optimizing water depth, increasing stocking density, and refining feed management, these systems increased milkfish yields by five- to eight-fold compared to traditional practices (Su et al., 2002). This foundational work set the stage for subsequent innovations aimed at intensifying production without compromising ecological balance.

In recent years, technological interventions have increasingly focused on systemic and value-chain solutions. Salayo et al. (2020) and Obiero et al. (2019) independently propose the establishment of regional seedstock command centers and processing enterprise development hubs in the Philippines. These centers are designed not only to ensure the availability of high-quality fry and fingerlings but also to streamline post-harvest processing and marketing. By centralizing critical functions, such hubs

reduce transaction costs, improve genetic quality control, and enhance the overall competitiveness of the milkfish industry.

At the farm level, innovative production systems are gaining traction. Widowati et al. (2021) and Yusuf et al. (2024) present evidence on the effectiveness of modular or tiered-plot techniques in traditional ponds, achieving an average growth increment of 0.15 cm per day in Indonesian settings. These modular systems enhance water circulation, optimize space utilization, and allow for better feed distribution, resulting in accelerated growth rates and higher survival percentages. Such innovations are particularly relevant to smallholder farmers who rely on limited land areas and need scalable solutions adaptable to local conditions.

Beyond physical infrastructure, recent research has also emphasized the process of innovation adoption. Vecchio et al. (2022) and Attahmid et al. (2019) highlight the utility of the AKAIE model—an extension of the AKAP (Awareness, Knowledge, Adoption, Practice) framework—which integrates additional stages of Implementation and Effectiveness. This model underscores that successful innovation is not achieved at the point of adoption alone; it requires iterative feedback during implementation and evidence of sustained effectiveness in generating environmental, economic, and social benefits. Such a framework is particularly useful for policymakers and extension services seeking to track and accelerate technology uptake in diverse aquaculture communities.

Equally important is the recognition that technological progress is inherently tied to knowledge generation and dissemination. Villarreal (2021) argues that innovation becomes meaningful only when knowledge flows effectively among stakeholders and leads to market-ready solutions. This perspective aligns with participatory approaches that bring together scientists, extension workers, fish farmers, and industry leaders to co-create, test, and refine

technologies. Collaborative platforms—whether through digital tools, farmer field schools, or multi-stakeholder workshops—serve as conduits for translating research outputs into practical, context-specific applications.

Additionally, these studies illustrate that technological innovation in milkfish aquaculture is not a linear process but a dynamic ecosystem of interventions, feedback loops, and collaborative networks. By integrating infrastructure development, system-level management, and robust adoption frameworks, Asian countries can address production bottlenecks, enhance value addition, and achieve long-term sustainability. Moving forward, policy support that nurtures these innovations—through funding, regulatory facilitation, and inclusive extension services—will be critical in ensuring that technological gains translate into broad-based welfare improvements for aquaculture communities across the region.

Gender and Labor Considerations

Gender dynamics remain a critical yet underexplored dimension of aquaculture and fisheries in Asia. Despite their significant involvement across multiple nodes of the milkfish value chain—from hatchery operations and pond management to post-harvest processing and marketing—women continue to face systemic barriers that limit their participation, remuneration, and decision-making power (Mengo et al., 2023; Elias et al., 2024). Studies consistently reveal that women's contributions are often undervalued and rendered invisible in official statistics and sectoral narratives (Nikita et al., 2020; St. Louis & Oliveira, 2020).

A gendered division of labor characterizes much of the aquaculture workforce, shaped by enduring cultural norms and stereotypes that dictate “appropriate” roles for men and women. While men are often perceived as the primary operators in production and decision-making, women are relegated to supporting roles—such as feed preparation, sorting, gleaning, and post-harvest

processing—that are typically informal and poorly remunerated (Mengo et al., 2023). Even when women perform similar work to men, wage disparities remain stark, with documented pay gaps reflecting both implicit bias and structural inequalities. This undervaluation perpetuates cycles of economic dependence and limits women's agency in household and community decision-making.

Paradoxically, research shows that when women are more equitably involved in aquaculture, positive ripple effects emerge at multiple scales. Their participation contributes to improved household food security, diversified income streams, and enhanced decision-making power within families (Mengo et al., 2023; St. Louis & Oliveira, 2020). In some regions, women have moved beyond traditional roles, taking leadership positions in production systems and even establishing vertically integrated enterprises that encompass hatchery, grow-out, and processing operations (Bosma et al., 2018). These examples highlight the transformative potential of gender-inclusive approaches, both for livelihoods and for the broader sustainability of aquaculture systems.

Yet structural barriers persist. Access to training and extension services remains uneven, with women often excluded from capacity-building initiatives that are crucial for adopting new technologies and improving productivity (Bosma et al., 2018). Decision-making bodies, from cooperatives to national policy councils, remain male-dominated, resulting in policies and programs that inadequately reflect women's perspectives and needs. Moreover, the invisibility of women's labor in official datasets continues to obscure their contributions. Scholars argue that if women's roles in gleaning, trading, and processing were fully enumerated, the sector might in fact be predominantly female (Weeratunge et al., 2010; Weeratunge & Snyder, 2015).

To address these issues, a livelihoods approach has been proposed, situating

gendered employment patterns within broader social, cultural, economic, and ecological contexts (Weeratunge et al., 2010). This perspective allows policymakers and researchers to understand not only what roles women occupy but also how these roles intersect with household labor dynamics, caregiving responsibilities, and community-level resource management. Key research priorities include the systematic collection of gender-disaggregated data, deeper analysis of the gendered nature of employment, and critical review of policies that inadvertently reinforce disparities (Weeratunge & Snyder, 2015; Weeratunge et al., 2012).

Encouragingly, there are ongoing efforts at regional and national levels to promote gender-sensitive policies and empower women in aquaculture. Organizations across Asia have begun implementing targeted initiatives—ranging from microfinance programs and leadership training for women’s cooperatives to gender mainstreaming in extension services—that aim to shift traditional gender perceptions and improve women’s access to resources (Elias et al., 2024; St. Louis & Oliveira, 2020). These interventions highlight that achieving gender equity in aquaculture is not only a moral imperative but also an economic and developmental one: empowering women strengthens value chains, enhances community resilience, and contributes directly to the sustainability of the sector.

Ultimately, integrating gender considerations into the planning and governance of milkfish aquaculture requires moving beyond tokenistic inclusion toward structural transformation. This entails dismantling barriers to participation, ensuring equal pay for equal work, embedding gender-disaggregated metrics in monitoring systems, and fostering inclusive decision-making environments. Only through such deliberate and systemic efforts can the aquaculture sector in Asia realize its full potential as a driver of sustainable development and social equity.

CONCLUSION

This review underscores the critical need for a holistic and integrated approach to the sustainability of milkfish aquaculture in Asia. The environmental, economic, and policy dimensions of milkfish farming are inextricably linked, and addressing these challenges in tandem is essential to ensure the long-term viability of the industry. Technological advancements, such as the adoption of Multitrophic Recirculating Aquaculture Systems (MRAS) and genetic improvements in hatchery technologies, offer promising solutions to reduce environmental impacts, optimize resource utilization, and enhance productivity. Moreover, the integration of innovative practices, such as aquaponics and biofiltration, highlights the potential for circular economy models that can significantly mitigate the sector's ecological footprint.

However, the paper also reveals significant gaps in governance, with inconsistent policy enforcement and a lack of clear frameworks hindering the development of sustainable practices in many regions. Strengthening regulatory systems, enhancing stakeholder participation, and fostering public-private partnerships are vital to overcoming these barriers. Additionally, addressing the growing impacts of climate change on aquaculture productivity requires adaptive strategies, including infrastructure improvements and climate-resilient practices, to safeguard against fluctuating water parameters and disease outbreaks.

Ultimately, for milkfish farming to continue to meet the growing global demand while maintaining environmental integrity, it is essential that the sector embraces a more sustainable and coordinated path. This paper provides a comprehensive framework for future research, policy development, and industry practices aimed at achieving sustainability in milkfish aquaculture, ensuring that it remains an essential source of food, income, and ecological balance for future generations across Asia.

Declaration by Authors

Acknowledgement: None

Source of Funding: None

Conflict of Interest: No conflicts of interest declared.

REFERENCES

1. Abao, J.U., Traverro, A.S., Puno, S.M., Herda, R.K., Bodbod, I.C. (2024). RECEIVING PROVISIONAL GRADES DURING THE PANDEMIC: UNIVERSITY STUDENTS' JOURNEY. *Science International (Lahore)*, 36(1), 103–106. <https://bit.ly/4eJ38vk>
2. Aguilar-Manjarrez, J., Kapetsky, J. M., & Soto, D. (2017). The potential of spatial planning tools to support the ecosystem approach to aquaculture. FAO Fisheries and Aquaculture Technical Paper No. 593. Food and Agriculture Organization of the United Nations.
3. Allison, E. H., Perry, A. L., Badjeck, M. C., Neil Adger, W., Brown, K., Conway, D., ... & Dulvy, N. K. (2011). Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries*, 10(2), 173–196. <https://doi.org/10.1111/j.1467-2979.2008.00310.x>
4. Argade, N. U., Chandak, P., Bansal, N., & Dubey, S. (2024). Alternative Financing Mechanisms. *Advances in Finance, Accounting, and Economics Book Series*, 201–226. <https://doi.org/10.4018/979-8-3693-7924-0.ch010>
5. Asrial, E., Sheyoputri, A. C. A., & Nuryadin, R. (2020). SUSTAINABILITY ANALYSIS OF MILKFISH AQUABUSINESS MANAGEMENT ON SUMBAWA ISLAND: A BIOECOLOGY, TECHNOLOGY, AND ECONOMIC APPROACH. *Jurnal AGRISEP Kajian Masalah Sosial Ekonomi Pertanian Dan Agribisnis*, 19(2), 417–432. <https://doi.org/10.31186/jagrisep.19.2.417-432>
6. Attahmid, N. F. U., Saleh, R., & Yusuf, M. (2019). Penerapan Teknologi Tepat Guna dan Diversifikasi Pangan pada UKM Olahan Ikan Bandeng di Desa Bulu Cindea Kecamatan Bungoro, Pangkep. *Jurnal Pengabdian Pada Masyarakat*, 4(4), 517–528. <https://doi.org/10.30653/002.201944.237>
7. Bosma, R. H., Hanh, C. T., Potting, J., & Anh, P. T. (2017). Environmental impact assessment of the Pangasius sector in the Mekong Delta, Vietnam. *Aquaculture Research*, 48(9), 4695–4707. <https://doi.org/10.1111/are.13297>
8. Bosma, R. H., Nguyen, T. D., Calumpang, L. M., & Carandang, S. A. (2018). Gender action plans in the aquaculture value chain: what's missing? *Reviews in Aquaculture*, 11(4), 1297–1307. <https://doi.org/10.1111/raq.12293>
9. Brugère, C., & Ridler, N. (2004). Global aquaculture outlook in the next decades: An analysis of national aquaculture production forecasts to 2030. FAO Fisheries Circular No. 1001. FAO.
10. Chang, B., Liao, C., Chang, Y., Chao, W., Yeh, S., Kuo, D., & Yang, C. (2019). Investigation of a Farm-scale Multitrophic Recirculating Aquaculture System with the Addition of *Rhodovulum sulfidophilum* for Milkfish (*Chanos chanos*) Coastal Aquaculture. *Sustainability*, 11(7), 1880. <https://doi.org/10.3390/su11071880>
11. Charles, A. (2023). Co-management and Community-Based Management. 382–409. <https://doi.org/10.1002/9781119511847.ch17>
12. DA-BFAR. (2018). Philippine Fisheries Profile 2018. Bureau of Fisheries and Aquatic Resources, Department of Agriculture. <https://www.bfar.da.gov.ph>
13. De Silva, S. S., & Soto, D. (2009). Climate change and aquaculture: Potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto, & T. Bahri (Eds.), *Climate change implications for fisheries and aquaculture* (pp. 151–212). FAO Fisheries and Aquaculture Technical Paper No. 530.
14. Elias, M., Zaremba, H., Tavenner, K., Ragasa, C., Valencia, A. M. P., Choudhury, A., & De Haan, N. (2024). Towards gender equality in forestry, livestock, fisheries and aquaculture. *Global Food Security*, 41, 100761. <https://doi.org/10.1016/j.gfs.2024.100761>
15. Elliott, V., Lynch, A. J., Phang, S. C., Cooke, S. J., Cowx, I. G., Claussen, J. E., Dalton, J., Darwall, W., Harrison, K., Murchie, K. J., Steel, E. A., & Stokes, G. L. (2022). A Future for the Inland Fish and Fisheries Hidden Within the Sustainable Development Goals. *Frontiers in Environmental Science*, 10. <https://doi.org/10.3389/fenvs.2022.756045>
16. Fadjjar, N. S., & Putri, R. N. H. (2024). Analysis of Market System Mapping Patterns and Potential for Milkfish Cultivation in Pangkahwetan Village, Gresik Indonesia. *International Journal of Applied Business and International Management*, 9(2), 1–14. <https://doi.org/10.32535/ijabim.v9i2.2191>
17. FAO. (2020). The state of world fisheries and aquaculture 2020: Sustainability in action. Food and Agriculture Organization of the United Nations. <https://doi.org/10.4060/ca9229en>

18. Galparsoro, I., Murillas, A., Pinarbasi, K., Sequeira, A. M., Stelzenmüller, V., Borja, Á., O'Hagan, A. M., Boyd, A., Bricker, S., Garmendia, J. M., Gimpel, A., Gangnery, A., Billing, S., Bergh, Ø., Strand, Ø., Hiu, L., Fragoso, B., Icely, J., Ren, J., . . . Tett, P. (2020). Global stakeholder vision for ecosystem-based marine aquaculture expansion from coastal to offshore areas. *Reviews in Aquaculture*, 12(4), 2061–2079. <https://doi.org/10.1111/raq.12422>
19. Garcia, Y. T., Garcia, M. E. T., & Garcia, A. G. (2020). Commercializing the milkfish Hatchery-Bred fry industry in the Philippines: A welfare analysis. *HOLISTICA – Journal of Business and Public Administration*, 11(3), 25–45. <https://doi.org/10.2478/hjbp-2020-0030>
20. Gutiérrez, N. L., Hilborn, R., & Defeo, O. (2011). Leadership, social capital and incentives promote successful fisheries. *Nature*, 470(7334), 386–389. <https://doi.org/10.1038/nature09689>
21. Jentoft, S., & Chuenpagdee, R. (2009). Fisheries and coastal governance as a wicked problem. *Marine Policy*, 33(4), 553–560. <https://doi.org/10.1016/j.marpol.2008.12.002>
22. Joffre, O. M., Klerkx, L., Dickson, M., Verdegem, M. C. J., & Bosma, R. H. (2019). How is innovation in aquaculture conceptualized and managed? A systematic literature review and reflection framework to inform analysis and action. *Aquaculture*, 507, 428–437. <https://doi.org/10.1016/j.aquaculture.2019.04.037>
23. Kawarazuka, N., & Béné, C. (2010). Linking small-scale fisheries and aquaculture to household nutritional security: An overview. *Food Security*, 2(4), 343–357. <https://doi.org/10.1007/s12571-010-0079-y>
24. Kuboja, B. N., Mazigo, A. F., Ibengwe, L. J., & Katikiro, R. E. (2024). *Legal and Regulatory Framework for Small-Scale Fisheries in Mainland Tanzania: Practical Realities and Opportunities* (pp. 381–406). Springer International Publishing. https://doi.org/10.1007/978-3-031-56716-2_18
25. Lu, Y., Huang, Y., Lee, J., & Huang, S. (2022). Evaluation of the technical efficiency of Taiwan's milkfish polyculture in consideration of differences in culturing models and environments. *Fishes*, 7(5), 224. <https://doi.org/10.3390/fishes7050224>
26. Lynch, A. J., Elliott, V., Phang, S. C., Phang, S. C., Claussen, J. E., Harrison, I., Murchie, K. J., Steel, E. A., & Stokes, G. L. (2020). *Inland fish and fisheries integral to achieving the Sustainable Development Goals*. 3(8), 579–587. <https://doi.org/10.1038/S41893-020-0517-6>
27. Macusi, E. D., Jimenez, J. E. M., Vender, E. K. E., Bong-as, H. P., Macusi, E. S., & Andam, M. B. (n.d.). *Bloodmeal, and Selected Indigenous Raw Materials As Cost-Effective Feeds for Milkfish Aquaculture*. <https://doi.org/10.20944/preprints202409.0150.v1>
28. Macusi, E. D., Macusi, E. S., Bongas, H. P., & Cayacay, M. A. (2023). *Typology of Milkfish (Chanos chanos) Farms: Their Operations, Socio-Economic Viability, and Challenges*. <https://doi.org/10.20944/preprints202312.0507.v1>
29. Macusi, E. D., Torres, J., Vender, E. K. E., Bongas, H. P., Macusi, E. S., & Andam, M. B. (2024). *Non-Fishmeal Based, and Selected Indigenous Raw Materials as Cost-Effective Feeds for Milkfish Aquaculture*. <https://doi.org/10.20944/preprints202409.0150.v2>
30. Manam, V.K. (2023). Fish feed nutrition and its management in aquaculture. *International Journal of Fisheries and Aquatic Studies*, 11(2): 58-61. Link to document
31. Manzilati, A., Kornitasari, Y., Wildana, M. D. A., & Rakhmania, N. A. (2023). The effect of transaction costs on the sustainability of milkfish aquaculture in north coast of Java, Indonesia. *MIGRATION LETTERS*, 20(S12), 188–201. <https://doi.org/10.59670/ml.v20is12.5872>
32. Marlana, N., & Sholekhuddin, M. (n.d.). *INCREASING MARKETING PERFORMANCE OF MILKFISH PROCESSING MICRO SMALL AND MEDIUM ENTERPRISE (msmes) IN EAST JAVA: BOTH PRODUCT INNOVATION AND SUPPLY CHAIN STILL CAN DO?* <https://doi.org/10.21009/econosains.0161.06>
33. Martins, C. I. M., Eding, E. H., Verdegem, M. C. J., Heinsbroek, L. T. N., Schneider, O., Blancheton, J. P., ... & Verreth, J. A. J. (2011). New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability. *Aquacultural Engineering*, 43(3), 83–93. <https://doi.org/10.1016/j.aquaeng.2010.09.002>
34. Maulu, S., Hasimuna, O. J., Haambiya, L. H., Monde, C., Musuka, C. G., Makorwa, T. H., Munganga, B. P., Phiri, K. J., & Nsekanabo, J. D. (2021). Climate change effects on aquaculture production: Sustainability

- implications, mitigation, and adaptations. *Frontiers in Sustainable Food Systems*, 5, 609097. <https://doi.org/10.3389/fsufs.2021.609097>
35. Mengo, E., Grilli, G., Murray, J. M., Capuzzo, E., Eisma-Osorio, R., Fronkova, L., Etcuban, J. O., Ferrater-Gimena, J. A., & Tan, A. (2023). Seaweed aquaculture through the lens of gender: Participation, roles, pay and empowerment in Bantayan, Philippines. *Journal of Rural Studies*, 100, 103025. <https://doi.org/10.1016/j.jrurstud.2023.103025>
36. Nagal C., Travero A., & Nagal M. (2024). Socio-demographic profile and resistance to change among university employees in the post-Covid era. *Science International (Lahore)*, 36(2), 149–152. <https://shorturl.at/DENeY>
37. Nagal, C. J. C. (2025). Harvesting Traditions: Exploring the Indigenous agricultural knowledge systems in Java, Indonesia and Mindanao, Philippines. *Millennial Asia*. <https://doi.org/10.1177/09763996251327672>
38. Naylor, R. L., Hardy, R. W., Bureau, D. P., Chiu, A., Elliott, M., Farrell, A. P., ... & Nichols, P. D. (2009). Feeding aquaculture in an era of finite resources. *Proceedings of the National Academy of Sciences*, 106(36), 15103–15110. <https://doi.org/10.1073/pnas.0905235106>
39. NEDA. (2023). Philippine Development Plan 2023–2028. National Economic and Development Authority. <https://pdp.neda.gov.ph/>
40. Nikita, Gopal, Méryl, Williams, Siri, Gerrard, Siar, S., Kusakabe, K., Lebel, L., Holly, Hapke, Marilyn, Porter, Anne, Coles, Natasha, Stacey, & Bhujel, R.B. (2020). Gender in Aquaculture and Fisheries: Engendering Security in Fisheries and Aquaculture.
41. Novianti, R., Afandi, A. Y., Rahmadya, A., Rohaningsih, D., Yuniarti, I., & Tampubolon, B. I. (2023). Water quality and financial feasibility analysis of the development of milkfish (*Chanos sp.*) farms in Pabean Ilir Village, Indramayu, West Java. *IOP Conference Series Earth and Environmental Science*, 1201(1), 012039. <https://doi.org/10.1088/1755-1315/1201/1/012039>
42. Obiero, K. O., Waidbacher, H., Nyawanda, B. O., Munguti, J. M., Manyala, J. O., & Kaunda-Arara, B. (2019). Predicting uptake of aquaculture technologies among smallholder fish farmers in Kenya. *Aquaculture International*, 27(6), 1689–1707. <https://doi.org/10.1007/s10499-019-00423-0>
43. Ohagan, J. M., Harnaiz, L. L. A., Nagal, C. J. C., Taylaran, R. D., & Gonzaga, A. B., Jr. (2023, June 23). Productivity of ‘Saba’ Banana (*Musa acuminata* x *balbisiana*) as influenced by Different Levels of NPK Fertilizer under Jasaan Soil Series. <https://mjst.ustp.edu.ph/index.php/mjst/article/view/1516>
44. Phan, K. L., Hsu, Y.-C., & Chen, S. (2024). Do sustainable development goals (SDGs) boost green productivity in national marine fisheries? International evidence. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, 16(6). <https://doi.org/10.1002/mcf2.10322>
45. Pomeroy, R. S., & Rivera-Guieb, R. (2006). Fishery co-management: A practical handbook. CABI Publishing.
46. Rahmah, H. A. (2022). APPLICATION OF SWOT ANALYSIS AND MILKSFISH TRADING STRATEGY IN INDONESIA. *Agrijo Jurnal Agribisnis Universitas Malikussaleh*, 7(2), 90. <https://doi.org/10.29103/ag.v7i2.5712>
47. Razman, K. K., Hanafiah, M. M., Ramli, A. N., & Harun, S. N. (2023). Industrial wastewater treatment methods employed in Southeast Asian countries. *IOP Conference Series: Earth and Environmental Science*, 1167(1), 012020. <https://doi.org/10.1088/1755-1315/1167/1/012020>
48. Riany, C. F., Partelow, S., & Nagel, B. (2023). Governance challenges for Indonesian pond aquaculture: a case study of milkfish production in Gresik. *Frontiers in Aquaculture*, 2. <https://doi.org/10.3389/faquc.2023.1254593>
49. Salayo, N. D., Marte, C. L., Toledo, J. D., Gaitan, A. G., & Agbayani, R. F. (2020). Developing a self-sufficient Philippine milkfish industry through value chain analysis. *Ocean & Coastal Management*, 201, 105426. <https://doi.org/10.1016/j.ocecoaman.2020.105426>
50. Schiemer, F., Amarasinghe, U. S., Simon, D., & Vijverberg, J. (2024). Sustainable aquatic resource management and inland fisheries in tropical Asia: Interdisciplinary and transdisciplinary approaches. *AMBIO: A Journal of the Human Environment*. <https://doi.org/10.1007/s13280-024-01996-8>
51. Schröder, J. J., Scholefield, D., Cabral, F., & Hofman, G. (2014). The effect of nutrient losses from agriculture on ground and surface water quality: The position of science in developing indicators for regulation. *Environmental Science & Policy*, 7(1), 15–23.

- [https://doi.org/10.1016/S1462-9011\(03\)00010-3](https://doi.org/10.1016/S1462-9011(03)00010-3)
52. Setyono, B. D. H., Pebrianti, N. L. M., Maudina, F., Suprianto, B., Santoso, B., Affandi, R. I., & Diamahesa, W. A. (2023). Pemberdayaan Pembudidaya Ikan Melalui Pemberian Bantuan Bibit Ikan Bandeng di Desa Growong Kidul, Pati, Jawa Tengah. *TEKIBA Jurnal Teknologi Dan Pengabdian Masyarakat*, 3(2), 28–33. <https://doi.org/10.36526/tekiba.v3i2.3162>
53. Shalli, M., Mmochi, A., Rubekie, A. P., Yona, G., Shoko, A., Limbu, S. M., Mwitad, C. J., Lamtanee, H. A., Hamedf, S. S., Jiddawi, N., & Mapenzi, L. L. (2023). *The contribution of milkfish (Chanos chanos) pond farming to socio-economics and coastal community livelihoods for a sustainable blue economy*. <https://doi.org/10.21203/rs.3.rs-3504011/v1>
54. Sharma, R. (2024). *From Compliance to Commitment: The Evolving Landscape of Sustainable Supply Chains considering BRSR and other Regulatory Frameworks*. <https://doi.org/10.58966/jcm2024318>
55. Shen, Y., Ma, K., & Yue, G. H. (2020b). Status, challenges and trends of aquaculture in Singapore. *Aquaculture*, 533, 736210. <https://doi.org/10.1016/j.aquaculture.2020.736210>
56. Sinan, H., Willis, C., Swartz, W., Sumaila, U. R., Forsdyke, R. E., Skerritt, D. J., Le Manach, F., Colléter, M., & Bailey, M. (2022). Subsidies and allocation: A legacy of distortion and intergenerational loss. *Frontiers in Human Dynamics*, 4. <https://doi.org/10.3389/fhumd.2022.1044321>
57. Smallhorn-West, P. F., Smallhorn-West, P. F., Stone, K., Ceccarelli, D. M., Malimali, S., Halafihi, T., Bridge, T. C. L., Bridge, T. C. L., Pressey, R. L., & Jones, G. P. (2020). Community management yields positive impacts for coastal fisheries resources and biodiversity conservation. *Conservation Letters*, 13(6). <https://doi.org/10.1111/CONL.12755>
58. St Louis, T. J., & Oliveira, N. M. (2020). Women's contribution to aquaculture's regional development: a literature review. *Journal of Applied Aquaculture*, 34(2), 294–313. <https://doi.org/10.1080/10454438.2020.1842284>
59. Su, M., Lee, C., & Liao, I. C. (2002). Technical Responses to challenges in Milkfish Aquaculture. *Reviews in Fisheries Science*, 10(3–4), 451–464. <https://doi.org/10.1080/20026491051749>
60. Sugimoto, A., Diego-McGlone, M. L. S., Paciencia, F., Milan, S. P., Tomas, E. T., Ramirez, C. C., Echavez, A., Gabatin, J., Fortes, M. D., & Nadaoka, K. (2016). Comanagement for aquaculture: Suggestions from a comparative study between two major production areas of milkfish in the Philippines. *Journal of Applied Aquaculture*, 28(4), 298–313. <https://doi.org/10.1080/10454438.2016.1209712>
61. Tang, H. (n.d.). *Research on Financial Support of Microfinance to Female Entrepreneurship*. <https://doi.org/10.3969/j.issn.1007-3698.2010.05.024>
62. Traverro, A., Nagal, C. J., & Herda, R. K. (2025). Study habits, mathematics performance and gender differences of agriculture students amidst the new normal. *Jurnal Wahana Pendidikan*, 12(1), 15. <https://doi.org/10.25157/jwp.v12i1.16856>
63. Troell, M., Naylor, R. L., Metian, M., Beveridge, M., Tyedmers, P. H., Folke, C., ... & Gren, Å. (2014). Does aquaculture add resilience to the global food system? *Proceedings of the National Academy of Sciences*, 111(37), 13257–13263. <https://doi.org/10.1073/pnas.1404067111>
64. Vanaja, S. (2021). Are people making correct choices: Drivers of water source choices in rural Jharkhand, India. *Journal of Emerging Technologies and Innovative Research (JETIR)*, 5(5), 1372. <https://www.jetir.org/papers/JETIR1805963.pdf>
65. Vecchio, Y., Masi, M., & Adinolfi, F. (2022). From the AKAP to AKAIE model to assess the uptake of technological innovations in the aquaculture sector. *Reviews in Aquaculture*, 15(2), 772–784. <https://doi.org/10.1111/raq.12756>
66. Villarreal, H. (2021). Collaborative knowledge generation and dissemination to strengthen technology development in science and technology parks as a strategy to innovate aquaculture production. *Journal of the World Aquaculture Society*, 52(2), 266–268. <https://doi.org/10.1111/jwas.12784>
67. Virapat, C. (2022). The current challenges of sustainable aquaculture in the Asia-Pacific region and the measures recommended. *Asia-Pacific Journal of Rural Development*, 32(2), 207–216. <https://doi.org/10.1177/10185291231193516>
68. Wang, Y., Rume, T., Islam, S. M. D.-U., Fan, W., Wu, J., & Li, X. (2022). Water quality criteria and ecological risk assessment of

- typical transition metals in South Asia. *International Journal of Environmental Research and Public Health*, 19(23), 16125. <https://doi.org/10.3390/ijerph192316125>
69. Weeratunge, N., & Snyder, K.A. (2015). Gleaner, fisher, trader, processor: understanding gendered employment in the fisheries and aquaculture sector.
70. Weeratunge, N., Chiuta, T., Choudhury, A., Ferrer, A.J., Husken, S., Kura, Y., Kusakabe, K., Madzudzo, E., Maetala, R., Naved, R.T., Schwarz, A., & Kantor, P. (2012). Transforming aquatic agricultural systems towards gender equality: a five-country review.
71. Weeratunge, N., Snyder, K. A., & Sze, C. P. (2010). Gleaner, fisher, trader, processor: understanding gendered employment in fisheries and aquaculture. *Fish and Fisheries*, 11(4), 405–420. <https://doi.org/10.1111/j.1467-2979.2010.00368.x>
72. Widowati, L. L., Ariyati, R. W., Rejeki, S., & Bosma, R. H. (2021). The impact of aquaculture field school on the shrimp and milkfish yield and income of farmers in Demak, Central Java. *Journal of the World Aquaculture Society*, 52(2), 362–377. <https://doi.org/10.1111/jwas.12770>
73. Xu, B., & Azam, S. M. F. (2024). The Impact of Financial Support on Household Entrepreneurship in China. *International Journal of Social Sciences and Public Administration*, 3(1), 161–166. <https://doi.org/10.62051/ijsspa.v3n1.25>
74. Yusoff, F. M., Umi, W. A. D., Ramli, N. M., & Harun, R. (2024). Water quality management in aquaculture. *Water*, Advance online publication. <https://doi.org/10.1017/wat.2024.6>
75. Yusuf, N. M., Jayadi, N., Suryahman, N. A., Riana, N. a. D., Malik, N., Kasim, N. N., Budiyati, N., & Syahrir, N. M. (2024). Modular system innovation for increasing milkfish production on traditional ponds in Usto village, Mare district, Bone. *Open Access Research Journal of Multidisciplinary Studies*, 7(1), 001–011. <https://doi.org/10.53022/oarjms.2024.7.1.0061>
76. Zapata, N. R. J., Sarmiento, J. a. C., & Cruz, M. B. (2023). Development of smart food Value Chain intervention models for the milkfish industry in region 1, Philippines. *Asian Journal of Agriculture and Development*, 20(1), 87–108. <https://doi.org/10.37801/ajad2023.20.1.6>
- How to cite this article: Jane Mar L. Alimorin. Sustainable aquaculture practices for milkfish (*Chanos chanos*): an integrated analysis of environmental, economic, and policy dimensions in Asia. *International Journal of Research and Review*. 2025; 12(7): 468-490. DOI: <https://doi.org/10.52403/ijrr.20250749>
