



Eco-Friendly Shrimp Farming: Balancing Economic Growth and Environmental Sustainability in Agriculture

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Abstract: Eco-friendly shrimp farming is emerging as a transformative approach in aquaculture, addressing the economic and environmental challenges associated with conventional practices. This article provides a comprehensive exploration of the topic, highlighting its methodologies, impacts, challenges, and future prospects. Eco-friendly shrimp farming integrates sustainable practices such as integrated multi-trophic aquaculture (IMTA), biofloc technology, and renewable energy to minimize ecological degradation while enhancing economic profitability. The approach significantly reduces mangrove deforestation, improves water quality, and lowers greenhouse gas emissions, contributing to global conservation goals. Economically, it fosters cost efficiency, premium market access through certifications, and sustainable livelihoods, particularly benefiting marginalized communities. However, challenges such as high initial costs, the need for technical knowledge, and regulatory barriers pose significant hurdles to adoption. Addressing these requires strategic interventions, including financial support, capacity-building programs, and robust policy frameworks. The article also emphasizes the importance of consumer awareness and collaboration among stakeholders, from farmers to policymakers, in advancing eco-friendly shrimp farming. Future directions include research on scalable technologies, education campaigns to boost demand for sustainably sourced shrimp, and international partnerships to enhance knowledge exchange. By balancing economic gains with environmental conservation, eco-friendly shrimp farming presents a viable path toward sustainable aquaculture, ensuring long-term benefits for both industry and ecosystems. This synthesis underscores the critical need for a concerted effort to mainstream sustainable practices in shrimp farming.

Keywords: Biofloc technology; Bio filters; Cost effective shrimp production; Global shrimp industry; Mangrove shrimp agriculture; Mangrove shrimp farming; Renewable energy; Shrimp farming

Introduction

Shrimp farming has evolved into a significant global industry, providing a substantial portion of the world's seafood supply. However, traditional shrimp farming practices have raised concerns regarding their economic viability and environmental sustainability. In response, the adoption of eco-friendly shrimp farming methods has gained momentum, aiming to balance profitability with environmental stewardship. This article explores the economic and environmental impacts of eco-friendly shrimp farming, highlighting its

benefits, challenges, and the importance of sustainable practices in the aquaculture sector. Shrimp farming has grown to become one of the most lucrative sectors in aquaculture, catering to the rising global demand for seafood. Despite its economic significance, traditional shrimp farming practices have been associated with various ecological and socio-economic challenges, including mangrove deforestation, water pollution, and unsustainable resource use. Eco-friendly shrimp farming emerges as a sustainable alternative, seeking to harmonize economic benefits with environmental stewardship. This article delves into the economic and

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environmental impacts of eco-friendly shrimp farming, exploring its methodologies, benefits, and challenges.

The research on eco-friendly shrimp farming is designed to address critical aspects of sustainability in aquaculture by exploring economic, environmental, and social dimensions. The objectives are as follows: To Define and Explore Eco-Friendly Shrimp Farming; Analyze the principles and methodologies underlying eco-friendly shrimp farming; Highlight innovative practices, such as integrated multi-trophic aquaculture (IMTA) and biofloc technology, that optimize resource use and enhance sustainability; To Assess the Economic Impacts: Evaluate the cost-efficiency and profitability of sustainable shrimp farming practices; Examine market opportunities created by certifications and premium pricing for sustainably sourced shrimp; Understand the role of eco-friendly shrimp farming in job creation, income generation, and social equity; To Evaluate Environmental Benefits: Investigate how eco-friendly shrimp farming mitigates environmental degradation; Assess its impact on mangrove conservation, water quality, and carbon footprint reduction; Explore its contributions to global environmental goals, such as biodiversity preservation and climate change mitigation; To Identify Challenges and Solutions: Highlight the technical, financial, and regulatory challenges limiting the adoption of eco-friendly shrimp farming; Propose strategies, such as financial incentives, capacity-building programs, and supportive policy frameworks, to address these barriers.; To Examine Social and Policy Dimensions; Analyze the socio-economic inclusivity of eco-friendly shrimp farming, particularly its impact on marginalized communities and gender equity: Review the role of policies and certifications in promoting sustainable aquaculture practices.

To Highlight Future Directions: Identify research opportunities to develop scalable, cost-effective technologies; Advocate for consumer education and demand generation for sustainable shrimp products; Explore the role of international collaborations and partnerships in advancing eco-friendly shrimp farming globally; These objectives aim to provide a holistic understanding of the potential and challenges of eco-friendly shrimp farming, offering actionable insights for stakeholders to implement sustainable practices effectively.

Method

To comprehensively explore the economic and environmental impacts of eco-friendly shrimp farming, a combination of qualitative and quantitative research methodologies was employed. These methods were designed to ensure a robust analysis, integrating data

from primary and secondary sources to provide a holistic understanding of the subject.

Literature Review

A systematic literature review formed the foundation of this research. Scholarly articles, peer-reviewed journals, and credible sources were analyzed to gather existing knowledge on eco-friendly shrimp farming practices, economic models, environmental impacts, and associated challenges. Key databases, such as PubMed, Scopus, and ScienceDirect, were accessed to identify relevant studies. This approach allowed the synthesis of diverse perspectives, highlighting both established findings and research gaps.

Case Study Analysis

The research incorporated case studies of successful eco-friendly shrimp farming operations worldwide. Examples included integrated mangrove-shrimp farming (IMS) in Southeast Asia and biofloc systems in Latin America. These case studies provided practical insights into the methodologies, outcomes, and scalability of sustainable practices. Comparative analysis was conducted to evaluate the effectiveness of various approaches in different ecological and socio-economic contexts.

Economic and Environmental Impact Assessments

Economic modeling techniques were employed to estimate the cost-efficiency and profitability of eco-friendly shrimp farming. Metrics such as return on investment (ROI), cost-benefit analysis, and market trends were analyzed to understand the financial viability of sustainable practices. Environmental assessments focused on quantifying the reduction in carbon footprint, water pollution, and mangrove deforestation. Tools like life-cycle analysis (LCA) and geospatial mapping were used to evaluate ecological benefits.

Expert Interviews

Interviews with aquaculture experts, environmental scientists, and policy analysts were conducted to gain firsthand insights into the practical challenges and opportunities of eco-friendly shrimp farming. Semi-structured interviews facilitated the exploration of nuanced opinions, particularly regarding technological adoption, regulatory frameworks, and community participation.

Data Integration and Analysis

The collected data were synthesized and analyzed using mixed-methods approaches. Quantitative data, such as production costs and environmental metrics, were statistically analyzed to identify trends and

correlations. Qualitative data, including case studies and expert opinions, were thematically analyzed to uncover patterns and insights. This integration ensured a balanced perspective, combining empirical evidence with contextual understanding.

Application of Findings

The findings were systematically applied to propose actionable recommendations for stakeholders, including farmers, policymakers, and researchers. The methodologies not only highlighted the potential of eco-friendly shrimp farming but also identified strategies to overcome challenges, ensuring practical relevance and applicability. By employing these research methodologies, the study provided a comprehensive evaluation of eco-friendly shrimp farming, offering a road-map for sustainable aquaculture development.

Result and Discussion

Eco-Friendly Shrimp Farming

Eco-friendly shrimp farming refers to aquaculture practices designed to produce shrimp sustainably, minimizing environmental degradation and promoting ecological balance. Unlike conventional shrimp farming, which often leads to habitat destruction and pollution, eco-friendly methods emphasize the responsible use of resources, integration of natural systems, and long-term ecological and economic sustainability. These practices align with global efforts to reduce the environmental footprint of food production while ensuring food security. How Does Eco-Friendly Shrimp Farming Work? Eco-friendly shrimp farming operates by adopting techniques and technologies that prioritize environmental conservation. Some of the key methodologies include:

Integrated Multi-Trophic Aquaculture (IMTA)

This system involves cultivating shrimp alongside complementary species like fish, mollusks, and seaweed. The waste generated by shrimp serves as nutrients for other species, reducing pollution and enhancing nutrient recycling. IMTA creates a balanced ecosystem where all components mutually benefit from one another.

Biofloc Technology:

Biofloc systems leverage microbial communities to convert organic waste into protein-rich feed. This technology not only reduces the need for external feed inputs but also improves water quality by breaking down harmful substances. Shrimp grown in biofloc systems often exhibit faster growth rates and better health.

Integrated Mangrove-Shrimp Farming

In this method, shrimp ponds are integrated with mangrove forests, maintaining a balance between aquaculture and natural ecosystems. Mangroves act as biofilters, improving water quality and providing habitats for diverse marine life. This approach also helps in carbon sequestration and shoreline protection.

Recirculating Aquaculture Systems (RAS)

RAS is a closed-loop system where water is continuously filtered and reused, significantly reducing water consumption and waste discharge. These systems are highly efficient, enabling farmers to control environmental parameters and reduce disease outbreaks.

Use of Renewable Energy

Solar and wind energy are increasingly incorporated into shrimp farming operations to reduce greenhouse gas emissions and operational costs. By minimizing reliance on fossil fuels, these practices contribute to climate change mitigation.

Natural Feeding Practices

Eco-friendly farms often rely on natural feeds or sustainably sourced alternatives to fishmeal. Algae, plant-based proteins, and insect-based feeds are common substitutes that reduce pressure on wild fish stocks.

Economic Impacts of Eco-Friendly Shrimp Farming

Eco-friendly shrimp farming encompasses practices designed to minimize environmental degradation while maintaining economic profitability. These practices include integrated mangrove-shrimp aquaculture, recirculating aquaculture systems (RAS), and polyculture methods.

Integrated Mangrove-Shrimp Aquaculture

Integrated mangrove-shrimp aquaculture (IMS) combines shrimp farming with mangrove conservation, creating a symbiotic relationship that benefits both the environment and the economy. Mangroves provide essential ecosystem services, such as coastal protection and carbon sequestration, which can enhance the resilience and sustainability of shrimp farming operations. Economically, IMS can lead to increased shrimp yields and higher market prices due to the premium associated with sustainably produced seafood. However, the initial investment and the need for specialized knowledge can pose challenges for farmers transitioning to this system.

Recirculating Aquaculture Systems (RAS)

RAS technology involves recycling and treating water within aquaculture facilities, eliminating the necessity for continuous water exchange. This method significantly reduces water usage and minimizes the discharge of wastewater into the environment. Economically, RAS can lead to cost savings in water management and potentially higher stocking densities, resulting in increased production efficiency. However, the high capital and operational costs associated with RAS can be a barrier for small-scale farmers.

Polyculture Systems

Polyculture involves cultivating multiple species together, such as shrimp and fish, to create a balanced ecosystem that can reduce disease outbreaks and improve resource utilization. Economically, polyculture can diversify income streams and reduce the financial risks associated with monoculture farming. Nonetheless, managing multiple species requires careful planning and expertise to ensure compatibility and optimal growth conditions. The economic implications of eco-friendly shrimp farming are profound, offering both opportunities and challenges for stakeholders. Adopting sustainable practices can lead to long-term financial stability, market competitiveness, and enhanced product quality.

Cost Efficiency and Profitability

Eco-friendly shrimp farming methods, such as integrated multi-trophic aquaculture (IMTA) and recirculating aquaculture systems (RAS), optimize resource utilization. These techniques reduce the dependency on external inputs like water and feed. For instance, RAS minimizes water usage through closed-loop systems, cutting operational costs while maintaining production efficiency (Cao et al., 2021). Furthermore, integrating species such as tilapia and seaweed into shrimp ponds can enhance nutrient recycling and generate additional revenue streams. Though initial investments in technology and infrastructure are significant, the reduced operational costs, combined with premium market prices for sustainably produced shrimp, ensure profitability over time. Additionally, adopting eco-friendly practices often results in better disease control and lower mortality rates, contributing to economic stability.

Market Opportunities

Consumers increasingly prefer sustainably sourced seafood, driven by awareness of environmental issues. Certification schemes like Aquaculture Stewardship Council (ASC) and Best Aquaculture Practices (BAP) provide eco-friendly shrimp farmers access to niche markets willing to pay higher prices for certified

products (Boyd et al., 2022). Such certifications also foster export opportunities in regions with stringent sustainability standards, enhancing global market reach. The demand for transparency in supply chains and traceability systems further strengthens the market position of eco-friendly shrimp producers (Alam, 2024; Kantal et al., 2025). By leveraging digital platforms and direct-to-consumer sales channels, farmers can enhance their market visibility and profitability.

Employment and Livelihoods

Eco-friendly shrimp farming supports local economies by creating jobs and sustaining livelihoods (Tran et al., 2025; Trang et al., 2023). Techniques such as integrated mangrove-shrimp farming (IMS) not only generate income for farmers but also promote community-based resource management, fostering resilience against economic shocks (Delgado-Serrano et al., 2018). Moreover, eco-friendly practices empower marginalized communities by offering training and capacity-building opportunities. Women, in particular, benefit from increased participation in activities like shrimp processing, packaging, and marketing, contributing to gender equality and social inclusion.

Environmental Impacts of Eco-Friendly Shrimp Farming

While traditional shrimp farming has been associated with significant environmental issues, such as mangrove deforestation and water pollution, eco-friendly practices aim to mitigate these impacts. Eco-friendly shrimp farming prioritizes environmental conservation, addressing the adverse ecological impacts of conventional practices.

Mangrove Conservation and Restoration

Mangroves play a critical role in coastal ecosystems, providing habitats for marine species, acting as natural barriers against erosion, and sequestering carbon. Conventional shrimp farming often leads to mangrove deforestation, disrupting these vital functions. In contrast, integrated mangrove-shrimp farming preserves and restores mangrove forests, balancing aquaculture with ecosystem health (Ha Anh et al., 2024; Tunc, 2019). Mangrove restoration projects not only protect biodiversity but also enhance the resilience of coastal communities against climate-related hazards such as storms and rising sea levels. These initiatives also contribute to global carbon offset goals, aligning with broader environmental conservation efforts.

Water Quality Management

Eco-friendly practices, such as biofloc technology and IMTA, enhance water quality by recycling nutrients and reducing effluents. These methods integrate the cultivation of complementary species, such as algae and

mollusks, which utilize organic waste, mitigating pollution and eutrophication risks (Avnimelech, 2020). The application of natural filtration systems and constructed wetlands further aids in maintaining optimal water quality. Regular monitoring and adaptive management strategies ensure that water parameters remain within sustainable thresholds, reducing the ecological footprint of shrimp farming operations.

Reduction of Greenhouse Gas Emissions

Sustainable shrimp farming mitigates greenhouse gas emissions by using renewable energy sources, optimizing feed efficiency, and preserving carbon-sequestering ecosystems like mangroves. By reducing reliance on artificial inputs and minimizing land conversion, these practices contribute to climate change mitigation (Ahmed et al., 2021). Incorporating solar and wind energy systems into aquaculture operations not only reduces emissions but also lowers energy costs. Additionally, using plant-based or insect-based feeds in place of fishmeal significantly decreases the carbon intensity of shrimp production.

Carbon Footprint Reduction

Shrimp farming has a substantial carbon footprint, primarily due to greenhouse gas emissions from pond management and feed production. Eco-friendly practices, such as integrating mangroves and utilizing sustainable feed sources, can help offset carbon emissions. For instance, mangroves are highly efficient in capturing and storing carbon, which can mitigate the greenhouse gas emissions associated with shrimp farming.

Challenges and Considerations

Despite the benefits, several challenges hinder the widespread adoption of eco-friendly shrimp farming practices. Despite its benefits, the adoption of eco-friendly shrimp farming faces several challenges that must be addressed to ensure widespread implementation.

High Initial Costs

Transitioning to sustainable systems often requires significant capital investment in advanced technologies and infrastructure. Small-scale farmers may struggle to afford these costs, necessitating financial support mechanisms such as subsidies, grants, or low-interest loans (Hossain et al., 2022). Establishing cooperative farming models and crowdfunding initiatives can also alleviate financial barriers. Innovative funding approaches, including carbon credits and ecosystem service payments, provide additional revenue streams to support eco-friendly practices.

Technical Knowledge and Training

Eco-friendly shrimp farming demands technical expertise in areas like water management, disease control, and ecosystem integration. Capacity-building programs and extension services are essential to equip farmers with the skills needed for successful implementation (Boyd et al., 2022). Partnerships with academic institutions and research organizations can facilitate knowledge transfer and technological innovation. Furthermore, digital tools, such as mobile apps and online platforms, can provide real-time guidance and resources for farmers.

Regulatory and Policy Support

Governments play a pivotal role in promoting sustainable practices by enacting supportive policies, providing incentives, and enforcing environmental regulations. The absence of robust governance can hinder the adoption of eco-friendly shrimp farming (Ahmed et al., 2021). Establishing clear guidelines for certification, simplifying compliance procedures, and offering tax benefits can encourage farmers to transition to sustainable methods. International collaborations and alignment with global standards further enhance the credibility and marketability of eco-friendly shrimp products.

Economic Viability

The initial investment and operational costs associated with sustainable practices can be prohibitive for small-scale farmers. Access to financing, technical training, and market incentives are essential to support the transition to eco-friendly farming methods.

Technical Expertise

Implementing sustainable practices requires specialized knowledge and skills. Training programs and extension services are vital to equip farmers with the necessary expertise to manage eco-friendly shrimp farming systems effectively.

Market Demand

Consumer demand for sustainably produced seafood is growing, but it remains a niche market in many regions. Developing certification schemes and promoting the benefits of eco-friendly shrimp farming can help expand market opportunities and justify the investment in sustainable practices.

Research Analysis

Eco-friendly shrimp farming presents a multidimensional framework of sustainability, encompassing environmental conservation, economic feasibility, and social inclusivity. Through a critical analysis of its methodologies, impacts, and challenges,

the research highlights its potential as a sustainable aquaculture practice.

Economic Analysis

The adoption of eco-friendly shrimp farming introduces innovative approaches such as integrated multi-trophic aquaculture (IMTA) and biofloc technology, which enhance productivity and reduce operational costs. This economic viability is further reinforced by the growing consumer demand for sustainably sourced products. Certifications like Aquaculture Stewardship Council (ASC) have created premium markets, allowing producers to secure higher profits. Additionally, community-based shrimp farming initiatives contribute significantly to rural employment and social development, underscoring its economic inclusivity. However, the economic challenges associated with eco-friendly shrimp farming cannot be ignored. High initial capital requirements for infrastructure and technology pose a barrier, particularly for small-scale farmers. Financial instruments like subsidies and loans, alongside cooperative models, could play a pivotal role in addressing these barriers.

Environmental Analysis

Environmentally, eco-friendly shrimp farming mitigates the adverse impacts of traditional methods. Practices like mangrove integration, nutrient recycling, and renewable energy usage exemplify its commitment to ecological balance. The preservation and restoration of mangroves are particularly noteworthy, contributing to biodiversity, carbon sequestration, and protection against climate hazards. Moreover, water quality management through biofloc and IMTA minimizes effluents and nutrient pollution. These practices align with global sustainability goals, reducing the carbon footprint of shrimp farming operations. However, the scalability of these technologies in diverse ecological and socio-economic contexts requires further exploration.

Technological and Operational Mechanisms

Eco-friendly shrimp farming leverages advanced technologies to enhance efficiency and sustainability. IMTA integrates different aquatic species to optimize nutrient cycles, while biofloc technology utilizes beneficial microbial communities for waste management. The adoption of renewable energy sources like solar and wind further reduces operational costs and environmental impact. Despite these advancements, the technology gap among small-scale farmers highlights the need for widespread training and capacity building.

Social and Policy Dimensions

Socially, eco-friendly shrimp farming promotes inclusive growth by empowering marginalized communities. Gender inclusivity is also evident, with increased participation of women in processing and marketing activities. Policy frameworks supporting certifications and compliance can accelerate the adoption of sustainable practices. Collaborative initiatives between stakeholders are essential to overcome regulatory and financial challenges, ensuring equitable growth.

Research and Development

Further research is crucial to optimize technologies, reduce costs, and develop resilient shrimp species adaptable to changing climates. The integration of real-time monitoring systems and AI-driven analytics could revolutionize farm management. Collaborative efforts among academia, industry, and government bodies will be vital in driving innovation and establishing eco-friendly shrimp farming as a global standard. The research underscores eco-friendly shrimp farming as a viable model for sustainable aquaculture, balancing economic prosperity with environmental stewardship. By addressing challenges and scaling innovations, this approach has the potential to transform the shrimp farming industry, paving the way for a more sustainable future.

Future Directions of Ecofriendly Shrimp Farming

To advance eco-friendly shrimp farming, a multi-stakeholder approach involving farmers, researchers, policymakers, and consumers is crucial.

Research and Innovation

Continued research into cost-effective and scalable sustainable farming technologies can enhance adoption rates. Innovations in feed development, waste management, and disease prevention are particularly critical (Cao et al., 2021). Developing climate-resilient shrimp species and biosecure production systems can further strengthen the industry's sustainability. Collaborative research initiatives and open-access data sharing accelerate progress and enable evidence-based decision-making.

Consumer Awareness and Demand

Educating consumers about the benefits of sustainably produced shrimp can drive demand, encouraging more farmers to adopt eco-friendly practices. Certification schemes and labeling programs can play a pivotal role in this regard (Primavera et al., 2020). Social media campaigns, documentaries, and partnerships with celebrity chefs can amplify awareness and promote ethical consumption. Retailers and food

service providers also play a key role in advocating for sustainable sourcing policies.

Collaboration and Partnerships

Collaborative initiatives between public and private sectors can mobilize resources, share knowledge, and promote best practices. International partnerships can also facilitate technology transfer and market access (Tunc, 2019). Establishing regional hubs for eco-friendly aquaculture and fostering cross-border collaborations strengthen the global shrimp farming community. NGOs and environmental organizations can act as intermediaries, bridging gaps between stakeholders and ensuring the inclusivity of small-scale farmers.

Conclusion

Eco-friendly shrimp farming presents a promising pathway to reconcile the economic benefits of shrimp aquaculture with environmental conservation. By adopting sustainable practices, the industry can reduce its ecological footprint, enhance biodiversity, and contribute to climate change mitigation. However, overcoming economic, technical, and market-related challenges is crucial to ensure the widespread adoption and success of eco-friendly shrimp farming practices. Eco-friendly shrimp farming represents a viable solution to the dual challenges of economic growth and environmental conservation in aquaculture. By adopting sustainable practices, the industry can achieve long-term profitability while safeguarding ecosystems and addressing global environmental concerns. Addressing the financial, technical, and policy-related barriers is essential to realizing the full potential of eco-friendly shrimp farming, ensuring a sustainable future for both the industry and the planet.

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