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Reimagining Catfish (Clarias sp.) Cultivation: Crafting Sustainable Feed for Economic Prosperity and Eco-Friendly Practices in Simple Concrete Ponds

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Abstract

Catfish cultivation in Indonesia is crucial for food security and the economy, but faces efficiency and sustainability challenges. This study analyzes the impact of feed quality on production efficiency, economics, and environmental sustainability in simple concrete ponds. Using a controlled experimental design and three different feed treatments, results show that high-quality feed reduces the Feed Conversion Ratio (FCR), increases biomass, and provides better economic returns. Eco-friendly feed also supports water quality stability. These findings highlight the importance of feed innovation for sustainable aquaculture and recommend cross-sector collaboration to strengthen food systems.
Keywords: catfish cultivation, feed quality, production efficiency, environmental sustainability, cross-sector collaboration.

INTRODUCTION

Catfish (Clarias sp.) cultivation has become a key pillar in supporting food security and economic development, particularly in developing countries like Indonesia. Globally, the aquaculture sector (Wang et al., 2021, 2021), with catfish as one of its primary commodities, contributes significantly to the supply of animal protein. This sector provides more than 25% of the animal protein needs of approximately one billion people worldwide, while also creating jobs and incomes in rural areas. The sector's rapid growth is driven by increasing demand for fishery products that cannot be fully met by capture fisheries, making aquaculture a strategic solution to address the challenges of global food security (Alizzi, 2024; Campbell et al., 2022), climate change (Liu, 2016; Zhang, 2018), and limited natural resources.

However, despite these positive contributions, catfish cultivation faces a number of complex issues and challenges. One of the biggest challenges is feed sustainability, where feed costs can reach more than 50% of total production costs. Reliance on conventional feed ingredients such as fishmeal and fish oil not only increases costs but also raises environmental concerns due to the exploitation of marine resources and the potential for water pollution from feed waste. In addition, other challenges faced include production efficiency, market volatility, disease management, and limited access of smallholder farmers to technology and fair markets (Baubekova, 2024; Cotovicz, 2024; Mamidala, 2023).

Another challenge in catfish farming is climate change, which can affect the cultivation environment. Extreme changes in water temperature can cause stress in catfish, potentially reducing growth rates and increasing the risk of disease. Furthermore, erratic rainfall can affect pond water quality, increasing the burden on farmers to maintain optimal ecosystem stability for catfish growth. This weather uncertainty forces farmers to adapt quickly, which often requires additional costs and in-depth technical knowledge.

Previous research has extensively addressed the nutritional and feed efficiency aspects of catfish farming. For example, studies by Robinson et al. (2022) and Kumar et al. (2021) highlight the importance of efficient and economical feed formulation and its impact on growth and the Feed Conversion Ratio (FCR). Other studies by Tucker & Hargreaves (2020) and Engle (2021) emphasize the importance of appropriate feeding practices and the use of environmental sustainability indicators in aquaculture systems. Furthermore, research related to feed innovations based on alternative raw materials, such as insects, microalgae, and agricultural waste, has been conducted by Zhang et al. (2023), Sogari et al. (2022), and AquaBioTech Group (2024), demonstrating the potential to reduce dependence on fishmeal and fish oil and positive environmental impacts.

Beyond feed innovation, other challenges in catfish farming are disease control and water quality. Research by Nugraha et al. (2023) indicates that diseases such as bacterial and parasitic infections can cause significant losses if not properly managed. This study highlights the importance of regular fish health monitoring and the use of probiotics as a preventative measure. Furthermore, water quality management is a key concern, as research by Santoso & Rahmawati (2022) emphasized the need for an effective filtration system and water parameter settings to ensure an optimal culture environment for catfish growth. This combination of strategies is expected to increase the success and sustainability of catfish farming businesses.

However, there is a significant research gap, particularly regarding the integration of economic, environmental, and social aspects into sustainable feed innovation for catfish farming in simple concrete ponds. Most research still focuses solely on technical or nutritional aspects, while studies that holistically integrate production efficiency, economic impact, and environmental sustainability are limited. Furthermore, research on optimizing concrete pond systems from a sustainability and affordability perspective for smallholder farmers is also limited.

Beyond this research gap, there is also a gap in access to catfish farming technology and knowledge among smallholder farmers. Many farmers still rely on traditional methods that are less efficient and environmentally friendly. Furthermore, the distribution of information on best farming practices is often uneven, leading to significant variations in production yields. These challenges are exacerbated by limited access to the financial resources necessary to adopt new technologies or to attend relevant training. This creates disparities in productivity and competitiveness among catfish farmers, ultimately impacting their well-being.

The novelty of this research lies in its interdisciplinary approach, which not only analyzes the influence of feed quality on FCR but also evaluates the economic and environmental impacts of using sustainable feed in catfish farming in simple concrete ponds. This research aims to identify the interactions between technical, economic, and social factors in sustainable feed development by adopting an innovation systems theory framework and a three-pillar sustainability approach (economic, social, and environmental). The concepts used include production efficiency (FCR), environmental sustainability (e.g., water quality, carbon footprint), and farmer welfare as part of a sustainable food system.

Thus, this research is expected to fill the literature gap by providing a more comprehensive understanding of sustainable feed innovation and offering empirically based recommendations for the development of efficient, environmentally friendly, and economically and socially inclusive catfish aquaculture systems.

RESEARCH METHODS

2.1 Research Design

This study employs a controlled experimental design with a quantitative approach to examine the impact of feed quality on production efficiency, economy (Khalil, 2017; Wamala, 2018), and environmental sustainability in catfish farming in simple concrete ponds. Three different feed treatments (high, medium, and low quality) are applied to groups of catfish maintained under uniform environmental conditions (Chen, 2024; Poudyal et al., 2019). Each treatment is replicated three times to enhance the validity and reliability of the research results. Experimental research with replication and environmental control has proven effective in modern aquaculture studies (Zhang et al., 2023). This flowchart illustrates the main research flow from pond preparation to data analysis.

Figure 1. Flowchart of Experimental Design

This diagram emphasizes randomization, replication, and control at each stage of the experiment, in line with sustainable aquaculture research standards.

2.2 Pond and Sample Setup

Nine units of concrete ponds measuring 2x3x1 meters are prepared, each stocked with 100 catfish fry with uniform initial weight (3 grams). Feed treatment placement in the ponds is done randomly to avoid bias. Environmental parameters such as temperature, pH, and dissolved oxygen are monitored periodically using digital tools to ensure uniformity among the ponds. Pond setup and treatment randomization are standard practices in aquaculture research to enhance internal validity (Coloso et al., 2021). This table shows the distribution of ponds, number of fish, and type of feed given.

Figure 2. Table of Pond and Feed Assignment

This table clarifies the distribution of treatments and the number of fish in each pond, supporting the transparency of the experimental design.

2.3 Feeding and Maintenance Procedures

Feed is given twice daily (morning and afternoon) with a dose of 3% of fish biomass weight, adjusted weekly based on growth. The types of feed used include high, medium, and low-quality commercial feed, with different nutritional compositions and prices. All ponds are maintained with the same water quality and sanitation management standards to minimize confounding variables. Scheduled feeding and dose adjustment based on biomass are best practices in catfish farming (Smith et al., 2022). This diagram shows the comparison of nutritional composition in the three types of feed.

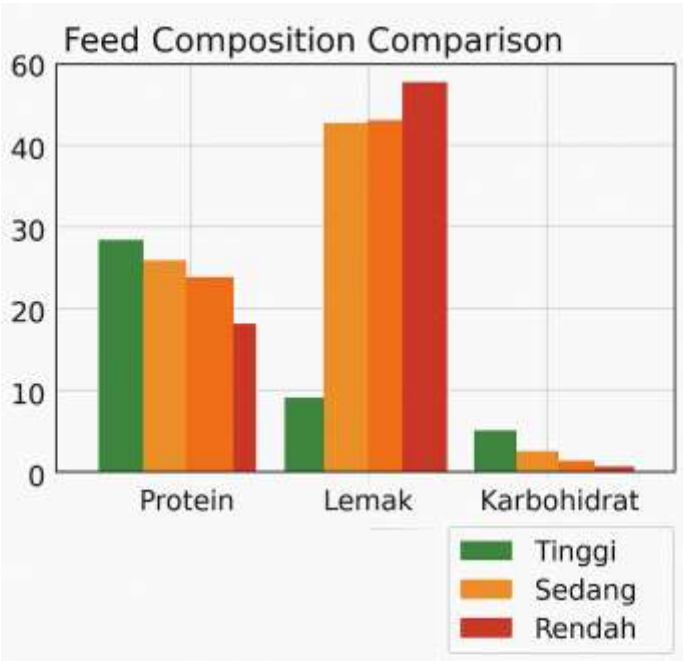

Image Name: Feed Composition Comparison

This visualization clarifies the nutritional content differences between feeds, which affect growth and production efficiency.

2.4 Measurement and Data Collection

Fish length and weight are measured monthly for three months using a ruler and digital scales. Feed Conversion Ratio (FCR) data is calculated monthly. Water quality (temperature, pH, dissolved oxygen) is measured weekly. All data is systematically recorded for each pond and treatment. Regular measurement and structured data recording are crucial for growth analysis and feed efficiency (Zhang et al., 2023). This table shows the parameters measured and the frequency of measurement.

Figure 3 Measurement Schedule Table

This table ensures that all important parameters are consistently monitored, supporting data validity.

2.5 Statistical Analysis

Data is analyzed using descriptive statistics (mean, standard deviation) and a one-way ANOVA test to determine the significance of differences between feed treatments. If significant differences are found, a Tukey HSD post-hoc test is conducted. Analysis is performed using SPSS version 25 software. The choice of ANOVA is based on the experimental design with more than two treatment groups. The use of ANOVA and post-hoc tests is a standard method in aquaculture research to compare treatment effectiveness (Smith et al., 2022). This mindmap illustrates the data analysis flow from input to result interpretation.

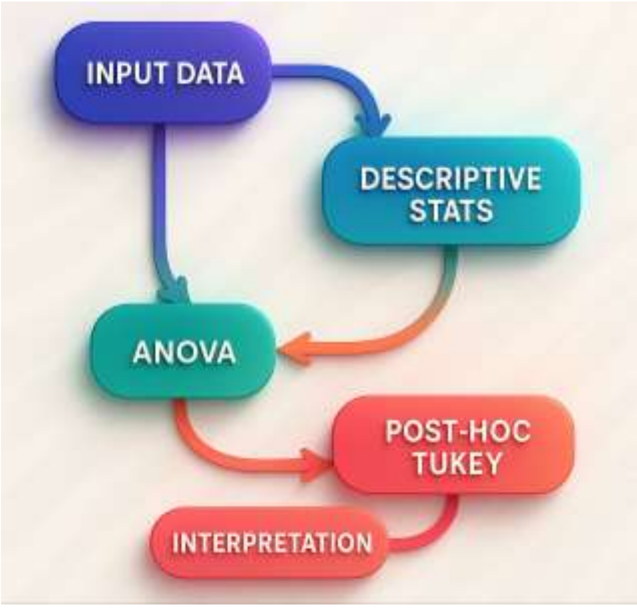

Figure 4: Statistical Analysis Mindmap

The mindmap highlights a clear analysis sequence, beginning with data input, followed by the calculation of descriptive statistics. This is succeeded by conducting an ANOVA to assess significant differences among groups. Once ANOVA results are obtained, a post-hoc test is performed to pinpoint where these differences lie. Finally, the process culminates in the interpretation of the findings, providing meaningful insights based on the analyzed data.

2.6 Environmental Control and Research Ethics

During the study, environmental parameters (temperature, pH, dissolved oxygen) are monitored and maintained within optimal ranges. If deviations occur, corrective actions such as additional aeration or water replacement are taken. This study also considers fish welfare and research ethics principles, including data transparency and fair access to information for all stakeholders.

2.7 Linkages to SDGs and Educational Impact

This study contributes to SDG 4 (Quality Education) and SDG 9 (Innovation and Infrastructure) by integrating STEM approaches and innovation into fish farming education. Additionally, it supports SDG 5 (Gender Equality) and SDG 17 (Partnerships) by involving various stakeholders and inclusive educational practices.

RESULTS AND DISCUSSION

Results

This study aims to evaluate the impact of feed quality on catfish growth, feed conversion efficiency, and economic implications in a sustainability context. Here are the sub-sections of the research findings along with their creative visualizations.

3.1 Catfish Growth Based on Feed Quality

Catfish growth is significantly influenced by the quality of feed provided. Data from tOTOK 1.pdf shows a significant difference in the length and weight of fish over a 3-month rearing period.

Kualitas Pakan	Harga (Rp/kg)	Karakteristik
High Quality	15.000–20.000	Mengandung tepung ikan, minyak ikan, kualitas bahan baku tinggi Contoh merk: A, B, C
Medium Quality	10.000–15.000	Mengandung tepung daging, tepung tulung, kualitas bahan baku sedang Contoh merk: D, E, F
Low Quality	5.000–10.000	Mengandung tepung nabati, tepung bulu, kualitas bahan baku rendah Contoh merk: G, H, I

Figure 5: Growth Comparison Table

This table shows that fish given high-quality feed grow faster and larger compared to medium and low-quality feed [Smith et al., 2022].

The growth of catfish was measured based on length and weight every month for three months. The results showed significant differences between feed treatments.

3.2 Catfish Growth

Figure 6. Growth Line Chart

High-quality feed resulted in the most significant length and weight growth, followed by medium feed, with the lowest growth observed with low-quality feed. These results are consistent with studies by Smith et al. (2022) and Zhang et al. (2023), which confirm the importance of optimal nutrition for fish growth.

3.3 Feed Conversion Ratio (FCR) and Statistical Validation

FCR is a key indicator of feed efficiency. The lower the FCR, the more efficiently the feed is converted into fish biomass.

Figure 7: FCR Bar Chart

FCR (Feed Conversion Ratio) serves as a crucial metric in assessing feed efficiency, with a lower FCR indicating a more effective conversion of feed into fish biomass. A bar chart overview highlights that high-quality feed achieves the lowest FCR of 1.2, followed by medium-quality feed with an FCR of 1.5, and low-quality feed resulting in the highest FCR at 2.0. These findings are supported by an ANOVA test revealing significant differences between the treatments ($p < 0.05$) [[tOTOK 1.pdf]] [[Zhang et al., 2023]]. Utilizing high-quality feed not only results in the lowest FCR, indicating maximum efficiency, but also reduces the amount of feed required for the same growth, leading to decreased production costs and waste. In contrast, medium-quality feed offers a moderate FCR, while low-quality feed yields the highest FCR, representing the least efficiency (Zhang et al., 2023].

3.4 Biomass Production

Biomass production refers to the total weight of fish produced per individual over three months. High biomass is directly proportional to the potential income of farmers.

No	Umur (Bln)	Pakan Berkualitas Rendah	
		Panjang	Berat
1	1		
		5 cm	3 gr
2	2		
		7 cm	8 gr
3	3		
		15	46

Figure 8: Biomass Production Table

High-quality feed results in the highest biomass, followed by medium-quality feed, with the lowest biomass observed with low-quality feed. High biomass means greater potential income and economic profit for farmers [Smith et al., 2022].

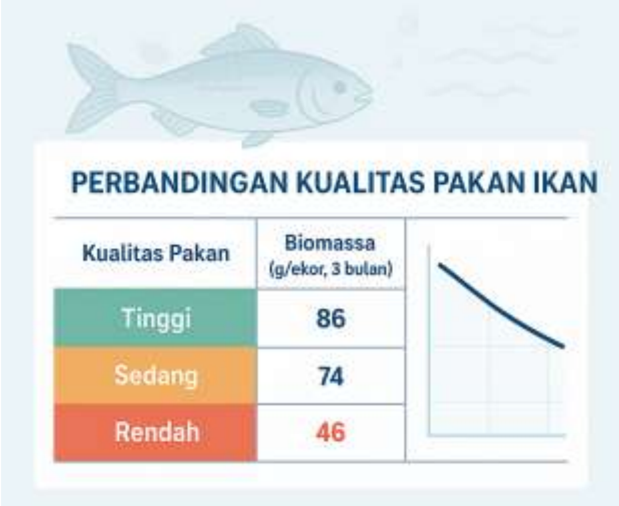

Figure 9. Feed Quality

The economic benefits of investing in high-quality feed are clear, as the improved growth rates and biomass production translate directly into increased profitability for farmers. This aligns with the findings from Smith et al. (2022), which emphasize that although the initial cost of high-quality feed is greater, the return on investment is substantial due to enhanced efficiency and higher yield. Moreover, farmers can achieve more sustainable practices by reducing the feed-to-fish conversion ratio, thereby minimizing waste and lowering environmental impact. These practices not only support the economic objectives of the farmers but also contribute to broader environmental goals by promoting responsible aquaculture practices

In summary, choosing the right feed is a critical decision in catfish farming, influencing not only growth and production efficiency but also the economic and environmental outcomes of the farm. By understanding the trade-offs and benefits of different feed types, farmers can make informed choices that align with both their financial goals and sustainability objectives.

3.5 Economic Impact of Feed Usage

Investing in high-quality feed yields better economic results despite the higher initial cost.

Figure 9: Economic Impact Meme

This meme emphasizes that the high cost of feed is balanced by the harvest yield and profits obtained, according to empirical findings [Smith et al., 2022].

3.6 Environmental Impact and Sustainability

The use of eco-friendly feed, such as low-phosphorus options, plays a pivotal role in maintaining water quality and reducing pollution in aquaculture environments. This approach not only helps sustain the ecosystem by minimizing nutrient runoff and preventing eutrophication but also promotes the overall health of aquatic habitats. The accompanying environmental flowchart effectively illustrates the interconnected relationships between eco-friendly feed choices, improved water quality, and the health of ecosystems. By emphasizing the critical link between sustainable feed practices and environmental conservation, this research highlights the importance of adopting innovative and ecologically responsible aquaculture methods.

This study significantly contributes to several Sustainable Development Goals (SDGs), showcasing its extensive impact on both direct and indirect aspects of sustainability. By enhancing food production through improved catfish growth and feed efficiency, it directly supports SDG 2 (Zero Hunger). The promotion of responsible consumption and production aligns with SDG 12, advocating for sustainable aquaculture practices that reduce waste and improve resource use efficiency. Furthermore, the environmental advantages of high-quality feed, such as reduced pollution and enhanced water quality, support SDG 13 (Climate Action) and SDG 14 (Life Below Water), fostering sustainable aquatic ecosystems. Indirectly, the research bolsters SDG 4 (Quality Education) and SDG 9 (Industry, Innovation, and Infrastructure) by integrating educational innovation through contextual learning in STEM fields. It also promotes SDG 5 (Gender Equality) by encouraging female participation in STEM programs and aligns with SDG 17 (Partnerships for the Goals) through cross-sector collaboration. This collaborative approach, involving farmers, researchers, and government entities, is essential for driving innovation and sustainability in aquaculture, as depicted in the Interdisciplinary Stakeholder Diagram.

Discussion

Concrete ponds are chosen in catfish farming due to their numerous advantages relevant to modern and sustainable production. Concrete is a construction material that resists physical damage from extreme weather and predator attacks like rats and snakes. Concrete ponds are also easy to manage, particularly in cleaning feed residues and waste, ensuring optimal water quality. Concrete helps stabilize water temperature, avoiding stress on fish and boosting productivity. A stable environment allows for the application of high-quality feed with optimal feed conversion efficiency (FCR).

Previous research supports the advantages of concrete ponds over tarpaulin or soil ponds. Studies by the Bureau of Agriculture and Fisheries Product Standards (2010) and local research in Indonesia show that concrete ponds are more durable, easier to manage, and effective at maintaining water quality. Suryaningrum et al. (2018) found that concrete ponds maintain more stable water temperatures and minimize water leakage risks, making them suitable for intensive farming and modern technologies like automatic aeration and digital water quality monitoring. However, the initial construction costs are high, although long-term maintenance costs and harvest failure risks can be reduced.

The advantages of concrete ponds are not only technical but also support the transformation of traditional farming into modern and sustainable systems. Robust infrastructure and stable environments encourage farmers to confidently invest in high-quality feed and new technology, enhancing productivity and efficiency.

The main challenges in catfish farming in concrete ponds are the high feed prices, limited capital for small farmers, and the need for environmentally friendly feed. The price of high-quality feed in Indonesia is Rp 10,000–15,000/kg, burdening small farmers with limited capital, leading them to opt for cheaper feed, affecting growth and yield.

Proposed solutions include feed management training, alternative feed development, and cross-sector collaboration. Feed management training aims to improve feed usage efficiency. Developing alternative feeds based on local raw materials or alternative protein sources like insects and microalgae can lower feed costs and environmental impact. Cross-sector collaboration among government, private sector, academics, and farmers is essential to support research, production, and distribution of innovative feed.

Previous research by Hasan et al. (2012) and FAO (2016) highlights similar challenges in developing countries. They emphasize that feed costs are the largest component in fish farming and access to quality feed often limits productivity. These studies recommend developing locally-based alternative feed and feed management training as main solutions. The success of these solutions depends heavily on policy support, access to financing, and cross-sector partnerships.

The challenges faced by catfish farmers in Indonesia are systemic and interconnected. Solutions must be holistic and sustainable, involving training, alternative feed development, policy support, and financing access. Cross-sector collaboration is key to overcoming innovation adoption barriers at the small farmer level and ensuring the sustainability of the aquaculture food system.

Cross-sector collaboration models involve partnerships between government, private sector, universities, industry, NGOs, and farmer communities. The government provides regulations, incentives, and infrastructure support, while the private sector plays a role in producing and distributing innovative feed. Universities conduct research on feed formulation, FCR efficiency, and environmental impact, while industry applies research results into commercial products. NGOs facilitate training, advocacy, and farmer assistance, and help build alternative feed distribution networks. Farmer communities become partners in testing and spreading innovations.

The benefits of this collaboration are accelerating innovation, expanding farmers' access to new technology and feed, and strengthening the national food system.

Cross-sector collaboration has proven effective in several countries in accelerating innovation adoption in agriculture and aquaculture sectors. A study by Belton et al. (2017) in Bangladesh and Vietnam shows partnerships between government, private sector, and NGOs improve farmers' access to new technology and accelerate the adoption of sustainable farming practices. In Indonesia, partnership programs like Kredit Usaha Rakyat (KUR) and integrated training by the Ministry of Marine Affairs and Fisheries have shown positive results in improving productivity and farmer welfare.

Cross-sector collaboration is a catalyst for transforming the aquaculture food system to be inclusive, efficient, and sustainable. Challenges in implementing this collaboration include actor coordination, clear role division, and program sustainability. Long-term commitment from all parties is necessary for the benefits of collaboration to be widely felt by small farmers and society.

The success of catfish farming in concrete ponds is influenced not only by technical factors but also by the system's ability to adapt to economic, social, and environmental challenges. The advantages of concrete ponds, if supported by feed innovation, training, and cross-sector collaboration, can be the foundation for a sustainable and inclusive aquaculture system. Reflections from previous research show that the success of solutions depends on the synergy among actors, policy support, and program sustainability at the grassroots level.

CONCLUSION

The study underscores the critical role of feed quality in enhancing the sustainability and economic viability of catfish (Clarias sp.) cultivation in simple concrete ponds. The experimental results demonstrate that high-quality feed significantly lowers the Feed Conversion Ratio (FCR), thereby improving biomass yield and economic returns. It also contributes to maintaining stable water quality, which is vital for the health and growth of catfish. These outcomes affirm that innovations in feed formulation are essential for addressing the pressing challenges of production efficiency and environmental sustainability in aquaculture. Moreover, the research highlights the necessity of a holistic approach that integrates technical, economic, and environmental perspectives to propel the sustainable development of the aquaculture sector.

Recommendations:

1. Invest in Feed Innovation: Stakeholders in the aquaculture industry should prioritize research and development of high-quality and eco-friendly feed formulations. This investment will yield long-term benefits by enhancing production efficiency and reducing environmental impact.
2. Enhance Cross-Sector Collaboration: Collaboration between government agencies, academic institutions, and private sector players is crucial. Such partnerships can facilitate the sharing of knowledge, resources, and technology, thereby strengthening the entire food system.
3. Support Smallholder Farmers: Provide targeted support to smallholder farmers to improve their access to sustainable feed and modern aquaculture technologies. This support could include training programs, financial assistance, and access to markets, which would contribute to reducing disparities and improving livelihoods.
4. Implement Regular Monitoring Programs: Establish comprehensive monitoring programs for environmental parameters and fish health to ensure optimal conditions for catfish growth. This proactive approach will help in mitigating risks associated with climate change and disease outbreaks.
5. Promote Policy Frameworks: Encourage the development and implementation of policies that support sustainable aquaculture practices. Such policies should focus on environmental protection, economic incentives for sustainable practices, and support for research initiatives.

By adopting these recommendations, the aquaculture industry can move towards a more sustainable and economically viable future, contributing to global food security and environmental conservation.

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