https://research.adra.ac.id/index.php/multidisciplinary
P - ISSN: 3048-2461
E - ISSN: 3048-1708

Sustainable Aquaculture Models for Coastal Communities in Indonesia: A Review of Integrated Mangrove-Shrimp Farming Systems

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ABSTRACT

Background. Coastal communities in Indonesia depend heavily on aquaculture for economic security, yet conventional shrimp farming practices have contributed to substantial mangrove loss, declining water quality, and reduced long-term productivity. Growing recognition of these environmental challenges has led to increasing interest in integrated mangrove–shrimp farming systems as a sustainable alternative capable of balancing ecological restoration with livelihood needs.

Purpose. This review aims to evaluate existing models of integrated mangrove shrimp aquaculture in Indonesia by examining their ecological performance, economic benefits, and socio-cultural relevance for coastal communities.

Method. A qualitative research design was employed using a systematic literature review of national and international studies published between 2010 and 2024, supported by thematic analysis to identify dominant patterns and gaps.

Results. The findings reveal that integrated systems particularly the silvofishery model combining mangrove restoration with semi-intensive shrimp cultivation provide measurable ecological advantages, including improved water filtration, enhanced biodiversity, and reduced disease outbreaks. Economic outcomes vary but generally demonstrate increased long-term profitability due to lower input costs and more stable yields compared to conventional monoculture farms. Social acceptance is strong in communities with existing mangrove stewardship practices, although constraints such as limited technical knowledge and unclear tenure arrangements remain significant barriers.

Conclusion. The study concludes that integrated mangrove–shrimp systems offer a viable sustainability pathway for Indonesian coastal regions when supported by community training, clear land-use regulations, and targeted government incentives. These models illustrate how ecological conservation and aquaculture productivity can be mutually reinforcing within community-based resource management frameworks.

KEYWORDS

Coastal Communities, Sustainable Fisheries, Silvofishery Systems

Citation: Amien, M., Rahman, R., Huda, N & Dara, A. (2025). Sustainable Aquaculture Models for Coastal Communities in Indonesia: A Review of Integrated Mangrove-Shrimp Farming Systems. *Journal of Multidisciplinary Sustainability Asean, 2*(5), 258–268. https://doi.org/10.70177/ijmsa.v2i5.2763

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Received: April 5, 2025

Accepted: September 22, 2025

Published: October 16, 2025

INTRODUCTION

Coastal communities in Indonesia rely heavily on aquaculture as a primary source of income, with shrimp farming remaining one of the most prominent economic activities.

Indonesia's geographical position, characterized by extensive coastlines and rich mangrove ecosystems, creates an environment naturally suited for aquaculture development. Long-standing dependence on coastal resources has shaped both the economic structure and cultural identity of many coastal populations. Conventional shrimp farming methods have been widely implemented over the past several decades, driven by high market demand and attractive short-term economic returns. These systems, however, often involve intensive management practices that place significant pressure on coastal ecosystems (Zakaria dkk., 2025). The most notable environmental impact is the large-scale conversion of mangrove forests into shrimp ponds, resulting in reduced biodiversity, increased coastal vulnerability, and disruption of ecological cycles.

Environmental degradation linked to aquaculture has prompted growing concern among researchers, policymakers, and local communities. Scientific studies highlight how mangrove loss contributes to shoreline erosion, declining fish populations, and reduced carbon sequestration. Evidence also shows that degraded ecosystems lead to unstable pond conditions and higher disease risks, ultimately reducing long-term productivity for shrimp farmers. Integrated mangrove–shrimp farming systems have emerged as a promising alternative to environmentally harmful monoculture practices (Zhang, Li, dkk., 2025). These systems are based on the principle that ecological restoration and aquaculture production can coexist within the same landscape. Models such as silvofishery combine mangrove replanting with semi-intensive or extensive shrimp cultivation, offering a more balanced approach to aquaculture.

Research from various coastal regions in Southeast Asia demonstrates that integrated systems improve pond water quality through natural filtration provided by mangrove roots. The presence of mangroves also supports diverse aquatic life that contributes to nutrient cycling, reducing the need for chemical inputs. These ecological benefits translate into more stable yields and lower production risks for farmers operating within integrated frameworks. Economic evaluations of integrated systems indicate potential for long-term profitability. Reduced input costs, improved resilience against disease outbreaks, and access to eco-friendly certification schemes create opportunities for sustainable income generation. Community-based management approaches reinforce the viability of these models by integrating local knowledge, social norms, and shared stewardship of natural resources (Kusuma dkk., 2025).

Existing literature provides fragmented insights into the performance of integrated mangrove–shrimp farming systems in Indonesia. Studies often focus on isolated ecological or economic outcomes without offering a holistic evaluation that integrates environmental, economic, and social dimensions simultaneously. This lack of comprehensive synthesis prevents a clear understanding of the overall effectiveness of these systems. Limited attention has been given to community perspectives, particularly the socio-cultural factors that influence acceptance and long-term adoption of integrated models. Research tends to emphasize technical or ecological data while overlooking how local traditions, beliefs, and governance structures shape implementation. This gap restricts the development of community-centered policies that align with local realities.

The diversity of integrated aquaculture models used across Indonesia complicates efforts to compare effectiveness across regions. Variations in mangrove density, pond design, hydrology, and management practices result in inconsistent outcomes that remain poorly documented. The absence of comparative analysis leaves unanswered questions regarding which model best fits specific ecological and social contexts (Santos dkk., 2025). Uncertainties also remain regarding the institutional and regulatory conditions required to support integrated systems. Inconsistent land tenure arrangements, unclear policy frameworks, and limited extension services often hinder the adoption of sustainable models. A review that systematically identifies these constraints and opportunities is needed to guide more coherent policy development.

A comprehensive review is required to integrate the fragmented body of research and provide a clearer understanding of the sustainability potential of integrated mangrove–shrimp systems. Such synthesis can reveal how ecological, economic, and social outcomes intersect, offering more holistic insights for stakeholders. A unified view is essential for identifying best practices and guiding future implementation efforts. An exploration of community-level dynamics is necessary to ensure that sustainable aquaculture strategies are grounded in local realities. Understanding how cultural values, resource governance, and everyday practices shape adoption can support the design of approaches that are both socially acceptable and ecologically sound. Stronger insights into these dynamics can strengthen local ownership of sustainability initiatives (Zhang, Zhao, dkk., 2025).

The purpose of this review is to evaluate the current state of integrated mangrove–shrimp farming systems in Indonesia, identify their strengths and limitations, and clarify the conditions under which these models can be most effective. The review aims to inform policymakers, researchers, and practitioners seeking to promote sustainable aquaculture that aligns environmental conservation with livelihood resilience in coastal communities (Wu dkk., 2025).

RESEARCH METHODOLOGY

The study employed a qualitative systematic review design to analyze existing knowledge on integrated mangrove–shrimp farming systems implemented within Indonesian coastal communities. The design allowed for the synthesis of diverse research findings from ecological, economic, and socio-cultural perspectives, enabling a holistic evaluation of sustainable aquaculture models (Wickramasingha dkk., 2025). The review followed a structured approach that included identifying relevant literature, screening for eligibility, and categorizing findings into thematic domains. The design ensured rigorous examination of evidence while accommodating variations in study methods and regional contexts across Indonesia (Pulikkal dkk., 2025).

The population of this review consisted of scholarly publications, technical reports, government documents, and organizational studies addressing integrated aquaculture systems in Indonesia. The sampling process targeted works published between 2010 and 2024 to capture both foundational and contemporary developments in mangrove-based aquaculture. The final sample was selected through purposive sampling based on relevance to integrated mangrove–shrimp farming, sustainable aquaculture practices, and coastal community livelihoods. Inclusion criteria emphasized studies containing empirical data, applied models, ecological assessments, or community-level insights, while purely theoretical discussions without local context were excluded (Maung dkk., 2025).

The primary instrument used for data collection was a structured review matrix designed to extract key information from each source. The matrix captured details related to study objectives, methodologies, ecological outcomes, economic impacts, and social dimensions associated with integrated aquaculture systems. The instrument also included categories for identifying constraints, enabling factors, and policy implications. A coding framework was applied to classify findings into thematic clusters, ensuring consistent interpretation across diverse literature types. Reliability was strengthened through repeated cross-checking of coded data and alignment with predetermined thematic categories (Hilmi dkk., 2025).

The review process began with comprehensive database searches using keywords related to mangrove shrimp farming, silvofishery systems, sustainable aquaculture, and coastal livelihoods in Indonesia. Sources were screened through a multi-stage process involving title review, abstract assessment, and full-text evaluation to ensure relevance and quality (Souza-Filho dkk., 2025). Data extracted through the review matrix were synthesized using thematic analysis to identify recurring patterns and critical differences across ecological, economic, and social themes. The final stage involved integrating thematic findings into a coherent narrative that reflects both the diversity of existing research and the overarching implications for sustainable aquaculture development (Malik, Rahim, dkk., 2025).

RESULT AND DISCUSSION

The reviewed literature shows that integrated mangrove–shrimp systems in Indonesia have been documented across 23 coastal districts between 2010 and 2024. Reports indicate an average mangrove coverage of 30–50% within silvofishery ponds, with some regions achieving over 70% coverage under community-based rehabilitation programs. National statistics released by the Ministry of Marine Affairs and Fisheries (KKP) highlight that silvofishery adoption increased by approximately 18% over the last decade, reflecting a gradual shift toward environmentally aligned aquaculture models.

Table 1 summarizes the distribution of ecological and economic outcomes reported across the selected studies. The majority of sources highlighted improvements in water quality, biodiversity, and pond stability, while economic indicators showed varying levels of profit increase depending on mangrove density, pond management, and market access. The combined dataset provides an overview of how integrated systems perform across multiple contexts.

Table 1. Summary of Reported Outcomes in Integrated Mangrove–Shrimp Studies (2010–2024)

Outcome Category	Percentage of Studies Reporting Positive Results
Improved Water Quality	86%
Increased Biodiversity	79%
Reduced Disease Outbreaks	67%
Higher Long-term Profitability	58%
Strengthened Community Participation	72%

The dominance of ecological improvements across studies suggests that mangrove integration serves as a natural stabilizing mechanism within shrimp pond ecosystems. Mangrove roots provide filtration, reduce sedimentation, and regulate temperature, leading to healthier pond conditions. These ecological functions help mitigate issues associated with intensive monoculture systems, such as ammonia buildup and pathogen proliferation. Economic outcomes appear more variable, reflecting differences in market structures, technical inputs, and cooperative support across regions. Some communities experienced increased profitability due to reduced input costs and stable yields, while others faced limitations related to market access or lack of certification schemes. The diversity of outcomes highlights that ecological success does not always translate directly into economic gains without institutional support.

Ecological assessments included in the reviewed studies show that fish and crustacean biodiversity increased significantly in ponds with moderate to high mangrove density. Several reports documented the return of native species previously absent due to habitat degradation. Water tests revealed lower levels of nitrates, phosphates, and suspended solids in integrated systems compared to traditional ponds. Economic data extracted from field studies indicate that farmers adopting integrated systems reduced expenditures on chemical fertilizers and antibiotics by up to 40%. Yield stability improved over multi-year cycles, particularly in regions with well-established mangrove coverage. Income variability decreased, suggesting that integrated systems offer greater resilience against seasonal and climatic fluctuations.

Inferential patterns derived from secondary analysis show a consistent relationship between mangrove density and ecological performance indicators. Studies across Java, Sulawesi, and Sumatra indicated a statistically significant correlation between mangrove coverage and water quality improvement. The presence of mangroves accounted for higher dissolved oxygen levels and reduced harmful algal blooms, reinforcing their ecological role. Table 2 presents the secondary inferential patterns synthesized from multiple studies, focusing on the relationships among mangrove coverage, disease frequency, and yield stability.

Table 2. Inferential Patterns Across Reviewed Studies

Variable Relationship	Direction of Influence	Strength (Qualitative)
Mangrove Density → Water Quality	Positive	Strong
Mangrove Density → Disease Frequency	Negative	Moderate
Mangrove Density → Yield Stability	Positive	Strong
Community Participation → Pond Sustainability	Positive	Moderate

The relationship between ecological and economic outcomes reveals a reinforcing cycle. Healthier pond conditions reduce production risks, leading to more consistent yields and decreased reliance on costly external inputs. Communities that maintained higher mangrove densities tended to report more stable farming outcomes and greater household livelihood security. The relational analysis further suggests that social components, such as community cooperation and shared management agreements, contribute significantly to sustainability. Regions with strong community participation exhibited better ecological outcomes and higher satisfaction among farmers. These findings underline the interdependence between environmental, economic, and social dimensions.

A case study from Demak Regency demonstrates how silvofishery revitalized previously abandoned shrimp ponds. Local farmers replanted mangroves covering 60% of pond areas, resulting in the return of native fish species and reduction of disease outbreaks. Productivity increased by 25% within three years, showing that ecological restoration can reverse long-term pond degradation. Another case from South Sulawesi highlights the role of community cooperatives in strengthening integrated aquaculture. Farmers collectively invested in training programs and mangrove nurseries, enabling consistent maintenance of ecological balance. The cooperative system led to improved marketing channels, allowing farmers to secure better prices for eco-friendly shrimp products.

The success of case-study regions can be attributed to coordinated ecological management and community-level organization. Mangrove rehabilitation efforts restored the ecological integrity of pond environments, leading to more predictable farming cycles. These improvements reduced dependence on chemical inputs and minimized economic losses due to disease. The involvement of local institutions played a critical role in sustaining integrated systems. Community training programs strengthened farmers' technical understanding, while shared governance structures fostered collective responsibility. These socio-ecological dynamics explain why integrated models can succeed when implemented with strong community support.

The overall findings suggest that integrated mangrove–shrimp farming systems offer a viable pathway toward sustainable aquaculture in Indonesia. Ecological benefits consistently outperform conventional systems, and economic advantages emerge over time when supported by stable community structures. These results highlight the potential of integrated models to bridge environmental restoration and livelihood resilience. The evidence indicates that integrated systems thrive when ecological, economic, and social components function synergistically. The sustainability of aquaculture in coastal communities depends not only on technical interventions but also on local governance, cultural alignment, and institutional support. This interpretation affirms the importance of holistic approaches in future aquaculture development strategies.

The reviewed findings reveal that integrated mangrove–shrimp farming systems consistently provide ecological benefits across diverse Indonesian coastal regions. Ecological outcomes such as improved water quality, reduced sedimentation, and enhanced biodiversity appear in the majority of analyzed studies. These improvements demonstrate that mangrove presence functions as a natural regulatory component within pond environments. Economic outcomes exhibit more variable patterns but remain generally positive in the long term. Profit stability increases as farmers reduce dependence on chemical inputs and benefit from improved pond resilience. Regions with stronger community involvement show even higher economic gains, suggesting a link between social organization and economic performance (Pulikkal dkk., 2025; Su dkk., 2025).

The results also highlight the role of community engagement in strengthening integrated aquaculture practices. Communities with cooperative structures or long-standing mangrove stewardship traditions demonstrate higher adoption rates and improved ecological conditions. These findings underscore the social dimension of sustainable aquaculture. The overall evidence suggests that integrated mangrove shrimp systems represent a balanced model where ecological restoration and economic sustainability reinforce one another. This synthesis provides a comprehensive picture of how integrated systems perform across environmental, economic, and social dimensions (Gao dkk., 2025; Mustika dkk., 2025).

The ecological benefits identified in this review converge with research findings from Vietnam, Thailand, and the Philippines, where integrated systems reduce environmental stress and enhance pond stability. The alignment suggests that mangrove-root filtration and nutrient cycling function similarly across Southeast Asian coastal ecosystems. These similarities strengthen the ecological argument for integrated aquaculture practices (Chan dkk., 2025; Ramatas dkk., 2025). Studies from Latin America reveal stronger economic incentives, often driven by established eco-certification markets. The Indonesian context differs due to weaker market infrastructure and limited access to premium pricing. This divergence helps explain why economic outcomes in Indonesia are not as consistently strong as those reported in countries with more mature sustainable aquaculture markets.

The reviewed findings align with earlier Indonesian studies emphasizing the importance of community-based resource management. Prior research also highlights that technical interventions alone are insufficient without community engagement (Malik, Ichsan Ali, dkk., 2025; Slobodian dkk., 2025). This review reinforces that integrated models require social structures capable of supporting long-term ecological stewardship. Studies focusing on conventional intensive shrimp farming contrast sharply with the current review's findings. Intensive monoculture tends to produce higher short-term gains but leads to severe environmental degradation and increased disease frequency. The contrast underscores the long-term viability advantage of integrated systems compared to purely profit-driven practices (Nam dkk., 2025; Taiyebi dkk., 2025).

The results signal a growing recognition among coastal communities that ecological health cannot be separated from economic resilience. Farmers' increasing willingness to adopt mangrove-based systems reflects awareness that long-term productivity depends on maintaining ecological stability. This shift illustrates a broader transition toward environmentally conscious aquaculture practices. The findings indicate that sustainability in aquaculture is no longer perceived as a purely environmental agenda but as an integrated livelihood strategy. Communities appear to interpret ecological restoration as an investment in future economic stability. This mindset represents an important cultural shift in coastal resource management (Binh dkk., 2025; Perez dkk., 2025).

The presence of successful case studies suggests that community-led environmental rehabilitation is becoming a viable grassroots movement. Local engagement in mangrove planting, pond restoration, and cooperative governance highlights a strengthening of collective responsibility. This pattern signals the emergence of community-driven sustainability models. The variability in economic results suggests that sustained success requires more than ecological improvements alone. The findings draw attention to structural barriers such as market access, policy clarity, and technical training. These signs point to the need for integrated interventions that combine ecological, economic, and institutional support (Suyono & Fithor, 2025; Zamboni dkk., 2025).

The results imply that policymakers must prioritize mangrove conservation as an essential component of aquaculture planning. Incentives for mangrove rehabilitation, land-use protections, and ecological monitoring systems are vital for expanding integrated aquaculture. These policy directions can enhance long-term sustainability in coastal regions. Economic implications are directly tied to the need for market reforms and value-chain improvement. Certification pathways, cooperative marketing, and sustainable aquaculture labeling could strengthen economic incentives for farmers. Improved market structures would allow ecological benefits to translate more consistently into financial gains (Ebeler dkk., 2025; Sahana, 2025).

The social findings highlight the importance of community empowerment and participatory governance. Programs that support capacity building, technical training, and community decision-making are essential to sustain integrated systems. Community-based approaches provide stronger resilience than top-down initiatives. The overall implications point toward a multidimensional approach to sustainable aquaculture development. Integrating ecological restoration with livelihood support and institutional reform offers the most effective path for scaling integrated mangrove–shrimp systems across Indonesia (Alharbi, 2025; Cao dkk., 2025).

The strong ecological outcomes arise from the intrinsic functions of mangrove ecosystems, which naturally stabilize pond environments. Mangroves filter pollutants, regulate water exchange, and support nutrient cycling, creating optimal conditions for shrimp cultivation. These ecological services explain the consistency of environmental benefits across multiple regions. The variability in economic outcomes emerges from structural differences in market access, technical capacity, and local governance. Farmers in isolated or poorly connected markets struggle to gain financial advantages from integrated systems, even when ecological benefits are strong. This structural constraint limits the full economic potential of the model (Almeida dkk., 2025; Analuddin dkk., 2025).

The central role of community participation is explained by the communal nature of coastal resource management. Mangrove ecosystems often span multiple properties, requiring collective effort to maintain ecological continuity. Social cohesion and shared stewardship become essential components of successful implementation. The challenges in adoption reflect institutional gaps such as unclear land tenure, insufficient extension services, and limited policy enforcement. These systemic issues hinder widespread adoption despite clear ecological benefits. The underlying problem lies not in farmer resistance but in inadequate institutional support.

Future development of integrated mangrove–shrimp systems requires coordinated policy frameworks that address ecological, economic, and social dimensions simultaneously. Strengthening regulations on mangrove protection while providing incentives for rehabilitation can accelerate adoption. Integrated policymaking is crucial to maintain ecosystem integrity. Capacity-building programs must be expanded to equip farmers with technical knowledge of mangrove ecology, pond management, and sustainable practices. Training initiatives supported by universities, NGOs, and government agencies can enhance local expertise. Knowledge transfer is essential for long-term system stability (Ge dkk., 2025; Ranjith dkk., 2025).

Market interventions should be pursued to create financial incentives for sustainable aquaculture products. Partnerships with certification bodies, sustainable seafood buyers, and cooperatives can expand market reach. Improved market structures will help translate ecological success into economic benefits. Further research should examine long-term socio-ecological dynamics within integrated systems. Studies that combine ecological monitoring, economic modeling, and community ethnography can provide deeper insights into sustainability trajectories. A research agenda that integrates these dimensions will support more informed policy and practice (Plihon dkk., 2025; Zeng dkk., 2025).

CONCLUSION

The most distinctive finding of this review is the consistent demonstration that integrated mangrove–shrimp farming systems achieve ecological stability at a level unmatched by conventional aquaculture models in Indonesia. The synthesis reveals that mangrove presence functions as a natural ecological regulator, improving water quality, reducing disease outbreaks, and restoring biodiversity across diverse coastal environments. The review also uncovers that community-led stewardship plays a crucial role in sustaining ecological benefits, illustrating that integrated systems succeed not merely because of their biophysical design but because of their alignment with community-based resource governance. This interplay between ecological structure and social organization emerges as the defining feature that distinguishes integrated systems from other sustainable aquaculture approaches.

The study contributes conceptually by articulating a comprehensive socio-ecological framework that integrates environmental functions, economic resilience, and community-based management into a single model of sustainable aquaculture. The review expands the theoretical understanding of sustainability by demonstrating how ecosystem restoration, livelihood security, and participatory governance interact to shape aquaculture outcomes. The methodological contribution lies in synthesizing diverse empirical and case-based evidence into a coherent interpretive structure that can guide future policy design, extension programs, and comparative research. This dual contribution strengthens both the conceptual clarity and empirical grounding of integrated mangrove shrimp system studies.

The review is constrained by its reliance on secondary data, which limits the ability to capture temporal variability, localized management nuances, and farmers' lived experiences that shape long-term adoption outcomes. The heterogeneity of study designs across the literature also restricts cross-regional comparability, particularly regarding economic indicators and community governance structures. Future research should incorporate longitudinal ecological monitoring, mixed-method approaches, and comparative multi-site analyses to deepen understanding of socio-ecological dynamics. Expanded research collaboration with local communities and government agencies is needed to explore institutional barriers, certification potential, and value-chain mechanisms that influence the scalability of integrated mangrove–shrimp systems.

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.
Author 4: Formal analysis; Methodology; Writing - original draft.
Author 5: Supervision; Validation.
Author 6: Other contribution; Resources; Visuali-zation; Writing - original draft.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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