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Biosecurity-Based Good Aquaculture Practices for Sustainable Aquaculture Environmental Management: A Literature Review

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Abstract

Introduction: *The rapid development of aquaculture contributes to meeting global fish protein demand; however, it also poses environmental challenges such as declining water quality, increased aquaculture waste, and heightened risks of disease transmission.* ***Objective:*** *This article aims to examine the role of biosecurity-based Good Aquaculture Practices (GAP) in supporting sustainable aquaculture environmental management.* ***Method:*** *This study employed a literature review method with a content analysis approach, drawing on relevant national and international scientific articles.* ***Results and Discussion:*** *The findings indicate that the implementation of biosecurity-based GAP contributes to improved water quality and waste management, enhanced sanitation and fish health management, and reduced use of antibiotics and chemicals that may contaminate the environment, with successful implementation influenced by managerial support and policy frameworks.* ***Conclusion:*** *Biosecurity-based Good Aquaculture Practices represent an important approach to aquaculture environmental management, as they support the sustainability of aquaculture activities while minimizing negative impacts on aquatic environments*

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Introduction

Aquaculture is one of the fastest-growing food production sectors globally and plays a vital role in meeting the increasing demand for animal protein, while also supporting economic development and food security. However, the rapid expansion and intensification of aquaculture systems have been accompanied by various challenges, particularly those related to disease outbreaks, environmental degradation, and sustainability issues (Brugere et al., 2025; FAO, 2024). The emergence of diseases in aquaculture systems not only causes significant economic losses but also poses potential negative impacts on surrounding aquatic ecosystems through pathogen transmission, excessive use of chemicals, and environmental pollution (Subasinghe & Alday-Sanz, 2023).

One of the main factors triggering disease outbreaks in aquaculture is the weak implementation of management systems, including inadequate water quality control, insufficient waste management, high stocking densities, and limited preventive measures against the introduction and spread of pathogens. These conditions can increase stress levels in cultured organisms, reduce immune resistance, and create environments that favor pathogen development (Can et al., 2023; Slette et al., 2025). Consequently, biosecurity has increasingly been recognized as a key component in the development of sustainable aquaculture, emphasizing preventive approaches rather than reactive disease treatment.

Biosecurity in aquaculture is defined as a set of managerial and operational measures designed to reduce the risk of pathogen introduction, establishment, and spread within and between aquaculture systems. Effective biosecurity implementation focuses on preventive actions, such as controlling the movement of organisms and equipment, applying sanitation and hygiene measures, and conducting regular fish health monitoring (Subasinghe & Alday-Sanz, 2023). Recent studies indicate that biosecurity measures are more effective and environmentally sound when integrated into a comprehensive aquaculture management framework, rather than being implemented as standalone actions (Brugere et al., 2025).

Good Aquaculture Practices (GAP) represent a management framework that integrates technical, environmental, and managerial principles to ensure responsible aquaculture practices. GAP emphasizes proper water quality management, feed efficiency, waste reduction, fish health management, and environmental protection. Several studies have demonstrated that the implementation of GAP not only contributes to increased productivity but also reduces environmental impacts and supports disease prevention when integrated with biosecurity principles (Can et al., 2023; Wijadmono et al., 2025). Thus, GAP serves as a preventive approach that supports biosecurity while promoting the sustainability of aquaculture systems.

The integration of biosecurity-based GAP plays an important role in reducing pollution loads, minimizing the use of antibiotics and chemicals, and protecting aquatic ecosystems surrounding aquaculture sites. Preventive disease management through the application of GAP can reduce dependence on therapeutic treatments, thereby lowering the risk of antimicrobial resistance and chemical residues in aquatic environments (Subasinghe & Alday-Sanz, 2023). Improved waste and water quality management through GAP implementation further supports ecosystem health and the long-term sustainability of aquaculture activities (Brugere et al., 2025).

Although research on GAP and biosecurity continues to expand, most existing studies remain fragmented, with a limited focus on technical disease control or productivity enhancement, while insufficiently addressing environmental implications in an integrated manner. There is still a lack of synthesis regarding how biosecurity-based GAP contributes to reducing nutrient pollution and organic loading (such as eutrophication and organic matter accumulation), minimizing antibiotic use and the spread of antimicrobial resistance (AMR), and preventing pathogen spillover into surrounding aquatic ecosystems. Addressing these interrelated dimensions is essential to understand the broader ecological value of biosecurity in aquaculture practice. Therefore, this article aims to review and synthesize current scientific literature related to the role of biosecurity-based Good Aquaculture Practices in supporting both disease prevention and environmental sustainability in aquaculture systems.

Method

This study employed a literature review method aimed at examining and synthesizing previous research findings related to the implementation of biosecurity-based *Good Aquaculture Practices* (GAP) in supporting environmental sustainability in aquaculture systems. The literature review approach was selected because it provides a comprehensive understanding of conceptual developments, empirical findings, and environmental implications reported in widely published studies (Snyder, 2019); (Xiao & Watson, 2019). Literature searches were conducted using several scientific databases, including Google Scholar and other relevant academic databases, as well as reputable national and international journals. The search process utilized keywords relevant to the research topic, including “Good Aquaculture Practices,” “biosecurity,” “biosafety,” “sustainable aquaculture,” and “environmental impact of aquaculture,” to ensure the relevance of the retrieved literature to the focus of the study. The literature included in this review was selected based on inclusion criteria, namely scientific articles addressing Good Aquaculture Practices (GAP), biosecurity, biosafety, or their relationship to environmental sustainability in aquaculture, and published in reputable national and international journals or reports from recognized international organizations. Exclusion criteria included articles that were not relevant to the research topic, non-scientific publications, and studies that did not provide sufficient information regarding the implementation of GAP or biosecurity in the aquaculture context.

The literature selection process involved an initial identification based on titles and abstracts, followed by a full-text review to assess alignment with the research objectives, resulting in the selection of the most relevant articles for in-depth analysis. The selected literature was then organized and summarized into synthesis tables to facilitate analysis and discussion. Data analysis was conducted using a descriptive qualitative approach with thematic synthesis, in which each article was analyzed to identify research focus, key findings, and contributions to the implementation of GAP and biosecurity, as recommended in thematic literature review studies (Snyder, 2019). The results of the analysis were subsequently grouped into major themes, including the concept of Good Aquaculture Practices, the role of biosecurity in disease prevention, and implications for environmental quality and aquaculture sustainability, which were then presented in the form of tables and narrative discussion in the results and discussion section.

Result and Discussion

This section presents the results of the literature synthesis related to the implementation of biosecurity-based *Good Aquaculture Practices* (GAP) and discusses their implications in the context of sustainable aquaculture environmental management. The findings were obtained through the analysis of relevant scientific articles and are presented in the form of tables to facilitate the understanding of patterns and trends across studies. These findings are then discussed narratively to explain the interrelationships among key concepts and their implications for sustainable aquaculture systems.

Characteristics and Key Findings of Studies on GAP and Biosecurity

As an initial step, a summary of scientific articles addressing *Good Aquaculture Practices* and biosecurity was conducted to identify research focus areas and key findings reported by previous studies. This summary aims to provide a general overview of research trends, methodological approaches, and major findings related to the role of GAP in supporting biosecurity in aquaculture systems. The synthesis of the reviewed literature is presented in Table 1.

Table 1

Summary of Reviewed Articles Related to Good Aquaculture Practices (GAP) and Biosecurity

No.	Author (Year)	Research Focus	Key Findings
1	Aladetohun et al. (2025)	Evaluation of biosecurity implementation in aquaculture enterprises	The level of biosecurity implementation remains low and is influenced by limited knowledge, experience, and awareness of aquaculture practitioners regarding the importance of biosecurity.
2	Balaka (2024)	Level of compliance and adoption of biosecurity in fish health management	Biosecurity compliance is categorized as low to moderate, with practices tending to be reactive to disease outbreaks, thereby increasing the risk of pathogen spread.
3	Schwarz et al. (2017)	Principles and practices of Good Aquaculture Practices (GAP)	GAP functions as a preventive approach through water quality management, sanitation, and fish health management to reduce disease risk.
4	Can et al. (2023)	Integration of biosecurity and aquaculture sustainability	The implementation of GAP-based biosecurity improves fish health, cultured organism welfare, and the sustainability of aquaculture systems.
5	Subasinghe & Alday-Sanz (2023)	Biosecurity as a strategy for reducing aquaculture diseases	Biosecurity effectively reduces reliance on antibiotics and chemicals, thereby minimizing negative impacts on aquatic environments.
6	Brugere et al. (2025)	Conceptual framework of biosecurity and the economic impacts of aquatic diseases	Biosecurity represents a strategic investment that not only reduces disease occurrence but also minimizes economic losses and environmental risks in aquaculture.
7	Slette et al. (2024)	Biosafety and biosecurity risks and management in intensive aquaculture systems	Biosecurity risk identification indicates that system design, sanitation, and operational management play important roles in preventing pathogen transmission.
8	Wijadmono et al. (2025)	Impacts of GAP implementation on aquaculture performance	GAP implementation has a positive effect on productivity and contributes to improved environmental management in aquaculture operations.

Based on table 1, most studies indicate that the level of biosecurity implementation in aquaculture systems remains low to moderate, particularly in small- and medium-scale aquaculture operations. Aladetohun et al. (2025) and Balaka (2024) reported that low biosecurity implementation is influenced by limited knowledge, experience, and awareness among aquaculture practitioners regarding the importance of disease prevention measures. This condition results in fish health management practices that tend to be reactive, implemented only after disease outbreaks occur, thereby increasing the risk of pathogen spread within aquaculture systems. Similar findings have been reported in global assessments, which highlight weak management capacity and the lack of preventive approaches as major factors contributing to the high incidence of aquaculture diseases across countries (FAO, 2024).

The implementation of *Good Aquaculture Practices* (GAP) integrated with biosecurity principles has been shown to function as an effective preventive approach. Schwarz et al. (2017) emphasized that GAP focuses on water quality management, facility sanitation, and fish health management, which directly contribute to reducing disease risks. This is consistent with the findings of Can et al. (2023), who stated that the integration of GAP-based biosecurity not only improves fish health and the welfare of cultured organisms but also supports the overall sustainability of aquaculture systems. Therefore, GAP serves not only as a technical production guideline but also as a comprehensive management framework that strengthens biosecurity systems.

Biosecurity is also widely regarded as an important strategy for reducing the negative environmental impacts of aquaculture. Subasinghe and Alday-Sanz (2023) reported that effective biosecurity implementation can reduce reliance on antibiotics and chemicals, thereby lowering the risks of environmental pollution and antimicrobial resistance. This view is aligned with Brugere et al. (2025), who described biosecurity as a strategic investment capable of reducing disease-related economic losses while simultaneously minimizing long-term environmental risks.

According to Slette et al. (2024), system design, sanitation, and operational management play critical roles in controlling biosecurity risks, particularly in intensive aquaculture systems. This finding highlights that successful biosecurity implementation is not determined by a single action, but rather by the consistent and comprehensive application of GAP principles. Similarly, Wijadmono et al. (2025) demonstrated that GAP implementation positively affects aquaculture productivity and operational performance, while also contributing to improved environmental management in aquaculture practices. These findings indicate that biosecurity-based GAP implementation can provide dual benefits, both in terms of production efficiency and environmental sustainability.

Overall, the synthesis presented in Table 1 reveals a gap between the conceptual understanding and practical implementation of GAP and biosecurity in the field. Although numerous studies have demonstrated the benefits of biosecurity-based GAP implementation, adoption levels remain relatively low. Therefore, efforts to enhance capacity building, awareness, and the integration of GAP principles into aquaculture management systems are needed to support fish health, environmental sustainability, and the long-term success of aquaculture operations.

Synthesis of Good Aquaculture Practices Implementation in Supporting Biosecurity

To obtain a deeper understanding, the reviewed studies were further synthesized to identify common patterns regarding how GAP implementation contributes to biosecurity in aquaculture systems. This synthesis was conducted by grouping various GAP aspects and linking them to their roles in preventing the introduction and spread of pathogens. The results of this synthesis are presented in table 2.

Table 2

Synthesis of the Relationship between Good Aquaculture Practices (GAP) and Biosecurity in Aquaculture

No.	GAP Aspect	Form of Implementation	Contribution to Biosecurity
1	Water quality management	Monitoring and controlling physical–chemical water parameters and managing aquaculture waste	Reduces stress levels in cultured organisms and inhibits pathogen development in the aquatic environment
2	Facility sanitation and hygiene	Disinfection of equipment, cleanliness of ponds/tanks, and restriction of human and equipment access	Prevents the introduction and spread of pathogens through equipment, humans, and environmental vectors
3	Fish health management	Routine health monitoring and early treatment of disease symptoms	Reduces the risk of disease outbreaks and limits pathogen transmission between culture units
4	Feed management	Use of high-quality feed and feeding according to the nutritional requirements of cultured organisms	Reduces feed waste and organic matter accumulation that may serve as a medium for pathogen growth
5	Control of input movement	Seed selection, regulation of organism entry and exit, and control of input sources	Reduces the risk of disease introduction from external sources into aquaculture systems
6	Sustainable preventive approach	Integration of GAP and biosecurity throughout all operational stages of aquaculture	Reduces dependence on antibiotics and chemicals while supporting environmental sustainability in aquaculture

Based on table 2, water quality management represents one of the most fundamental GAP aspects in supporting aquaculture biosecurity. Monitoring and controlling physical–chemical water parameters, such as temperature, dissolved oxygen, pH, and organic matter concentrations, play a crucial role in reducing stress levels in cultured organisms and creating conditions that are less favorable for pathogen development. Can et al. (2023) reported that well-managed water quality enhances fish resistance to diseases and reduces opportunities for pathogen proliferation. Effective aquaculture waste management also contributes to limiting the accumulation of organic matter that may serve as a source of pollution and a medium for pathogenic microorganisms (Brugere et al., 2025).

Facility sanitation and hygiene also play a significant role in supporting biosecurity. Equipment disinfection, maintaining the cleanliness of ponds or tanks, and restricting human and equipment access to culture areas are effective preventive measures to prevent the introduction and spread of pathogens. According to Slette et al. (2024), facility sanitation and access control are key components of biosecurity, particularly in intensive aquaculture systems that face higher risks of disease transmission. Consistent sanitation practices can reduce the likelihood of pathogen transfer between culture units via human and equipment vectors.

Fish health management is another GAP aspect that directly contributes to biosecurity. Routine fish health monitoring and early treatment of disease symptoms enable early detection and prevention of disease spread before outbreaks occur. Subasinghe and Alday-Sanz (2023) emphasized that preventive approaches through regular fish health monitoring are more effective than reactive disease control, as they reduce mortality rates and limit pathogen transmission within aquaculture systems.

Proper feed management also plays an important role in supporting aquaculture biosecurity. The use of high-quality feed and feeding according to the nutritional requirements of cultured organisms can reduce feed waste and the accumulation of organic matter in aquatic environments. According to FAO (2022), organic matter accumulation resulting from inefficient feeding practices can deteriorate water quality and create conditions that favor pathogen growth. Therefore, feed efficiency affects not only productivity but also the environmental health of aquaculture systems.

Control of input movement, such as seed selection and regulation of the entry and exit of cultured organisms, is a critical component in preventing the introduction of diseases from external sources. Can et al. (2023) noted that seeds that do not undergo proper selection and quarantine procedures may serve as primary sources of pathogen introduction into aquaculture systems. Thus, controlling input movement is a strategic step in strengthening biosecurity from the early stages of production.

Overall, the synthesis presented in table 2 demonstrates that a sustainable preventive approach through the integration of GAP and biosecurity across all operational stages of aquaculture is an effective strategy for reducing dependence on antibiotics and chemicals. This approach not only supports the health of cultured organisms but also contributes to long-term environmental sustainability in aquaculture systems. Brugere et al. (2025) emphasized that the integration of technical, managerial, and environmental aspects within GAP is essential for achieving healthy, productive, and sustainable aquaculture systems.

Environmental Implications of Biosecurity-Based GAP Implementation in Aquaculture

In addition to its effects on the health of cultured organisms, the implementation of biosecurity-based GAP also has important implications for the aquaculture environment. Therefore, this study examines the environmental impacts of GAP implementation on key environmental aspects, including water quality, organic waste, chemical use, and the sustainability of aquatic ecosystems. A summary of the environmental implications of biosecurity-based GAP implementation is presented in table 3

Table 3
Environmental Implications of Biosecurity-Based Good Aquaculture Practices (GAP) Implementation in Aquaculture

No.	Environmental Aspect	Biosecurity-Based GAP Implementation	Environmental Impact
1	Water quality	Water quality management and control of aquaculture waste	Reduces water pollution and maintains the stability of physical–chemical environmental parameters
2	Organic waste	Feed management and appropriate stocking density	Reduces organic matter accumulation and the risk of water eutrophication
3	Chemical use	Preventive approach through biosecurity	Reduces dependence on antibiotics and chemicals that may potentially contaminate the environment
4	Aquatic ecosystem health	Prevention of pathogen introduction and spread	Maintains ecosystem balance and reduces the risk of disease transmission to wild organisms
5	Resource sustainability	Integration of GAP into aquaculture management systems	Supports environmentally friendly and long-term sustainable aquaculture systems

Based on table 3, the implementation of biosecurity-based GAP provides significant positive implications for water quality in aquaculture environments. Proper water quality management, including the control of aquaculture waste, plays an important role in reducing pollution levels and maintaining the stability of physical–chemical water parameters. According to Boyd et al. (2020), integrated water quality management within sustainable aquaculture practices can reduce nutrient loads and pollutants released into aquatic environments. This is essential to prevent water quality degradation that may negatively affect cultured organisms as well as surrounding aquatic ecosystems.

Organic waste management is also a major concern in the implementation of biosecurity-based GAP. Efficient feed management and appropriate stocking density can reduce the accumulation of organic matter on the bottom of water bodies and minimize the risk of eutrophication. Ahmed et al. (2021) reported that uneaten feed and waste produced by cultured organisms are the primary sources of increased organic matter in aquaculture systems, which, if not properly managed, can lead to environmental degradation. Therefore, GAP implementation that emphasizes feed efficiency directly contributes to reducing environmental pressures.

The application of biosecurity within the GAP framework also leads to reduced use of chemicals and antibiotics. Preventive approaches through disease risk management can minimize reliance on therapeutic treatments that have the potential to contaminate the environment. According to Rico et al. (2020), excessive use of antibiotics and chemicals in aquaculture may result in residual contamination of aquatic environments and increase the risk of antimicrobial resistance. Thus, effective biosecurity implementation contributes to the protection of environmental quality and the health of aquatic ecosystems.

Preventing the introduction and spread of pathogens through the application of biosecurity-based GAP plays a critical role in maintaining the health of aquatic ecosystems. Pathogen control not only protects cultured organisms but also reduces the risk of disease transmission to wild organisms in surrounding waters. Lafferty et al. (2020) emphasized that aquaculture activities lacking adequate disease control measures may serve as sources of pathogen spillover into natural ecosystems, thereby disrupting aquatic ecosystem balance.

The integration of GAP into aquaculture management systems supports long-term resource sustainability. This approach promotes environmentally friendly farming practices, efficient resource utilization, and the minimization of negative environmental impacts. Troell et al. (2021) stated that the implementation of integrated sustainable aquaculture practices is essential to ensure the long-term viability of aquaculture production without compromising aquatic ecosystem functions. Therefore, biosecurity-based GAP can be regarded as an important strategy for supporting sustainable aquaculture development from an environmental perspective.

Conclusion

Based on the results of the literature review, it can be concluded that the implementation of *Good Aquaculture Practices* (GAP) integrated with biosecurity principles plays an important role in supporting environmental sustainability in aquaculture. The synthesis of the reviewed studies indicates that GAP not only contributes to improved health and productivity of cultured organisms but also serves as a preventive approach to reducing the risks of disease introduction and spread within aquaculture systems.

The implementation of biosecurity-based GAP has been shown to positively influence various aspects of aquaculture management, particularly through water quality management, facility sanitation and hygiene, feed management, and control of input movement. The integration of these aspects helps reduce stress in cultured organisms, inhibit pathogen development, and decrease reliance on antibiotics and chemicals. Thus, biosecurity applied within the GAP framework represents an effective strategy for supporting healthier and more sustainable aquaculture systems.

From an environmental perspective, biosecurity-based GAP implementation provides significant positive implications, especially in maintaining water quality, reducing organic waste accumulation, protecting aquatic ecosystem health, and supporting long-term resource sustainability. Improved water quality and waste management contribute to reducing water pollution and the risk of eutrophication, while preventive disease control approaches help minimize the negative environmental impacts of aquaculture activities.

Although numerous studies have demonstrated the benefits of biosecurity-based GAP implementation, adoption and implementation levels in practice remain relatively low and uneven. Therefore, efforts to enhance capacity building, awareness, policy support, and technical assistance for aquaculture practitioners are needed to ensure consistent application of GAP and biosecurity principles. Overall, the implementation of biosecurity-based GAP is a key strategy for achieving productive, environmentally friendly, and sustainable aquaculture systems.

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