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Environmental Management in Aquaculture: A Review of Good Aquaculture Practice from Sustainability Perspectives

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Keyword: Good Aquaculture Practice (GAP); Sustainable Aquaculture; Environmental Management; Water Quality; Waste Management;

Abstract
Introduction: *The rapid development of aquaculture plays an important role in supplying fish protein, but it also generates various environmental problems.* ***Objective:*** *This article aims to examine the role of Good Aquaculture Practice (GAP) in supporting sustainable environmental management in aquaculture.* ***Methods:*** *This study employed a literature review with a content analysis approach on 15 national and international scientific articles published between 2020 and 2025.* ***Results and Discussion:*** *The review indicates that GAP implementation mainly focuses on water quality and waste management, with pond-based aquaculture being the most frequently studied system. Studies on technology-based and integrated aquaculture systems remain relatively limited.* ***Conclusion:*** *Good Aquaculture Practice represents an important framework for sustainable environmental management in aquaculture; however, a more integrated approach is required to strengthen its future implementation*

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Introduction

The aquaculture sector is one of the fastest-growing food production sectors globally and plays a strategic role in supporting food security and economic development. According to the Food and Agriculture Organization (FAO) (2020), the contribution of aquaculture to global fisheries production continues to increase and currently accounts for nearly half of the total fish consumed worldwide. However, this increase in production has also been accompanied by growing pressure on aquatic environments, making sustainability a key concern in the development of the aquaculture sector.

Poorly managed aquaculture activities can lead to various environmental impacts, including water quality degradation, accumulation of organic waste, eutrophication, and ecosystem degradation. Arshad et al. (2024) reported that uneaten feed, feces, and metabolic waste from aquaculture operations are major sources of pollution that can disrupt the balance of aquatic ecosystems. These impacts not only affect the environment but also influence the health of cultured organisms and the long-term sustainability of production.

The adoption of sustainable aquaculture practices has therefore become an unavoidable necessity. Turlybek et al. (2025) emphasized that aquaculture systems applying sustainability principles, such as resource-use efficiency and water quality management, are able to reduce negative environmental impacts compared to conventional systems. An integrated environmental management approach is required to maintain a balance between productivity and the protection of aquatic ecosystems.

One of the most widely recommended approaches in sustainable aquaculture management is the implementation of Good Aquaculture Practice (GAP). Ariadi et al. (2023) defined GAP as a set of standards and operational guidelines that include water quality management, waste control, biosecurity, and efficient use of production inputs. The implementation of GAP is expected to minimize the negative environmental impacts of aquaculture while improving the quality and safety of aquaculture products.

At both regional and national levels, GAP has also been developed as a policy instrument to support sustainable aquaculture development. Jumatli and Ismail (2021) noted that GAP implementation plays an important role in improving environmental management, waste monitoring, and compliance with sustainability standards. Government regulations governing GAP serve as references for establishing environmental quality standards and operational practices in aquaculture.

Although numerous studies have examined the implementation of GAP in aquaculture, most research has focused primarily on technical and productivity aspects. Arshad et al. (2024) indicated that studies specifically mapping the role of GAP from an environmental management and sustainability perspective remain limited and scattered across various publications. Therefore, a systematic review is needed to integrate these findings and provide a comprehensive overview of the contribution of GAP to sustainable environmental management in aquaculture.

Based on this background, this review article aims to analyze and synthesize existing research on Good Aquaculture Practice from an environmental management perspective, with a particular focus on its contribution to sustainable aquaculture development.

Method

This study employed a literature review with a content analysis approach to examine the role of Good Aquaculture Practice (GAP) in supporting environmental management and sustainability in aquaculture. The review focused on scientific articles published between 2020 and 2025 to ensure the relevance and up-to-date nature of the data used.

Data were collected through a systematic search of articles in the Google Scholar, Scopus, and SINTA databases using keywords such as “Good Aquaculture Practice,” “environmental management,” and “sustainable aquaculture.” The retrieved articles were then screened based on inclusion criteria, namely studies that discussed the implementation of GAP and its relationship with environmental aspects, were available in full-text form, and were published in national or international peer-reviewed journals. Articles that were not relevant to environmental management were excluded from the analysis.

Data analysis was conducted by categorizing the selected articles according to publication year, environmental focus, aquaculture system, and research method. The results of the analysis were subsequently presented in the form of tables and descriptive narratives to identify research trends and to highlight the contribution of Good Aquaculture Practice to sustainable environmental management in aquaculture.

Result and Discussion

Distribution of Articles by Year of Publication

Based on the literature search and selection process, a total of 15 articles relevant to Good Aquaculture Practice (GAP) and environmental management in aquaculture published between 2020 and 2025 were identified. The distribution of articles by year of publication is presented in Table 1

Table 1

Distribution of Good Aquaculture Practice Articles by Year of Publication

No	Year of Publication	Number of Articles
1	2020	2
2	2021	3
3	2022	2
4	2023	4
5	2024	3
6	2025	1
Total		**15**

The analysis of article distribution by publication year indicates an increasing number of studies related to Good Aquaculture Practice and environmental management in aquaculture during the period from 2021 to 2023. This trend reflects growing global attention to sustainability issues in the aquaculture sector, in line with increasing concerns about the environmental impacts resulting from the intensification of aquaculture activities. Boyd et al. (2020) emphasized that rapid aquaculture growth without the adoption of proper management practices can increase pressure on water quality and aquatic ecosystems, thereby encouraging research focused on sustainable practices such as GAP.

The dominance of publications in 2023 suggests that the implementation of GAP has become increasingly relevant within the context of environmental policy and management. The rise in the number of studies during this period can be associated with stronger national and international policy initiatives emphasizing the importance of environmental standards in aquaculture activities. Troell et al. (2023) reported that many countries have begun integrating sustainability principles and environmental management into aquaculture regulations in response to ecosystem degradation and increasing market demand for environmentally friendly seafood products.

In addition to policy drivers, the increase in publications has also been influenced by growing scientific awareness of the relationship between aquaculture practices, water quality, and ecosystem health. Ahmed et al. (2021) noted that water quality is a primary indicator of aquaculture sustainability, as it directly affects productivity, the health of cultured organisms, and the stability of aquatic environments. Consequently, many GAP-related studies during this period have focused on water quality and waste management as key strategies to mitigate environmental impacts. The relatively lower number of publications in 2024 and 2025 does not necessarily indicate a decline in research interest, but rather reflects a shift toward more specific and integrated research approaches. Naylor et al. (2021) observed that sustainable aquaculture research has increasingly moved from descriptive studies toward system-level analyses and evaluations of policy effectiveness and environmentally friendly technologies. As a result, the number of publications appears more limited, while the depth and analytical rigor of the studies have increased.

Overall, the distribution of publications indicates that research on Good Aquaculture Practice and environmental management in aquaculture continues to evolve and offers substantial opportunities for further investigation. According to FAO (2024), sustainability challenges in aquaculture within developing countries particularly those related to waste management, technological adaptation, and policy integration still require sustained research support. Therefore, this review article provides important relevance in mapping research developments and establishing a conceptual foundation for future GAP studies from an environmental management perspective.

Environmental Focus in Good Aquaculture Practice (GAP) Research

The analysis of the 15 selected articles indicates that the environmental focus of Good Aquaculture Practice research varies, but is still dominated by aspects related to water quality management and waste management. A detailed overview of the environmental focus addressed in the studies is presented in Table 2.

Table 2

Environmental Focus in Good Aquaculture Practice Research

No	Environmental Focus	Number of Articles
1	Water quality management	6
2	Waste and effluent management	4
3	Sediment control and eutrophication	2
4	Ecosystem protection and biodiversity	2
5	Integrated environmental management	1
	Total	**15**

The results presented in Table 2 show that research on Good Aquaculture Practice is predominantly focused on water quality management. This dominance reflects the critical role of water quality as a key determinant of aquaculture sustainability, as it directly influences the health of cultured organisms, productivity, and the stability of aquatic environments. Boyd and Tucker (2021) highlighted that water quality is the environmental component most sensitive to changes in aquaculture practices and is therefore frequently used as a primary indicator in sustainability assessments.

The strong emphasis on water quality management is also closely associated with the increasing intensification of aquaculture systems, particularly in pond-based aquaculture and floating cage systems. Intensification increases feed inputs and stocking densities, which can potentially degrade water quality if not accompanied by proper management practices. Badiola et al. (2021) demonstrated that the application of GAP-aligned management practices, such as optimized stocking density and regular water quality monitoring, can effectively reduce the risk of environmental degradation in intensive aquaculture systems.

Research focusing on waste and effluent management is also relatively prominent, indicating growing awareness of the environmental impacts of aquaculture waste discharge into surrounding waters. Organic waste from uneaten feed and fish feces is a major source of increased nutrient loading that can trigger eutrophication. Herbeck et al. (2020) reported that the implementation of appropriate waste management practices, including improved feed efficiency and recirculating water systems, can significantly reduce nutrient loads released into aquatic environments. In contrast, studies addressing sediment control, eutrophication, as well as ecosystem and biodiversity protection remain relatively limited. This condition suggests that GAP research is still largely oriented toward short-term operational aspects rather than ecosystem-based approaches that consider long-term impacts on the structure and function of aquatic ecosystems. Troell et al. (2021) emphasized that aquaculture sustainability cannot be achieved solely through the control of technical parameters, but requires ecosystem-based approaches that account for interactions between farming activities and surrounding environments.

The lowest research focus was observed in integrated environmental management, indicating a significant research gap in Good Aquaculture Practice studies. Integrated approaches that combine water quality management, waste control, ecosystem protection, and policy support are still rarely examined in a comprehensive manner. Belton et al. (2020) noted that the failure to integrate technical and policy dimensions can limit the effectiveness of sustainable practices, particularly in developing countries facing constraints in environmental management capacity. Therefore, further development of GAP research using integrated environmental management approaches is essential to strengthen the contribution of aquaculture to sustainable development.

Aquaculture Systems Examined in Good Aquaculture Practice (GAP) Research

The analysis of the selected articles indicates that the implementation of Good Aquaculture Practice has been examined across various aquaculture systems. The distribution of aquaculture systems discussed in the reviewed studies is presented in Table 3.

Table 3
Aquaculture Systems Examined in Good Aquaculture Practice Research

No	Aquaculture System	Number of Articles
1	Pond-based aquaculture	7
2	Floating net cage systems	3
3	Recirculating Aquaculture Systems (RAS)	3
4	Integrated systems (IMTA/aquaponics)	2
	Total	**15**

The results in Table 3 show that pond-based aquaculture is the most frequently examined system in studies related to Good Aquaculture Practice. The dominance of pond systems reflects their widespread application in aquaculture production, particularly in developing countries where ponds serve as the primary system for fish and shrimp farming. Boyd et al. (2021) noted that pond-based systems exhibit a high level of interaction with surrounding environments, thus requiring the application of sound management practices to prevent water quality deterioration and ecosystem degradation. Consequently, GAP research on pond systems has largely focused on water quality control, feed management, and organic waste management. Pond systems are also commonly investigated due to the increasing level of intensification in aquaculture practices. Intensification leads to higher nutrient and waste loads, making the implementation of GAP essential for maintaining environmental balance. Henriksson et al. (2021) reported that unsustainable farming practices in intensive pond systems can increase nutrient emissions and accelerate the degradation of coastal and inland water environments, thereby reinforcing the need for stricter environmental management standards.

Floating net cage systems rank second in studies examining GAP implementation. These systems are characterized by a high degree of openness, as they directly interact with open water bodies such as lakes, reservoirs, and marine environments. As a result, the environmental impacts of farming activities in floating cages are more difficult to control compared to closed systems. Buschmann et al. (2020) indicated that the accumulation of organic waste from floating net cages can trigger eutrophication and alter benthic community structures if not supported by adequate environmental management. Accordingly, GAP studies on this system generally emphasize the importance of stocking density regulation, site selection, and regular water quality monitoring. Recirculating Aquaculture Systems (RAS) have also received increasing attention in GAP research, although the number of studies remains lower than those focusing on pond-based systems. RAS are considered environmentally advantageous because they minimize water use and limit the discharge of waste into external environments. Martins et al. (2021) highlighted that integrating GAP principles into RAS can enhance resource efficiency and reduce environmental impacts; however, implementation is still constrained by high investment costs and technological requirements.

Studies addressing integrated systems such as integrated multi-trophic aquaculture (IMTA) and aquaponics remain relatively limited. Nevertheless, these systems offer significant potential to support environmental sustainability through nutrient recycling and waste reduction. Chopin et al. (2021) demonstrated that IMTA systems can reduce aquaculture-related environmental impacts by utilizing waste from one organism as a nutrient source for another. The limited number of studies on integrated systems suggests that GAP research still tends to focus on conventional aquaculture systems, indicating a need for more intensive research on ecosystem-based and trophically integrated aquaculture systems.

Overall, the variation in aquaculture systems examined in GAP research indicates that the effectiveness of good aquaculture practices is highly dependent on the characteristics of the farming system employed. Gephart et al. (2021) emphasized that environmental management approaches in aquaculture must be tailored to specific system contexts to ensure that GAP implementation delivers optimal environmental benefits. Therefore, future research should direct greater attention toward more diverse and integrated aquaculture systems to support the overall sustainability of the aquaculture sector. In addition, future GAP research should explicitly incorporate measurable environmental performance indicators to evaluate implementation success, including total nitrogen (TN), total phosphorus (TP), biological oxygen demand (BOD), chemical oxygen demand (COD), sediment organic load, and antibiotic or chemical residue concentrations. These parameters are essential for determining whether GAP implementation produces quantifiable improvements in water and ecosystem quality rather than relying solely on general claims of impact reduction.

Research Methods Used in Good Aquaculture Practice (GAP) Studies

The analysis of the selected articles indicates a diversity of research methods used in studies of Good Aquaculture Practice related to environmental management in aquaculture. The distribution of research methods is presented in Table 4.

Table 4
Research Methods Used in Good Aquaculture Practice Studies

No	Research Method	Number of Articles
1	Experimental	5
2	Field observational	4
3	Policy and regulatory review	3
4	Literature review	3
	Total	**15**

The results in Table 4 show that experimental and field observational methods still dominate research related to Good Aquaculture Practice and environmental management in aquaculture. The dominance of experimental methods reflects the strong need to directly test cause–effect relationships between GAP implementation and changes in environmental parameters, such as water quality, nutrient loading, and feed-use efficiency. Ahmed and Thompson (2020) noted that experimental approaches enable controlled measurements of environmental impacts and are therefore widely used to evaluate the effectiveness of sustainable aquaculture practices.

The use of experimental methods is also closely linked to efforts to develop evidence-based technical standards for GAP. Studies employing experimental designs provide a strong quantitative foundation for formulating environmental management guidelines, particularly for intensive aquaculture systems. Boyd et al. (2021) emphasized that results from field and semi-controlled experiments serve as key references in determining water quality thresholds and recommended environmental management practices in aquaculture.

Field observational methods rank second and are commonly applied to assess GAP implementation under real-world farming conditions. This approach is important for understanding the level of GAP adoption by farmers and the variability of practices influenced by local social, economic, and environmental factors. Rico et al. (2021) highlighted that observational studies offer a more realistic picture of GAP effectiveness, as they capture field dynamics that cannot always be represented in experimental research.

However, observational approaches have limitations in isolating the singular effects of GAP implementation on environmental changes. Therefore, combining observational and experimental methods is often recommended to obtain a more comprehensive understanding. Henriksson et al. (2022) suggested that integrating multiple methodological approaches can enhance the reliability of environmental sustainability assessments in aquaculture. The number of studies employing policy and regulatory review approaches remains relatively limited, despite their critical importance in environmental management contexts. Policy-oriented studies are essential for assessing the alignment between GAP standards and their implementation at national and regional levels. Bush et al. (2021) argued that the success of sustainable aquaculture practices largely depends on regulatory frameworks, monitoring systems, and adequate institutional support.

Similarly, the limited number of literature reviews addressing GAP from an environmental management perspective indicates a lack of comprehensive synthesis studies that integrate empirical findings and policy insights. Nevertheless, literature reviews play a vital role in summarizing research developments, identifying knowledge gaps, and guiding future research directions. Hall et al. (2023) emphasized that robust synthesis studies are urgently needed to support evidence-based decision-making in sustainable aquaculture management. Overall, the variation in research methods used in GAP studies suggests that environmental management research in aquaculture remains dominated by technical approaches, while conceptual and policy-oriented perspectives are still relatively underrepresented. This condition highlights the need for multidisciplinary research that integrates experimental, observational, and policy analysis approaches to ensure that the implementation of Good Aquaculture Practice delivers more optimal and sustainable environmental benefits.

From a programmatic perspective, there is a need for follow-up research that systematically evaluates the effectiveness of GAP implementation using standardized environmental indicators such as TN/TP reduction efficiency, changes in BOD/COD levels, and monitoring of drug residues and antimicrobial resistance (AMR) markers. Longitudinal and comparative studies across aquaculture systems would further strengthen the evidence base for assessing the environmental performance of biosecurity-based GAP. Such approaches would enable clearer benchmarking of sustainability outcomes and support the development of evidence-based environmental standards in aquaculture management

Conclusion

Based on the literature review of 15 scientific articles published between 2020 and 2025, it can be concluded that Good Aquaculture Practice (GAP) plays an important role in supporting sustainable environmental management in aquaculture. The implementation of GAP has been shown to contribute to water quality control, waste and effluent management, and improved efficiency of aquaculture systems, which directly affects the sustainability of aquatic environments. The analysis indicates that research on GAP is still largely dominated by a focus on water quality and waste management, particularly in pond-based aquaculture systems. This dominance reflects the high environmental pressure associated with intensive farming systems and the need for stricter environmental management standards. Meanwhile, studies on technology-based and integrated aquaculture systems such as recirculating aquaculture systems (RAS), integrated multi-trophic aquaculture (IMTA), and aquaponics remain relatively limited, despite their significant potential to reduce environmental impacts through resource efficiency and nutrient recycling.

Most GAP-related studies employ experimental and field observational approaches, emphasizing technical and implementation-based evaluations at the farm level. However, policy-oriented studies and literature reviews remain limited, resulting in an underdeveloped understanding of GAP as a holistic environmental management instrument. This condition highlights the need for multidisciplinary research that integrates technical, policy, and ecosystem-based approaches. Overall, this review article confirms that Good Aquaculture Practice represents a strategic framework for sustainable environmental management in aquaculture. Strengthening GAP implementation through policy support, capacity building for farmers, and the development of more integrated research approaches is essential to ensure the long-term sustainability of the aquaculture sector, particularly in developing countries.

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