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Enhancing Smallholder Aquaculture in Philippine Peatlands: Challenges, Opportunities, and Nature-Based Solutions in the Leyte Sab-a Basin

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ABSTRACT

This study explores the status, challenges, and opportunities of smallholder aquaculture in the Leyte Sab-a Basin Peatland (LSBP), with a particular focus on the application of Nature-Based Solutions (NbS) for sustainable management. Using a mixed-methods approach that combines a comprehensive literature review with a focus group discussion (FGD) involving 22 local practitioners, the study identifies both traditional practices—such as bamboo pond structures and the use of Kangkong (*Ipomoea aquatica*) and *Azolla* as fish feed—and key constraints to productivity. These include environmental vulnerabilities (e.g., declining water quality, climate variability), technical limitations (e.g., disease risks, lack of fingerlings), and socio-economic barriers (e.g., limited market access, financial insecurity, and gender inequality). While most smallholders are unfamiliar with formal NbS frameworks, their current practices already reflect ecological principles aligned with NbS. The study further highlights the socio-economic significance of aquaculture as both a livelihood resource and a contributor to food security in rural peatland communities. Linking traditional knowledge with scientifically guided NbS—such as Integrated Multi-Trophic Aquaculture (IMTA), aquaponics, and biofiltration systems—can enhance ecosystem resilience and livelihood security. In addition, strengthening gender-inclusive participation and providing equitable access to training and financial support are critical to improving resilience. This study concludes that targeted capacity-building, financial support mechanisms, and multi-stakeholder partnerships are needed to facilitate inclusive, sustainable, and climate-resilient aquaculture systems in peatland environments. Beyond addressing immediate livelihood

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changes, these strategies also contribute to biodiversity conservation, ecosystem restoration, and climate adaptation in fragile wetland landscapes.

Keywords: Smallholder Aquaculture; Peatland Sustainability; Nature-Based Solutions (NbS); Leyte Sab-a Basin Peatland (LSBP)

1. Introduction

Smallholder aquaculture in tropical peatlands presents both a challenge and an opportunity for sustainable food systems, particularly in climate-vulnerable countries like the Philippines. Peatlands are among the most efficient ecosystems for storing carbon, offering a critical defense against global warming by capturing and holding vast amounts of carbon that would otherwise be released into the atmosphere. Despite covering only a small percentage of the planet's surface, tropical peatlands, including those in the Philippines, store more carbon than all other vegetation types combined, including forests. Peatlands hold between 69.6 and 129.8 gigatons of carbon, representing roughly 19% of the total global carbon stored in peatlands [1,2]. The distinct characteristics of tropical peatlands, including their rich biodiversity and high carbon sequestration capacity, emphasize their ecological importance and the need for sustainable management [3]. Given the ecological value of peatlands, integrating sustainable practices such as smallholder aquaculture, supported by Nature-Based Solutions (NbS), can help balance conservation efforts with local livelihoods. Smallholder aquaculture, particularly when enhanced through NbS approaches, provides a promising path toward the sustainable use of peatland resources. Such integrated approaches are essential for places like the Leyte Sab-a Basin Peatland, where conservation intersects with the socio-economic needs of the local community.

Two confirmed forested peatlands in the Philippines are the Agusan Marsh on Mindanao Island and the Leyte Sab-a Basin Peatland (LSBP) [4,5]. Of particular focus in this review is the LSBP, where aquaculture practices must be aligned with conservation goals to support community livelihoods and maintain ecosystem health. Recent studies have highlighted differences in above- and belowground carbon stocks in contrasting peatlands in the Philippines, providing critical data for understanding carbon sequestration potential in these ecosystems [6]. The Agusan Marsh has an estimated carbon stock of 22.9 million tons, with a mean belowground carbon stock of 4,659 tons per hectare and an aboveground stock of 53 tons of carbon per hectare [7]. Similarly, the Leyte Sab-a Basin Peatland stores 36.6 million tons of carbon and sequesters 134.5 million tons of CO_2, representing 0.04% of tropical peat carbon [8].

At the same time, peatlands are highly vulnerable to degradation from deforestation, drainage, and infrastructure development. When disturbed, these ecosystems release stored carbon into the atmosphere, worsening climate change effects rather than lessening them [2]. Much uncertainty still exists about their geographic distribution and the total amount of carbon they hold [9].

Beyond their role in carbon storage, peatlands like the Agusan Marsh and the Leyte Sab-a Basin Peatland (LSBP) also offer important environmental and socio-economic benefits. The Agusan Marsh is among Southeast Asia's most vital wetlands, serving as both a carbon sink and a key habitat for biodiversity. In contrast, the LSBP presents a unique situation where peatland conservation directly involves human livelihoods.

Smallholder communities in the region rely heavily on the biodiversity resources of the peatland, maintaining a fragile balance between resource use and environmental protection [10,11]. The continued degradation of these peatlands presents serious risks to biodiversity and the socio-economic stability of local communities.

Furthermore, the ecological significance of the Leyte Sab-a Basin goes beyond carbon storage, as it also supports a wide variety of species. In addition to the area's bird species [12], it is home to diverse herpetofauna and mammal species [13], some of which are endemic and threatened. Recent evaluations of the area have documented these species, highlighting the importance of conservation efforts to safeguard their habitats.

Meanwhile, smallholder agroforestry systems also play a vital role in carbon storage. When well-managed, these systems significantly contribute to carbon sequestration, supporting global efforts to combat climate change [14]. Combining smallholder aquaculture with sustainable land management practices can further boost the environmental advantages of both systems, promoting carbon storage while also supporting livelihoods.

The rising demand for healthier diets to secure global food supply amidst climate change and biodiversity decline calls for innovative food production and consumption methods, especially for protein sources like aquatic plants and animals. A 20-year retrospective review of global aquaculture [15] shows notable progress in production and ongoing challenges related to sustainability and environmental effects, emphasizing the need for integrated solutions.

Nature-based solutions (NbS) can boost food production while reducing climate change effects and restoring biodiversity [16]. In the Leyte Sab-a Basin Peatland, fishing is a main livelihood activity, with over half of the respondents regularly harvesting for sustenance and income. The most common species caught include *Channa striata* (striped snakehead), *Clarias macrocephalus* (bighead catfish), and *Oreochromis niloticus* (Tilapia) [11]. NbS also aims to enhance ecosystem services such as food and water supply, disease and climate regulation, crop pollination, and soil formation [17]. Aquatic foods, rich in essential nutrients like iron, zinc, calcium, vitamin A, and omega-3 fatty acids, can improve food security and support small-scale producers' livelihoods [17–131]. Aquaculture plays an important role in meeting global food needs and providing nutrition, especially in areas with limited land for traditional farming [18]. NbS are increasingly recognized as key strategies to address peatland degradation. These solutions focus on restoring and managing peatlands sustainably while offering environmental, social, and economic benefits. Various NbS approaches [19], such as reforestation, sustainable farming, and community-led conservation, can be effectively used in peatland ecosystems to bolster ecological resilience and offer sustainable livelihoods for residents. Examples include rewetting dried peatlands, promoting sustainable agricultural methods that avoid draining peatlands, and supporting community-driven conservation efforts. These solutions protect peatland ecosystems and improve the well-being of communities relying on them. Giving these communities the knowledge and tools to manage their environments sustainably is crucial for lasting success [19,20].

Conducting a literature review on peatland aquaculture in the Philippines is significant for several reasons. It provides a comprehensive understanding of the current state of smallholder aquaculture practices within this unique and challenging ecosystem. By synthesizing existing research, the review highlights the specific environmental, socio-economic, and technical conditions that shape peatland aquaculture activities, offering insights into how these factors influence productivity and sustainability. Moreover, the review identifies key challenges smallholders face, such as the impacts of climate change, limited access to resources, and socio-economic barriers, which are critical for policymakers, development agencies, and local communities to address. The review's exploration of NbS in peatland aquaculture is particularly relevant, aligning with global and national priorities for sustainable development. By identifying pathways to enhance resilience and productivity, the review contributes to the ongoing development of sustainable aquaculture practices in the Philippines' peatlands. It is a vital resource for guiding policy, practice, and future research efforts.

This review explores the current state of smallholder aquaculture in the Leyte Sab-a Basin peatland, its challenges, and the potential of Nature-Based Solutions (NbS) to enhance sustainability and resilience. By addressing these issues, this paper aims to propose a sustainable pathway for smallholder farmers to maximize productivity while conserving fragile peatland ecosystems.

To better understand the current conditions and challenges of smallholder aquaculture in peatland systems, this review draws upon existing literature and a participatory focus group discussion (FGD) conducted in the Leyte Sab-a Basin Peatland, Philippines.

1.1. Objectives of the Review

The primary purpose of this literature review is to provide a comprehensive analysis of smallholder aquaculture in peatland systems within the Philippines. Peatlands are unique ecosystems with significant ecological, economic, and socio-cultural importance. However, smallholder aquaculture in these environments faces numerous challenges, ranging from environmental degradation to socio-economic constraints. This review aims to bridge the gap in current knowledge by exploring the state of smallholder aquaculture, understanding the barriers these communities face, and evaluating potential solutions that could support sustainable development in these regions.

The specific objectives of this literature review are to:

1. Assess the current state of smallholder aquaculture in the Philippines, focusing on peatland systems.
2. Identify the key issues and constraints faced by smallholders in peatland environments.
3. Explore the potential of Nature-Based Solutions (NBS) to address these challenges.
4. Highlight gaps in the existing literature and suggest areas for future research.

The first objective is to assess the current state of smallholder aquaculture in peatland systems from a socio-economic perspective. This involves examining smallholder farmers' and pond owners' aquaculture productivity and resource access. Understanding these factors is essential as they directly impact the livelihoods of rural communities and their capacity to manage aquaculture operations in peatland areas sustainably. The second objective identifies smallholders' key issues and constraints in peatland environments. These challenges include limited access to technology, environmental degradation, and socio-economic barriers that hinder the growth and sustainability of aquaculture. Recognizing these constraints is crucial for developing effective strategies and interventions that can support the resilience of smallholder aquaculture in these fragile ecosystems. The third objective is to explore the potential of Nature-based Solutions (NbS) to address these challenges. NbS approaches focus on using natural processes and ecosystem-based management practices to enhance the productivity and sustainability of aquaculture while mitigating environmental impacts. By evaluating the role of NbS in peatland systems, this review aims to highlight innovative solutions that could improve the livelihoods of smallholder communities while preserving the integrity of peatland ecosystems. The final objective is to highlight gaps in the existing literature and suggest areas for future research. Despite the growing interest in peatland conservation and smallholder aquaculture, there are still significant gaps in our understanding of how these two areas intersect. This review seeks to identify underexplored areas that warrant further investigation, thereby providing direction for future studies and policy interventions to enhance smallholder aquaculture in peatland systems. This literature review is intended to provide a detailed overview of smallholder aquaculture in the peatland regions of the Philippines. It will offer insights into socio-economic conditions, environmental challenges, and the potential of nature-based solutions while also identifying gaps that future research could address.

2. Materials and Methods

This literature review aims to explore the status of smallholder aquaculture in these fragile ecosystems, identify the key challenges and issues smallholders face, and propose potential Nature-based Solutions (NbS) that could be implemented to address these challenges. To achieve this, the study is guided by three central research questions: What is the current status of smallholder aquaculture in peatland systems in the Philippines? What are smallholder aquaculture farmers' key issues and challenges in these ecosystems? Moreover, what potential NbS can be implemented to enhance the sustainability and productivity of these systems?

2.1. Literature Review

A systematic literature review was conducted to establish a foundational understanding of smallholder aquaculture practices and constraints in tropical peatlands, with a particular focus on the Philippines. Academic databases consulted included Google Scholar, ScienceDirect, Wiley Online Library, SpringerLink, and ResearchGate (Table 1). These sources were selected for their wide coverage of peer-reviewed journals, technical papers, and interdisciplinary research.

The search strategy applied specific keywords and Boolean operators (e.g., "smallholder aquaculture" AND "peatlands" AND "Philippines") to refine results. To ensure the relevance and quality of the literature, the following inclusion criteria were applied: 1) Studies that directly addressed smallholder aquaculture in peatland systems, 2) Research offering insights applicable to the Philippine context, and 3) Literature discussing NbS in relation to aquaculture, sustainability, or ecosystem resilience.

Exclusion criteria included studies lacking relevance to the research questions, those with geographic foci outside Southeast Asia (unless generalizable), and articles that did not address sustainability or livelihood outcomes in aquaculture. This process ensured that only high-quality, contextually relevant literature informed the review.

Table 1. Search sites, keywords, and inclusion-exclusion criteria used.

Search Sites	Keywords and Search Phrases	Inclusion-Exclusion Criteria
Google Scholar, ScienceDirect, Wiley Online Library, SpringerLink, and ResearchGate	"Smallholder aquaculture" "Smallholder aquaculture Philippines" "Smallholder aquaculture and/or peatlands and/or Southeast Asia" "Tropical peatlands" "Aquaculture sustainability peatlands" "Nature-based Solutions aquaculture" "Challenges in aquaculture in peatlands"	Studies focused on smallholder aquaculture, and in peatland systems, provides insights applicable to the Philippines, or discussed Nature-based Solutions within the context of aquaculture and peatland ecosystems.

2.2. Focus Group Discussion (FGD)

To complement the desk review, a Focus Group Discussion (FGD) was conducted to capture localized perspectives, validate literature findings, and obtain context-specific data. The FGD was facilitated by the authors and involved 22 smallholder aquaculture practitioners from the Leyte Sab-a Basin Peatland (LSBP). Participants were purposively selected based on their experience (minimum one year) in operating aquaculture systems within or adjacent to peatland environments.

The FGD followed a structured guide consisting of key discussion points. Responses were transcribed, reviewed, and analyzed using a thematic framework. Recurring themes were manually identified, and the frequency of similar responses was tallied to produce a semi-quantitative summary of participant perspectives.

The discussion explored a range of topics, including: (1) current aquaculture practices and species cultivated; (2) environmental and technical constraints (e.g., water quality, disease management); (3) socio-economic issues such as market access, financial limitations, and gender roles; and (4) local perceptions and informal practices that align with NbS principles.

Participants represented five barangays: Divisoria, Veteranos, Langit, and Tabangohay in Alangalang, and San Isidro in Sta. Fe, Leyte. The gender distribution was 50% male (n = 11) and 50% female (n = 11), which occurred naturally and not by design. The FGD was conducted in a participatory setting, recorded with prior consent, and moderated by the researchers.

Following the session, transcripts were reviewed and validated by the facilitators. The data were thematically analyzed using inductive coding to identify recurring patterns and community-driven insights. These themes were then synthesized alongside the literature to develop a comprehensive understanding of the status, constraints, and opportunities within smallholder peatland aquaculture.

2.3. Data Integration and Analysis

The insights derived from the literature and FGD were analyzed using a thematic approach to allow triangulation between global academic findings and localized knowledge. This approach ensured that the review did not merely aggregate published knowledge but was also grounded in the lived experiences of aquaculture practitioners in the LSBP.

This methodology enables a nuanced and contextually responsive discussion of aquaculture practices in fragile peatland ecosystems, bridging macro-level scientific discourse with micro-level community realities. It also strengthens the review's relevance for policy formulation, capacity-building initiatives, and the promotion of sustainable aquaculture pathways through NbS.

3. Results

The thematic analysis of the literature review and the focus group discussion (FGD) results is structured around three key themes: (1) Current Status and Practices of Aquaculture in the Philippines, (2) Challenges and Constraints, and (3) Opportunities and Potential Solutions through Nature-based Solutions (NbS).

3.1. Current Status and Practices of Aquaculture in the Philippines

3.1.1. Socio-Economic Importance

Smallholder aquaculture plays a vital role in supporting household food security and income in the Philippines, particularly in rural areas with limited livelihood options. In the context of peatland ecosystems such as the Leyte Sab-a Basin Peatland (LSBP), small-scale aquaculture contributes to both subsistence consumption and market-oriented production. This aligns with national trends in which aquaculture continues to outpace the growth of capture fisheries, offering a more stable and scalable option for fish production [23–27].

The substantial impact of aquaculture on equity and poverty reduction in rural Philippine communities underscores its transformative potential for improving socio-economic outcomes [21]. Many smallholders rely on aquaculture not only for household nutrition but also as a source of livelihood, reflecting the broader global trend where aquaculture plays a crucial role in addressing food insecurity and supporting economic development in low-income regions [22].

Aquaculture accounts for a substantial portion of the Philippines' fishery output. In 2021, the country ranked 11th globally in fisheries production, with aquaculture contributing approximately 23% of the total national volume [23]. Unlike capture fisheries, which are subject to environmental fluctuations and regulatory pressures, aquaculture—particularly inland and freshwater operations—has shown consistent growth. This is especially relevant in smallholder settings where access to marine resources is limited.

Data from the Bureau of Fisheries and Aquatic Resources (BFAR) indicate that inland municipal fisheries are significant contributors to rural food systems. In 2022, the top commodities harvested in these systems included Tilapia (*Oreochromis* spp.), striped snakehead (*Channa striata*), snail species, carp (*Cyprinus carpio* and *Aristichthys nobilis*), and gourami (*Osphronemus gouramy*), among others (**Table 2**). Tilapia remained the dominant species, accounting for nearly 30% of total inland fish production, demonstrating its adaptability and market acceptance across diverse ecological settings.

Table 2. Top ten commodities in Inland Municipal Fisheries, 2022.

Commodity	Amount (MT)	Rate (%)
Tilapia	52,126.25	29.73
Mudfish	21,643.26	12.34
Snail	21,321.13	12.16
Carp (includes Carp and Bighead carp)	16,640.66	9.49
Gourami	16,137.35	9.20
Catfish	13,147.81	7.50
Crab (includes Blue crab, Freshwater crab, and Mud crab)	4,635.62	2.64
Shrimp (includes Endeavor prawn, Freshwater shrimp, Tiger prawn, and White shrimp)	4,622.62	2.64
Freshwater goby	3,073.28	1.75
Climbing perch	2,752.74	1.57
Others	19,250.84	10.98
Total	**175,351.56**	**100.00**

Source: Bureau of Fisheries and Aquatic Resources [23].

The emphasis on inland municipal fisheries highlights the importance of smallholder aquaculture systems in providing sustainable and locally sourced aquatic food. Small-scale operations like these contribute significantly to rural livelihoods by offering supplementary income and enhancing food security in regions where resources may not be readily accessible. Smallholders in inland areas optimize available water resources to support their households and the broader community by cultivating adaptable and locally popular species such as Tilapia, mudfish, and catfish. While aquaculture is crucial for socio-economic well-being, the choice of species cultivated also plays a significant role in determining the sustainability and profitability of these operations. The significance of smallholder aquaculture in sustaining rural livelihoods is evident in its socio-economic contributions and the diversity of species cultivated across these systems, each playing a crucial role in local food security and market demands.

In summary, aquaculture's socio-economic importance is evident in providing essential food security and income for rural households and contributing to the country's fisheries production.

3.1.2. Major Species Cultivated and Their Impact on Smallholder Livelihoods

Understanding the key aquaculture species cultivated in the Philippines provides valuable insight into smallholder systems' productivity, economic viability, and sustainability, particularly in ecologically sensitive areas such as peatlands. Nationally, the aquaculture sector is dominated by seaweeds (*Kappaphycus* and *Eucheuma* spp.), milkfish (*Chanos chanos*), Tilapia (*Oreochromis* spp.), and shrimp/prawns (*Penaeus*, *Metapenaeus*, and *Macrobrachium* spp.), which collectively contributed 91.38% of total aquaculture production in 2018 [23,28,29].

Among inland aquaculture commodities, Tilapia is the most widely cultivated species, with production reaching 52,126.25 metric tons in 2022, accounting for 29.73% of the total output in inland municipal fisheries [23,31]. Its popularity stems from its adaptability to diverse water conditions, rapid growth, and consumer acceptance. During the FGD, LSBP practitioners confirmed that Tilapia (*O. niloticus*) remains their primary species due to its ease of management, local marketability, and resistance to moderate environmental stressors.

Historically, Tilapia culture has evolved significantly since the introduction of *O. mossambicus* in 1950 and *O. niloticus* in 1972. Over time, strains such as the Mozambique Tilapia (*O. mossambicus*), Nile Tilapia (*O. niloticus*), Blue Tilapia (*O. aureus*), and hybrid Red Tilapia have been farmed using various systems: pond culture, cage culture, monosex male culture, and aquaponics [32–36,38,39]. The species' reputation as the "aquatic chicken" reflects its suitability for semi-intensive and intensive production systems and its relevance in low-cost protein provisioning for rural communities [35].

In contrast, [23,30]. Species such as *Penaeus monodon* (tiger prawn), *P. vannamei* (white leg shrimp), and *Macrobrachium rosenbergii* (giant freshwater prawn) are cultivated in brackish and freshwater systems. The FGD revealed that although shrimp farming is less prevalent in the LSBP due to limited technical support, some smallholders have shown interest in its expansion, particularly for tiger prawn, which has high market value.

Disease outbreaks remain a major constraint across both Tilapia and shrimp farming systems. Tilapia is vulnerable to bacterial infections such as *Pseudomonas fluorescens*, *Streptococcus agalactiae*, and *Aeromonas hydrophila*, which can lead to substantial mortality in hatcheries and cage systems [40–42]. Similarly, shrimp aquaculture is threatened by viral and bacterial pathogens such as White Spot Syndrome Virus (WSSV) and Acute Hepatopancreatic Necrosis Disease (AHPND), which severely affect yield and farm viability [43]. The FGD participants highlighted episodes of fish kills and poor water quality, particularly during prolonged rainfall or dry spells, underscoring the need for localized disease management strategies.

While government agencies and research institutions have introduced structured breeding programs and biosecurity protocols to mitigate these risks [37], their adoption among smallholders remains uneven. The lack of access to pathogen-free broodstock, technical assistance, and diagnostics often limits effective implementation at the community level. Hence, developing affordable, site-specific interventions—especially in peatland ecosystems where water conditions fluctuate seasonally—is essential.

Importantly, the sustainability of species cultivation also hinges on traditional knowledge systems. The FGD participants reported the continued use of low-cost inputs such as *Kangkong* (*Ipomoea aquatica*) and *Azolla* as feed, and bamboo fencing for pond construction—practices that reflect adaptive responses to resource scarcity and that align with NbS principles. These local innovations illustrate how smallholders manage production under financial and ecological constraints.

In summary, Tilapia and shrimp are the dominant aquaculture species cultivated by smallholders in the Philippines and the LSBP. While these species contribute significantly to household livelihoods and national food production, disease risks and input limitations remain persistent challenges. Strengthening disease control, improving access to genetically enhanced broodstock, and integrating traditional practices with science-based management are crucial to enhancing resilience and productivity in peatland aquaculture systems.

3.1.3. Traditional Practices

Smallholder farmers in the Philippines' peatland areas adopt traditional practices that are inherently sustainable. In the LSBP, local pond owners and practitioners use traditional practices, such as using organic materials, such as Azolla and Kangkong (*Ipomoea aquatica*), as natural feed and bamboo for pond support structures, reducing input costs while maintaining ecological balance. In other regions, traditional practices also involve integrating aquaculture with other farming activities, such as rice-fish systems [44,45] and agroforestry techniques, which enhance productivity and resource efficiency. A similar approach is seen in China, where the traditional rice-fish farming system is recognized as an essential agricultural heritage, contributing to productivity and ecological sustainability [46].

In the Leyte Sab-a Basin Peatland, smallholders have adapted to their unique environmental conditions by cultivating species like Tilapia, catfish, and gourami, which are well-suited to peatland environments. They rely on minimal external inputs, leveraging natural feed and pond ecosystems to maintain productivity. However, challenges such as the unintended introduction of non-native species and predation by local predators highlight the need for careful management and adaptive practices.

Aquaculture is crucial not only from a production standpoint but also for its socio-economic contributions. Smallholder farmers view aquaculture as a reliable and sustainable food source, especially important in regions with limited access to affordable, nutritious food. By cultivating fish, they meet their nutritional needs and contribute to the broader community's food availability. Beyond food security [47,48], aquaculture is a vital economic activity for many participants, providing supplementary income primarily through fish vending in local markets [49]. This additional income supports household economies, particularly in areas with limited alternative income opportunities. Thus, small-scale aquaculture helps buffer against economic instability and offers financial resilience for rural households.

Moreover, FGD participants emphasized the social and recreational value of aquaculture. For many, aquaculture is not merely a means of survival or income generation; it also offers leisure and family bonding opportunities. Engaging in aquaculture provides satisfaction and fulfillment, fostering stronger family ties and enhancing community cohesion. This social dimension underscores aquaculture's value beyond economic benefits, contributing to personal and communal well-being.

The culture systems in the Philippines vary by species and environment, with fishponds, fish cages, fish pens, and mariculture used in brackish water, freshwater, and marine environments [50]. Despite this variety, traditional practices dominate, particularly in regions like Leyte Sab-a Basin Peatland. Farmers here use minimal technology or inputs such as commercial feed, highlighting a contrast with modern, more intensive approaches that could offer greater yields. For example, integrating agroforestry into aquaculture could better manage land and water resources, enhancing productivity and sustainability [51].

Smallholders in Southeast Asia, including the Philippines, rely on subsistence-level operations using natural resources, which limits their productivity due to low-quality seed stock, insufficient feed, and limited access to technology. The reliance on natural pond systems and traditional feed contrasts with modern aquaculture's potential use of optimized feed and technology that can significantly increase productivity and mitigate issues like disease. In LSBP, some FGD participants have fishponds within the peatland, while others have "upland fishponds" on the periphery. The species cultivated—Tilapia (*Oreochromis* spp.), Catfish (*Clarias macrocephalus*), gourami (*Osphronemus gouramy*), and Koi (*Cyprinus* spp.)—reflect strategic choices for adaptability and market demand. However, using minimal modern technology means these traditional systems often need help from natural predators and environmental conditions that impact productivity.

One FGD participant attempted to cultivate non-native crayfish, but a flood washed out the pond, unintentionally introducing the species into the peatland. Such incidents pose ecological risks as non-native species may disrupt local ecosystems and compete with native species, underscoring the complexities of managing aquaculture in sensitive environments like peatlands. In Southeast Asia, fish farming is often integrated with rice cultivation, livestock, and vegetable production, suggesting the importance of using available resources efficiently. The FAO's primer on integrated agriculture-aquaculture practices emphasizes that combining fish farming with other agricultural activities can improve resource use efficiency, increase productivity, and diversify smallholder income streams [52]. FGD participants in LSBP reported that peatland ponds yield higher harvests, attributed to the abundance of natural food sources in these nutrient-rich environments. However, challenges such as natural predators like the striped snakehead (*Channa striata*), offset benefits, which can substantially threaten productivity.

Aquaculture in the Philippines plays a critical role in fisheries, with traditional practices remaining prevalent among smallholder farmers. There is, however, a growing recognition of the need for improved techniques, especially in sensitive ecosystems like the Leyte Sab-a Basin Peatland. Addressing challenges posed by environmental factors, resource limitations, and the introduction of non-native species through modern technology, improved resource management, and community-driven initiatives will be essential to ensure sustainability and productivity. Despite the benefits of traditional practices in promoting sustainability, smallholder aquaculture in peatland regions continues to face challenges, including resource limitations, environmental pressures, and invasive species. Strengthening these systems through a balance of traditional and modern practices can help unlock their full potential for rural livelihoods. Community-based technology transfer, as successfully demonstrated in the case of mud crab nurseries, highlights the importance of involving local farmers in learning and decision-making to improve productivity and sustainability [53]. These environmental challenges underscore the need for resilient management strategies, which Nature-Based Solutions (NbS) can effectively address.

These traditional practices, while effective in maintaining productivity, indicate a need for enhanced methods, like NbS, to address the emerging challenges of climate variability and environmental degradation.

3.1.4. Summary of FGD Findings: Status and Constraints

Based on the Focus Group Discussion (FGD) conducted with 22 smallholder aquaculture practitioners in the Leyte Sab-a Basin Peatland (LSBP), several key themes emerged regarding the operational status of aquaculture systems and the challenges encountered by farmers. **Tables 3** and **4** summarize the frequency and percentage of responses for these core themes.

Table 3. Quantitative summary of current aquaculture status in LSBP.

Theme	Key Responses	No. of Respondents Mentioning	Percentage (%)
Operational Status	Aquaculture operations are active but limited in scale.	18	81.8
Purpose/Use	Primarily used for personal consumption and recreational purposes.	16	72.7
Perceived Benefits	Supplemental food source and an avenue for additional income.	19	86.4

Table 4. Quantitative summary of issues and challenges in smallholder aquaculture.

Challenge Area	Specific Issues	No. of Respondents Mentioning	Percentage (%)
Water Source and Quality	Limited access to clean and stable water supply	18	81.8
Financial Capital	Lack of startup capital or financial support mechanisms	16	72.7
Infrastructure and Materials	Need for initial pond setup materials and infrastructure	15	68.2
Capacity Building	Lack of actual seminars, demonstrations, and hands-on training	19	86.4
Technical Knowledge	Limited knowledge on aquaculture operations and synthetic feed preparation	17	77.3
Fingerling Supply	Unreliable access to quality fingerlings	15	68.2

The majority of participants reported that aquaculture operations are currently active but limited to subsistence-level production. While sustainability and supplemental income were frequently cited benefits, persistent constraints included poor water quality, limited access to capital, and a lack of training opportunities.

3.2. Challenges and Constraints

The challenges reported by smallholder aquaculture practitioners in the LSBP are multifaceted and reflect the fragile balance between ecological sustainability and livelihood demands. These can be grouped into environmental, technical, socio-economic, and institutional constraints.

3.2.1. Environmental Challenges

Environmental challenges are among the most significant hurdles that smallholder aquaculture practitioners face, particularly in peatland ecosystems, which are inherently sensitive to climatic variations. FGD participants highlighted their awareness of changing weather patterns, noting prolonged wet and dry seasons and extreme temperature fluctuations as their key concerns. These climatic changes directly impact aquaculture operations, influencing the daily management of ponds and broader agricultural practices.

For instance, prolonged dry seasons lead to shallow ponds drying up, drastically reducing fish yields. This reduction affects the immediate productivity of the ponds and puts long-term sustainability at risk, as repeated drying can degrade the pond environment. One respondent stated that during a prolonged dry season, his pond walls would crack, and when the rain comes, more often than not, it would cause the collapse of the pond walls or lead to washout during flooding. The literature supports these concerns, indicating that climate change poses significant challenges, including increased extreme weather events, temperature fluctuations, and water acidification, directly affecting fish survival, growth, and reproduction [54]. Furthermore, extreme precipitation regimes have been shown to destabilize water table dynamics in peatlands, causing cascading effects on carbon fluxes and impacting the resilience of aquaculture systems [55].

Similar environmental challenges are observed in other semi-arid regions, such as Tanzania, where prolonged dry seasons, inadequate water management, limited infrastructure, and issues of climate adaptability significantly affect aquaculture productivity [56,57]. Peatland areas, in particular, are highly vulnerable to these impacts due to their unique ecosystem characteristics, which are highly sensitive to changes in water levels and quality [58]. Changes in rainfall frequency and intensity can alter peatland structure and carbon sequestration capacity, especially in ecosystems dominated by moss and vascular plants [59]. Additionally, the conversion of the LSBP for agriculture and other land uses has been shown to significantly affect carbon stocks and alter physico-chemical properties, leading to challenges for aquaculture operations in these sensitive ecosystems [60,61].

Drained peatlands are also a significant source of carbon emissions, contributing to climate change and exacerbating environmental conditions that further complicate aquaculture sustainability. Ongoing drainage and conversion of Southeast Asian peatlands have led to substantial carbon dioxide emissions, intensifying environmental stress [62]. Two decades of rapid degradation in Southeast Asia's peat swamp forests further highlight the consequences of land conversion and increased ecological vulnerability [63]. These sensitivities are also observed in fishponds near Manila Bay, where water quality fluctuations significantly impact aquaculture viability [64]. National trends indicate that such environmental challenges are consistent across Philippine aquaculture systems [25].

Climate variability in Southeast Asia has particularly profound implications for peatland aquaculture systems due to its influence on water quality, hydrology, and aquaculture sustainability [65]. The increasing frequency of prolonged dry spells and erratic rainfall patterns severely disrupts fishpond operations. In Indonesia, for instance, extreme weather conditions have reduced aquaculture yields, undermining system resilience [66]. Similarly, temperature and precipitation anomalies have affected aquaculture in Vietnam's Mekong Delta, influencing water quality and fish survival [67]. These findings align with a recent regional study that documented the intensifying impacts of drought amplification due to deforestation and land-use change in Indonesian peatlands [131], which significantly reduces water availability and compromises pond infrastructure.

Excessive rainfall also causes major disruptions. FGD participants reported that flood events often lead to fish loss, infrastructure damage, and the accidental introduction of invasive species, such as crayfish, into the peatland ecosystem. These invasions threaten native species and destabilize ecosystem balance. Manipulating water tables through drying and rewetting experiments has shown that extreme rainfall events can alter peatland carbon dynamics, reducing methane emissions and affecting nutrient cycling, which have long-term impacts on aquaculture sustainability [68,69]. Persistent extreme weather, like prolonged high temperatures and decreased rainfall, can also deplete peatland carbon stocks, emphasizing the need for adaptive management practices to enhance peatland resilience [70]. Extreme precipitation changes peatland hydrology and carbon cycling, potentially impacting nutrient retention and methane emissions [132]. These changes ultimately threaten aquaculture sustainability in such ecologically fragile systems.

The catastrophic effects of Typhoon Yolanda, which destroyed fishponds and resulted in major stock losses in the region, further emphasize the vulnerability of aquaculture infrastructure to extreme climatic events. In such cases, the effects extend beyond temporary setbacks to long-term disruptions of livelihood and production cycles. Empirical evidence from a recent study linking extreme climate anomalies to disrupted aquaculture schedules and compromised fish growth and reproduction in tropical aquaculture systems [133].

Fluctuating hydrological regimes also worsen water quality degradation and bacterial outbreaks. In the Philippines and Malaysia, erratic rainfall patterns and seasonal transitions have been linked to increased fish mortality due to compromised water quality and pathogen outbreaks [66,71]. The findings from Vietnam [134] reinforce this observation, showing how climate-driven water level changes in aquaculture correlate with heightened disease outbreaks, providing insight into the cascading ecological risks associated with climate volatility.

Prolonged sun exposure and drought-related pond drying remain core concerns in the LSBP. Respondents shared that high heat exposure contributes to soil cracking, pond collapse, and water loss. This challenge is also prominent in Indonesia, where it has been documented that deforestation and excessive drainage result in lowered groundwater tables and increased hydrological drought, severely impacting peatland health and reducing ecosystem resilience [72,73]. The environmental degradation caused by land conversion and drainage [131,132] amplifies the effects of climatic drought, lowering groundwater tables and increasing peat desiccation.

To respond to these challenges, adaptive management strategies are essential. The integration of Traditional Ecological Knowledge (TEK), promotion of drought-resistant fish species, improved drainage management, and infrastructure designed for extreme events must be prioritized. These strategies are increasingly emphasized in recent studies and represent a critical path forward for building resilience in smallholder aquaculture systems in peatland environments [74].

3.2.2. Technical Challenges

Technical challenges in smallholder aquaculture are closely interlinked with environmental conditions, particularly in peatland ecosystems, where water quality, disease management, and infrastructure maintenance are highly susceptible to hydrological fluctuations. The Focus Group Discussion (FGD) revealed multiple technical barriers that limit productivity, resilience, and long-term sustainability in the Leyte Sab-a Basin Peatland (LSBP).

Water Quality and Supply

Water quality emerged as a critical concern among participants. Peatlands are naturally acidic, and smallholders noted difficulties maintaining optimal pH and dissolved oxygen levels. Siltation, limited aeration, and high turbidity were also identified as constraints to healthy fish growth. During dry seasons, pond water tends to stagnate or evaporate, leading to shallow conditions that are unsuitable for sustaining fish, especially fingerlings. These observations mirror broader trends in Philippine aquaculture. In Taal Lake, water quality indicators such as nutrient levels and dissolved oxygen have been shown to significantly influence fish yields [75], while similar constraints in inland aquaculture systems have been reported across Southeast Asia [64].

Disease Susceptibility and Pathogen Management

Although FGD participants reported no active disease outbreaks, they expressed concerns about future risks. The threat of Tilapia Lake Virus (TiLV) is well-documented in the Philippines and elsewhere, with significant losses attributed to this emerging pathogen [78–80]. Other bacterial infections, such as *Aeromonas hydrophila* and *Streptococcus agalactiae*, both previously isolated from Tilapia ponds in Luzon, pose risks of high mortality, especially in systems with poor water quality [81,82]. The absence of active disease in LSBP systems may be due to the semi-extensive nature of operations. However, low awareness and limited veterinary outreach still leave smallholders vulnerable to sudden outbreaks.

Access to Fingerlings

Several participants cited the irregular availability of fingerlings as a persistent challenge. Restocking ponds becomes difficult without reliable hatcheries or transport systems, especially after weather-related losses. This inconsistency disrupts production cycles and reduces overall efficiency. The issue is particularly acute in peatland areas, where geographic isolation and poor infrastructure further constrain access.

Predation and Biodiversity Conflicts

Natural predation emerged as a technical constraint, particularly by *Channa striata* (striped snakehead, locally known as "Turobay"). FGD participants noted that this predator frequently enters ponds during flood events or heavy rains, resulting in substantial stock losses. Some also mentioned fingerlings consumed by other introduced species, further complicating efforts to maintain balanced aquaculture systems. These concerns reflect the dynamic interactions between aquaculture and the native biotic community of peatland landscapes.

Infrastructure and Pond Management

Another shared concern was maintaining pond structures in a fluctuating peatland hydrology. Smallholder ponds are often constructed using bamboo or earthen bunds, which degrade during prolonged dry spells or collapse during flash floods. These issues require technical interventions—such as reinforced pond walls or improved drainage systems—that are beyond the current financial or technical capacity of most practitioners.

Training and Technical Knowledge Gaps

Participants consistently identified a lack of access to formal training on aquaculture operations in peatland contexts. Topics such as water quality management, feed formulation, disease prevention, and species compatibility are rarely covered in local extension programs. This gap in technical capacity prevents farmers from adapting to new methods like aquaponics or Integrated Multi-Trophic Aquaculture (IMTA), which could offer more sustainable alternatives. The literature confirms that knowledge limitations are a significant barrier to technology adoption in smallholder aquaculture across low-income regions [54,76].

Capital and Technological Inputs

Financial barriers compound technical limitations. Pond establishment, maintenance, and equipment (e.g., aerators, water pumps) require capital investment that most smallholders lack. Many participants cited their inability to purchase necessary inputs, such as formulated feeds or liners for pond sealing. This has resulted in a continued reliance on low-input traditional systems, which, while ecologically adaptive, tend to yield lower productivity. Transitioning to modern systems remains prohibitive without external support or subsidy mechanisms [83].

In sum, the technical challenges identified in this study—ranging from water quality issues and disease susceptibility to infrastructure maintenance and knowledge gaps—reflect the complex and interdependent pressures smallholder aquaculture practitioners face in peatland ecosystems. These challenges are not merely operational but structural, requiring targeted support through training, infrastructure investments, fingerling supply networks, and localized technical innovations. Addressing them is vital to achieving sustainable, resilient, and inclusive aquaculture in areas like the LSBP.

The technical challenges identified through the FGDs reflect diverse aquaculture practices across distinct microenvironments within and around the Leyte Sab-a Basin Peatland (LSBP). Notably, some concerns such as water quality degradation were primarily raised by upland smallholders whose pond systems are located outside the peatland core, while infrastructure-related issues—such as pond wall cracking and collapse—were commonly reported by inland farmers situated at the peatland periphery. These spatial nuances highlight the need for differentiated interventions tailored to the hydrological and ecological conditions of each farming context. **Table 5** summarizes these key technical constraints and offers corresponding interpretations and suggested interventions based on participant narratives and relevant literature.

Table 5. Technical Challenges in smallholder aquaculture identified from FGD and corresponding interpretations.

Challenge Category	Description from FGD	Interpretation	Suggested Intervention
Water Quality	Upland smallholders reported issues with siltation, poor water retention, and pH fluctuations. These concerns were less commonly raised by peatland farmers.	Water quality concerns appear more prominent in upland or peripheral sites, where runoff and soil properties differ from peatland-based systems.	Develop site-specific water quality management strategies; conduct water testing; train farmers in pH and oxygen monitoring and mitigation practices.
Fingerling Supply	Participants cited irregular availability and high cost of fingerlings, especially after weather-related losses.	Unreliable access to fingerlings disrupts production cycles and limits scalability.	Establish local hatchery networks; facilitate partnerships with government breeding stations; organize cooperative purchase systems.
Pond Infrastructure	Inland smallholders with ponds near the peatland periphery reported pond wall cracking during drought and collapse during floods.	Infrastructure is highly vulnerable to fluctuating water tables and extreme weather, especially in peripheral or non-peat ponds.	Promote reinforced pond design using low-cost lining or concrete bunds; train on site-specific construction for variable hydrological conditions.
Technical Knowledge	Limited access to training on aquaculture techniques, including feed formulation, pond maintenance, and disease prevention.	Knowledge gaps reduce productivity and prevent the adoption of more resilient or efficient practices.	Expand extension services focused on aquaculture in peatland and upland areas; support peer-learning platforms and demo farms.
Disease Management	No major disease outbreaks reported, but concerns raised about future risks, especially under poor water quality conditions.	Disease risks are latent; systems with low awareness and poor biosecurity are vulnerable to emerging pathogens like TiLV and bacterial infections.	Introduce basic fish health management workshops; develop a local early-warning network; encourage semi-extensive biosecurity measures.

3.2.3. Socio-Economic Challenges

Market Access

Market access remains a critical socio-economic barrier affecting the viability of smallholder aquaculture in peatland environments. FGD participants consistently reported difficulties in marketing their produce beyond the local level. Most farmers sell their fish in public markets within Alangalang and Santa Fe, while only a few can sell in bulk to buyers in Tacloban City. This restricted market access often results in lower selling prices and reduced income, undermining the financial sustainability of their aquaculture operations.

These local challenges mirror broader regional trends across Southeast Asia. In Indonesia, for instance, smallholder aquaculture producers face high input costs—especially for feed and fingerlings—and struggle with inconsistent market prices, limiting their capacity to scale up and sustain operations [86]. Similarly, small-scale fish farmers in Thailand contend with inadequate infrastructure, such as poor transport and limited cold storage, which hampers their ability to access more profitable urban markets [87]. In Vietnam, aquaculture producers—particularly in the northern provinces—grapple with economic instability and ecological stressors, making them highly vulnerable to fluctuating seafood prices and climate-related risks [88,89].

Comparable socio-economic constraints have been documented in East Africa. A review of small-scale aquaculture systems in Tanzania identified limited access to markets, credit, and technical support as persistent obstacles to improving productivity and livelihoods [90]. These cross-regional parallels underscore the structural nature of the challenge and point to the need for coordinated interventions.

In response to these issues, integrating agroforestry into aquaculture systems is emerging as a promising strategy. Studies show that smallholder-managed trees in South and Southeast Asia contribute to income diversification while enhancing ecological resilience [91]. Such integrated systems are particularly relevant in peatland settings, where land-use efficiency and environmental conservation must go hand in hand. Furthermore, organizing smallholders into cooperatives or producer groups has been shown to strengthen bargaining power, reduce input costs, and facilitate shared access to technical assistance and infrastructure [92]. These models can support more inclusive market participation and build economic resilience among smallholder aquaculture communities.

Gender Division

The Focus Group Discussion (FGD) revealed a clear gendered division of labor in smallholder aquaculture. Men typically handle physical tasks such as feeding, pond maintenance, and marketing, while women focus on supervision, financial management, and profit-tracking. This division reflects traditional gender roles that often limit women's participation in technical and decision-making domains.

This pattern aligns with broader trends in Southeast Asia. In Northeast Thailand, for example, women contribute significantly to small-scale aquaculture, yet their participation tends to decline as production systems intensify, reinforcing male-dominated roles [93]. Across the region, women are often confined to post-harvest activities, bookkeeping, and household-based aquaculture tasks, with limited involvement in operational or leadership roles [94–96]. Although essential, these contributions remain undervalued, reinforcing socio-economic inequalities and limiting women's access to aquaculture's full benefits.

FGD participants echoed these challenges, citing limited access to technical training, financial resources, and formal roles in community aquaculture projects. Similar constraints have been noted in Cambodia, Lao PDR, and Vietnam, where gender policies often exist on paper but face implementation gaps that prevent meaningful empowerment [97]. Despite gender policies in the aquaculture sector, many action plans fail to address structural inequalities across the value chain, often overlooking women's roles in production and upstream decision-making [99].

Nonetheless, targeted interventions have shown promise. For example, the WISH-Pond initiative in Cambodia employed participatory science to train women in hatchery management and pond operation, significantly increasing their technical involvement [100]. Likewise, forming women's cooperatives has demonstrated positive outcomes—enhancing collective bargaining power, expanding market access, and creating platforms for shared learning and decision-making [96].

To foster inclusive aquaculture systems, multiple strategies are needed, such as 1) Gender-sensitive training that adapts to women's schedules and addresses both technical and managerial competencies; 2) Access to credit and financial services, enabling women to invest in aquaculture infrastructure and production inputs; 3) Community sensitization campaigns aimed at challenging restrictive norms and highlighting the socio-economic value of women's participation; 4) Support for gender-transformative approaches, such as engaging men and community leaders in advocacy, which have proven effective in promoting equitable labor division and decision-making authority [102,103].

Empirical evidence underscores that empowering women in aquaculture enhances household nutrition, increases income stability, and improves sustainability outcomes [98,101,104]. Furthermore, women are more likely to reinvest aquaculture income into education and health, amplifying the developmental impacts of their participation.

In conclusion, addressing gender disparities in aquaculture is not only a matter of equity but also a strategic imperative for enhancing productivity and resilience in peatland communities. Integrating women fully into aquaculture systems—from production to decision-making—will help ensure a more just, efficient, and sustainable future for smallholder livelihoods.

The gendered division of labor observed during the FGDs was reflected in qualitative narratives and the concrete distribution of tasks across male and female participants. While men were more involved in physical and production-related roles, women assumed responsibilities in financial management and post-harvest activities. **Table 6** summarizes the number and percentage of male and female participants engaged in specific aquaculture-related tasks, reinforcing the narrative evidence with empirical support. This breakdown provides a clearer picture of how gender roles manifest in the daily operations of smallholder aquaculture in the LSBP.

Table 6. Gender division of labor in smallholder aquaculture (FGD-based).

Activity	Male (n)	Male (%)	Female (n)	Female (%)
Pond preparation and maintenance	9	75.0%	0	0.0%
Feeding and daily care	7	58.3%	5	41.7%
Bookkeeping and financial tasks	2	16.7%	10	83.3%
Harvesting	8	66.7%	1	8.3%
Marketing	6	50.0%	3	25.0%
Decision-making	9	75.0%	3	25.0%
Post-harvest processing	3	25.0%	7	58.3%

Note: Percentages are based on 12 FGD participants. Some activities may involve multiple individuals of each gender.

Lack of Access to Financial Services

The Focus Group Discussion (FGD) participants underscored that one of the most persistent socio-economic constraints is the lack of access to capital and formal financial services. Without adequate financial support, smallholder aquaculture practitioners cannot invest in infrastructure, quality inputs, or technological innovations needed to enhance productivity. This financial exclusion restricts their capacity to scale up operations, manage risks, or adopt climate-adaptive practices. The challenge is not unique to the Philippines. In African aquaculture systems, similar socio-economic limitations—particularly resource scarcity and limited infrastructure—significantly impede productivity and food security efforts [105].

Studies show that aquaculture farmers who lack access to affordable credit are less likely to invest in high-quality feed, improved pond design, or disease prevention, resulting in diminished yields and efficiency [106]. High input costs, limited extension services, and institutional hurdles further aggravate this issue, pushing smallholders to operate at subsistence levels without prospects for upward mobility [107]. The absence of tailored financial instruments for small and medium-scale aquaculture exacerbates these limitations. Most available credit programs are either inaccessible due to stringent collateral requirements or misaligned with the cash flow cycles of aquaculture production systems [108].

Financial insecurity also compromises smallholders' capacity to adapt to environmental stressors, such as unpredictable rainfall, flooding, or drought. With limited resources, farmers often delay critical interventions, such as reinforcing pond dikes or procuring new fingerlings after stock loss. In this context, both government and NGO actors have a crucial role to play in offering flexible, affordable financial mechanisms that directly respond to the needs of rural aquaculture stakeholders [83].

Community-based models rooted in Traditional Ecological Knowledge (TEK) offer promising avenues for bolstering resilience among financially marginalized smallholders.

In Indonesia, for example, rewetting initiatives in peatlands have been met with mixed success, primarily due to limited community engagement and a lack of financial support for affected households. In Sumatra, the restoration success is closely tied to smallholder perceptions and incentives, highlighting the need for inclusive planning and sustained funding [109,131].

In the Philippines, initiatives such as cluster farming and tree-growing systems illustrate the potential of collective strategies. In Mindanao, smallholder farmers participating in cluster farming benefited from pooled resources, improved access to larger markets, and enhanced technical support. Although sustainability issues emerged after donor support ended, clusters that institutionalized financial literacy and market knowledge showed greater resilience and autonomy [110,111]. Similarly, agroforestry initiatives in Claveria, Northern Mindanao, demonstrated how integrating tree-growing with aquaculture or agriculture provided a diversified income stream while enhancing soil and water retention, improving long-term sustainability [112].

To address the entrenched issue of financial exclusion, a multi-pronged approach is needed: expanding financial products tailored for aquaculture; promoting community-level financial cooperatives; integrating TEK with scientific management; and reinforcing social capital through collective action. These strategies will not only improve the financial viability of smallholder aquaculture but also strengthen local capacities for environmental stewardship and climate resilience in peatland areas.

The FGD responses revealed both the depth of financial constraints experienced by smallholder aquaculture practitioners and their openness to collective solutions. As shown in **Table 7**, the vast majority reported relying on personal savings or informal loans due to limited access to formal credit. Notably, many expressed interest in cooperative models or cluster farming arrangements, highlighting the potential for community-based financial strategies to address structural exclusion and improve economic resilience.

Table 7. Financial challenges and collective farming interest among FGD participants.

Theme/Response Category	Frequency (n)	Percentage (%)
Reported lack of access to formal credit	1	91.7%
Dependent on personal savings/family loans	9	75.0%
Expressed interest in cooperatives or clustering	7	58.3%
Reported past involvement in cluster farming	3	25.0%
Requested financial assistance (grants/subsidies)	13*	108.3%*

Note: *One participant may mention multiple concerns or solutions, resulting in cumulative percentages exceeding 100%.

3.2.4. Regulatory Challenges

FGD participants perceived regulatory challenges as minimal; however, this perception largely stems from limited awareness of existing policies relevant to aquaculture in peatland environments. Most participants admitted unfamiliarity with formal regulatory frameworks governing their practices, suggesting a potential gap in policy dissemination and grassroots engagement. This lack of awareness may inadvertently contribute to non-compliance with environmental safeguards, sustainability standards, and aquaculture best practices.

Rather than viewing regulations as obstructive, the participants emphasized the absence of proactive support from local government units (LGUs). Their concerns centered on the lack of structured assistance—such as access to training, funding, and technical guidance—rather than restrictive policies. They needed moral and institutional support to improve their practices and align them with broader regulatory and sustainability goals.

The literature highlights that aquaculture governance in sensitive ecosystems like peatlands often suffers from fragmented and weakly enforced regulatory systems. In many contexts, including the Philippines, there is a lack of coherent policies specifically addressing the intersection of aquaculture and peatland conservation, thereby creating ambiguity in implementation and enforcement [113]. This regulatory vacuum leaves smallholders without clear guidance or incentives to adopt sustainable approaches, and weakens institutional accountability.

Nonetheless, this challenge allows local institutions to take a more active role. LGUs and relevant government agencies can bridge this gap by mainstreaming peatland-specific aquaculture regulations into local policy frameworks and extension programs. Training initiatives on regulatory compliance, incentives for adopting nature-based and climate-smart practices, and improved access to technical services and markets can significantly empower smallholder practitioners.

In summary, while regulatory challenges were not a prominent concern for the FGD participants, their responses underscore the need for improved regulatory visibility and institutional engagement. Strengthening governance through inclusive and context-sensitive policies, backed by LGU support, is essential to enhance compliance, improve sustainability, and unlock the full potential of smallholder aquaculture in peatland systems.

3.3. Opportunities and Potential Solutions through Nature-Based Solutions (NbS)

Although FGD participants had limited formal knowledge of Nature-Based Solutions (NbS), several of their traditional practices intuitively aligned with NbS principles. These included using bamboo to reinforce pond dikes and incorporating *Kangkong* and *Azolla* as supplemental fish feed—methods that reflect an ecological approach to farming by harnessing natural materials and cycles. These align with the core NbS principle of working with, rather than against, ecosystem functions to achieve socio-environmental outcomes [84,85,114].

Participants expressed strong interest in formally adopting NbS strategies—such as vegetative strips for water filtration, biofiltration systems, and integrating aquaculture with cropping systems—provided they receive training, technical support, and financial aid. These solutions mirror NbS applications in other sustainable aquaculture contexts, where vegetative buffers and constructed wetlands improve water quality and support biodiversity [84,116].

Globally, sustainable aquaculture practices such as Integrated Multi-Trophic Aquaculture (IMTA), rice–fish systems, polyculture, and aquaponics are promoted for their capacity to enhance resilience, optimize resource use, and reduce environmental impacts [58,115,117,118]. These systems use ecological interactions—such as fish waste fertilizing crops or complementary species mitigating disease—to maintain balance. For instance, rice–fish farming systems in China and Southeast Asia have proven effective in integrating food production with environmental management [46,119], while aquaponics has shown promise in maximizing nutrient cycling and water efficiency [77].

However, challenges remain in scaling such practices. For example, commercial aquaponic systems still face barriers in nutrient optimization and profitability for high-value crops like tomatoes and sweet peppers. Research suggests that using plant growth-promoting microbes can enhance nutrient uptake and system efficiency, making aquaponics more viable for smallholder applications [131]. Moreover, the use of nature-aligned strategies such as native vegetation buffers and water recirculation systems has been proposed to improve sustainability in aquaculture landscapes [134].

In the context of peatlands, NbS strategies that restore hydrology and biodiversity while supporting livelihoods are essential. Studies have shown that peatland ecosystems are highly responsive to land-use management and can benefit from integrated aquaculture systems that stabilize water levels and reduce greenhouse gas emissions [132]. Aligning aquaculture with peatland restoration thus offers a dual benefit: sustaining production and improving ecosystem function.

It is noted that the successful implementation of NbS requires supportive policy, institutional backing, and targeted capacity-building initiatives [133]. FGD participants emphasized the need for external support in training, technology access, and financial resources—factors similarly identified in other Southeast Asian and African contexts as critical enablers of smallholder innovation and resilience [83,120].

Universities and research institutions were seen as key partners in this process. Demonstration farms and action research can test NbS applications, improve local capacities, and encourage adaptive management. Research from European and Asian contexts supports the effectiveness of interdisciplinary, community-anchored innovation systems in scaling sustainable practices [126–128]. In the Philippines, the cluster farming model—successfully implemented in smallholder vegetable systems in Mindanao—serves as a practical model for collective market access and technical capacity [111].

Finally, achieving inclusive NbS adoption requires intentional efforts to empower marginalized groups, particularly women. Gender-responsive training, access to credit, and cooperative formation can enhance both social equity and environmental stewardship. Women who are trained in technical aquaculture roles have been shown to improve household food security and income, and to adopt more sustainable practices [96,101,102].

In conclusion, aligning traditional ecological knowledge with formal NbS strategies provides a promising pathway toward sustainable, inclusive, and climate-resilient aquaculture in peatland areas. The potential for NbS to support livelihood security, enhance ecosystem services, and build adaptive capacity makes it an essential framework for guiding future interventions in smallholder aquaculture.

4. Discussion

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

The study addresses the current status of smallholder aquaculture in peatland systems in the Philippines, focusing on traditional and emerging practices. It identifies key species cultivated, such as Tilapia, catfish, gourami, and koi, while highlighting the socio-economic significance of aquaculture for rural communities. Additionally, the study notes that many aquaculture practices align with Nature-Based Solutions (NbS) concepts, although formal awareness of NbS still needs to be improved among smallholders.

Traditional practices, such as using bamboo for pond support and Kangkong and Azolla as feed, demonstrate an inherent understanding of working with nature, thus reflecting NbS principles. Participants in the study showed openness to new NbS strategies, including biofiltration systems, vegetative strips, and other sustainable approaches that could enhance both productivity and environmental resilience. However, despite the benefits, smallholder aquaculture in peatlands faces numerous challenges, particularly environmental constraints like fluctuating water levels, financial limitations, and technical knowledge gaps. There is an apparent demand for external support in the form of training, technical assistance, and financial resources to enhance the resilience and sustainability of these systems.

Furthermore, participants acknowledged the role that the academe and other research institutions can play in developing demonstration projects that showcase NbS applications in real-world peatland settings. This would facilitate learning and broader adoption of sustainable practices. The study also explored opportunities for gender empowerment in aquaculture, proposing that increased women's involvement in aquaculture production could improve overall productivity, economic resilience, and community cohesion.

4.1. Gaps Identified

1. Limited Formal Awareness of Nature-Based Solutions (NbS): Although many traditional practices align with NbS concepts, smallholder aquaculture practitioners in the LSBP need more formal education and a structured understanding of NbS. Training and capacity-building programs are necessary to bridge this knowledge gap and integrate formal NbS strategies into their operations.
2. Lack of Financial and Technical Support: Smallholder farmers face significant challenges accessing financial resources and technical assistance. This hinders the adoption of more sustainable and innovative practices such as Integrated Multi-Trophic Aquaculture (IMTA), aquaponics, and other NbS-aligned methods. The lack of access to necessary infrastructure and technology limits their ability to scale and improve the efficiency of their operations.
3. Environmental Vulnerabilities: Peatland ecosystems' sensitivity to water levels and quality changes poses a significant challenge for aquaculture. More adaptive practices are needed to handle the environmental volatility of peatlands, such as fluctuations in water availability, acidification, and the risk of flooding or drought.
4. Underutilized Role of Research Institutions: While the study emphasizes the potential for universities and research institutions to lead demonstration projects, there is currently a gap in their involvement in local aquaculture practices. More proactive engagement by research institutions is needed to test and implement NbS in peatland aquaculture settings.
5. Gender Gaps in Aquaculture Participation: The study recognizes the potential for more significant gender equity in aquaculture, but there remains a gap in how women are engaged in the sector. Providing targeted training, resources, and opportunities for women could empower them and enhance the resilience and productivity of smallholder aquaculture systems.

4.2. Ways Forward

1. Enhancing NbS Awareness and Adoption: Develop targeted training programs for smallholder farmers to in-

crease their understanding of NbS and its potential to enhance productivity and environmental sustainability. Demonstration projects led by local research institutions and universities can serve as models for broader adoption.

2. Integrating Traditional Practices with Modern NbS Strategies: Smallholder aquaculture already incorporates many traditional practices that align with NbS. To improve sustainability without requiring significant shifts in current farming systems, these practices can be integrated with more formal NbS strategies, such as biofiltration and polyculture systems.
3. Improving Financial and Technical Access: Create financial mechanisms and government support programs to provide smallholders with the resources needed to invest in sustainable infrastructure and new technologies. This could include access to microfinance, subsidies, or grants for implementing NbS-aligned practices.
4. Adapting to Environmental Challenges: Encourage the development of adaptive management techniques tailored to the environmental volatility of peatland ecosystems. Practices such as water-level management, biofilters, and vegetative buffers can help mitigate the impacts of changing water conditions.
5. Expanding Gender Participation in Aquaculture: Support initiatives that increase women's involvement in aquaculture through targeted training programs and policies promoting gender equity. Increased women's participation can lead to diversified income streams and strengthen community resilience.
6. Scaling Research and Development Initiatives: Universities and research institutions should lead efforts in developing scalable and replicable NbS demonstration projects in peatlands. These projects can serve as learning hubs for local farmers and as platforms for innovation in sustainable aquaculture practices.

By addressing these gaps and opportunities, smallholder aquaculture in peatland systems in the Philippines can move towards greater sustainability, enhanced productivity, and resilience to environmental and socio-economic challenges. Integrating Nature-Based Solutions offers a pathway for environmental conservation and economic development in these sensitive ecosystems.

4.3. Policy and Program Recommendations

To operationalize the strategic directions outlined above, the following targeted policy and program interventions are recommended to guide government agencies and development partners in supporting smallholder aquaculture in the Leyte Sab-a Basin Peatland:

1. Establish a National NbS Framework for Aquaculture in Peatlands: The Department of Agriculture – Bureau of Fisheries and Aquatic Resources (DA-BFAR), in collaboration with the Department of Environment and Natural Resources (DENR), should develop a national framework that integrates Nature-based Solutions (NbS) into inland aquaculture policy. This should include guidelines for ecological pond design, integration of vegetation buffers, and water management tailored for peatland ecosystems.
2. Create Municipal-Level NbS Aquaculture Plans: Local Government Units (LGUs) surrounding the Leyte Sab-a Basin peatland should be supported in crafting localized aquaculture development plans aligned with NbS principles. These plans must be informed by participatory mapping, community consultations, and ecosystem assessments, and should be integrated into local climate and development plans.
3. Institutionalize Gender-Responsive Aquaculture Programs: Design gender-inclusive aquaculture programs that ensure women's participation in training, access to resources, and representation in fisherfolk councils. Programs should include targeted grants for women-led aquaculture enterprises and support mechanisms for childcare and flexible training schedules.
4. Launch Community-Based Extension and NbS Training Centers: Establish village-level training centers, possibly in partnership with state universities and colleges (SUCs), that provide technical training, demonstration ponds, and extension services for sustainable aquaculture practices. These centers should serve as convergence points for government support, NGO technical assistance, and farmer innovation.
5. Develop Financial Instruments for Sustainable Aquaculture: Government financial institutions (e.g., Land Bank, Agricultural Credit Policy Council) should offer dedicated

microfinance windows and insurance packages for NbS-aligned aquaculture infrastructure (e.g., vegetative dikes, low-input systems). These programs should prioritize smallholders in ecologically sensitive areas like peatlands.

6. Support Participatory Research and Monitoring: Incentivize universities and NGOs to engage in long-term research and participatory monitoring with smallholder communities. Research should focus on productivity metrics, biodiversity indicators, and socio-economic outcomes of NbS interventions. These data can inform adaptive policy revisions and investment priorities.
7. Establish a Peatland Aquaculture Innovation Fund: Create a funding mechanism that specifically supports pilot projects, start-ups, and community-led innovations in peatland aquaculture. This can be administered jointly by BFAR, the Climate Change Commission, and regional development councils, with a focus on scalability, replication, and sustainability.

By implementing these policy measures, government and development partners can create conditions that enable smallholders to succeed in fragile peatland ecosystems. These recommendations aim not only to boost productivity and income but also to establish ecological stewardship and social inclusion as core principles of aquaculture development.

5. Conclusion

The thematic analysis reveals that smallholder aquaculture in the peatlands of the Philippines presents both opportunities and challenges. While there is potential for high productivity in these environments, the inherent environmental volatility and the smallholder farmer's limited technical knowledge frequently undermine the full realization of this potential. However, adopting Nature-based Solutions (NbS) offers a promising pathway to overcome these challenges. However, the successful implementation of NbS requires significant investments in capacity building, infrastructure, and training - areas where support from key stakeholders, such as government agencies, NGOs, and academic institutions, will be essential. These stakeholders can play a crucial role in providing the necessary resources, technical guidance, and demonstration projects to promote sustainable practices tailored to the unique conditions of peatland systems.

Government agencies should prioritize creating financial mechanisms that support NbS integration, such as grants or subsidies to encourage smallholder adoption. NGOs can facilitate community-based training programs that empower farmers with the necessary technical skills. At the same time, academic institutions must focus on developing demonstration projects that showcase the benefits of NbS in real-world settings. These stakeholders can play a crucial role in providing the necessary resources, technical guidance, and demonstration projects to promote sustainable practices tailored to the unique conditions of peatland systems.

This study underscores the socio-economic significance of smallholder aquaculture in the Philippines' peatland systems, highlighting its potential for sustainable development through NbS. While many traditional practices already align with NbS principles, there remains a significant gap in formal awareness and understanding of NbS among smallholder farmers. Addressing this knowledge gap is critical, and targeted community-led training programs facilitated by NGOs can ensure farmers are equipped to adopt and benefit from these practices. This approach will enhance the resilience of aquaculture systems and the peatland ecosystems they depend on.

Several key challenges were identified in this study, including environmental vulnerabilities due to the sensitive nature of peatlands, financial and technical constraints that limit the adoption of advanced aquaculture practices, underutilization of research institutions in advancing sustainable and innovative aquaculture solutions, and gender gaps in aquaculture participation. These challenges present clear opportunities for targeted interventions, particularly in training, financial support, and technical guidance. Integrating NbS strategies such as biofiltration, polyculture, and aquaponics into existing traditional practices provides a promising pathway for improving the sustainability of smallholder aquaculture in peatlands. The involvement of academic institutions and research bodies will be crucial in developing practical demonstration projects that showcase the application of NbS, offering valuable learning opportunities for smallholders and encouraging the broader adoption of sustainable practices.

Integrating Nature-Based Solutions, with the active participation of all stakeholders, offers the most viable pathway for ensuring sustainable aquaculture in peatland systems, balancing ecological conservation with socio-economic development. Several research areas warrant further exploration to enhance the intersection of smallholder aquaculture and NbS. These include:

1. Knowledge Dissemination and Adoption Barriers: Future research should investigate the barriers that prevent smallholder farmers from adopting NbS, including socioeconomic factors, cultural constraints, and the efficacy of various knowledge dissemination methods. Understanding these barriers will help develop more effective training programs tailored to the needs of local communities.
2. Economic Viability of NbS: More comprehensive studies are needed on the economic feasibility of integrating NbS into smallholder aquaculture, particularly concerning the cost-benefit analysis of practices like biofiltration and aquaponics. Research could also focus on identifying incentives and financial models encouraging smallholders to adopt NbS, such as carbon credit schemes or eco-tourism opportunities.
3. Demonstration Projects and Adaptive Strategies: More research on adaptive management techniques suitable for peatland ecosystems is needed, particularly regarding fluctuating water levels and soil stability. Action research and demonstration projects can help validate and refine these adaptive NbS strategies, ensuring their practical applicability in the field. Demonstration farms can act as valuable learning centers, fostering knowledge-sharing and encouraging community-wide adoption.
4. Gender Integration and Empowerment: Exploring effective strategies for integrating and empowering women within aquaculture systems is another critical area for future research. Studies should examine the impact of gender-targeted training programs and resource distribution on aquaculture productivity, economic stability, and overall community resilience. This research could help inform policies that promote gender equity in smallholder aquaculture, benefiting both community welfare and sustainability.
5. Environmental Impact Assessment: Research should also focus on assessing the long-term environmental impacts of NbS integration in peatland aquaculture, including changes in water quality, carbon sequestration potential, and overall ecosystem health. Such studies will provide valuable data for refining NbS practices to ensure they contribute positively to peatland conservation while supporting sustainable livelihoods.

Moreover, addressing the environmental challenges posed by the sensitivity of peatland ecosystems will require adaptive management techniques supported by government policies and financial mechanisms. These initiatives should equip smallholder farmers with the necessary resources to manage fluctuating water levels, protect soil integrity, and promote ecological balance within their farming systems. Gender empowerment in aquaculture also presents an opportunity to strengthen community resilience. By providing targeted training and resources to increase women's participation in aquaculture, overall productivity and economic stability could be significantly enhanced. This approach promotes gender equity while fostering greater community participation in sustainable practices.

While smallholder aquaculture in peatland systems faces considerable challenges, there is immense potential for transformation through Nature-based Solutions. With suitable support structures - including training, financial assistance, policy interventions, and research initiatives - smallholder aquaculture can evolve into a model for sustainable and resilient livelihoods in peatland ecosystems. The integration of NbS offers not only a pathway to improved productivity but also a means of preserving the ecological integrity of peatlands, ensuring long-term sustainability for both the environment and the communities that depend on these ecosystems. Ultimately, enhancing smallholder aquaculture through NbS can significantly contribute to broader global goals, such as ensuring food security, building climate resilience, and conserving biodiversity, which are essential for a sustainable future in the face of climate change and ecological degradation.

Author Contributions

Conceptualization, L.A.F.D.; methodology, L.A.F.D.; validation, L.A.F.D. and H.E.M.; formal analysis, L.A.F.D.; investigation, L.A.F.D. and H.E.M.; resources, L.A.F.D. and H.E.M.; data curation, L.A.F.D. and H.E.M.; writing—original draft preparation, L.A.F.D.; writing—review and editing, L.A.F.D.; visualization, L.A.F.D.; supervision, L.A.F.D.; project administration, L.A.F.D.; funding acquisition, L.A.F.D. and H.E.M. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Ethical review and approval were waived for this study because it involved non-invasive focus group discussions with adult participants who were fully informed about the purpose of the research, their voluntary participation, and the recording of their responses. The study posed minimal risk and involved no sensitive or personal data. Ethical principles consistent with the Declaration of Helsinki were followed throughout the research process.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

This study is primarily a literature review and did not generate new datasets. The research is based on previously published journal articles and qualitative insights gathered through focus group discussions. Summarized responses from the focus group discussions, which support the analysis and conclusions of the paper, and the FGD questionnaire used in this study are available from the corresponding author upon reasonable request, subject to ethical considerations and participant confidentiality.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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