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# An assessment of government-funded small-scale cage fish farming in Siavonga District, Zambia: performance, challenges and opportunities

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Aquaculture is a key driver of food and nutrition security, rural livelihoods, and economic development in Zambia. This study evaluated the performance, challenges, and opportunities associated with government-funded small-scale cage fish farming in Siavonga District, contributing to the discourse on sustainable aquatic food systems and climate resilience. Using mixed methods including questionnaires, interviews, and insights from the Ministry of Fisheries, data were gathered from 30 purposively selected farmers between 2020 and 2023. The findings show that government investments have improved income generation and job creation by lowering entry barriers through infrastructure support and extension services. However, constraints such as theft, fish predation, currency fluctuations, and bureaucratic inefficiencies continue to hinder adaptive decision-making and reduce the competitiveness of publicly supported farmers compared to their private-sector counterparts. Key opportunities for sustainable transformation include expanding access to quality inputs such as fingerlings and feed, improving lake transport systems, and fostering public-private partnerships. Importantly, this study offers a climate-smart perspective by highlighting how adaptive support systems and inclusive policy frameworks can enhance the resilience of small-scale aquaculture in the face of climate variability. Integrating government-led initiatives with market-driven innovations is essential to strengthen the resilience, inclusivity, and long-term viability of Zambia's aquaculture sector. The study provides practical insights for advancing blue transformation in similar socio-ecological settings.

KEYWORDS

aquaculture, fish farming, public-private partnerships, small-scale cage aquaculture, small-scale fisheries, sustainable aquaculture, Zambia

## 1 Introduction

Aquaculture, the cultivation of fish, shellfish, and aquatic plants in controlled environments, is essential for enhancing global food and nutritional security. It serves as a vital source of protein, contributing to dietary diversity and meeting the growing demand for sustainable food production. It enhances fish growth and production while supporting food security, job creation, and economic development, especially in low-income communities (Musuka and Musonda, 2013; Hasimuna et al., 2019; Maulu et al., 2024a). In Africa, fish culture is rapidly expanding as a key strategy to combat malnutrition and strengthen food security (Maulu et al., 2020, 2024a; Muhala et al., 2021b; Adeleke et al., 2021; Langi et al., 2024). Zambia, driven by a growing population and rising demand for fish and fish products (Zhang et al., 2023; Mbewe et al., 2024; Maulu et al., 2024a), has positioned itself as a key player in aquaculture (Hasimuna et al., 2020a). It is the fifth-largest producer of farmed fish in Africa (Adeleke et al., 2021), highlighting its significant role in the continent's aquaculture sector. The Department of Fisheries (DoF) reported a notable increase in Zambia's aquaculture production, rising from 75,647 metric tonnes (MT) in 2022 to 81,000 MT in 2023. With the government's creation of favorable investment opportunities and support for small-scale farmers, Zambia has the potential to double its aquaculture production within the next decade. Aquaculture represents a lucrative and viable business opportunity for small-scale farmers in Zambia, offering substantial economic benefits (Hasimuna et al., 2023; Mphande et al., 2023).

A significant portion of Zambia's fish production comes from diverse systems, including ponds, recirculating tanks, dams, and cages (Hasimuna et al., 2019, 2023; Musaba and Namanwe, 2020; Maulu et al., 2024a). Cage aquaculture, the practice of raising fish in net enclosures, has become the leading contributor to national fish production due to its efficiency and scalability (Halide et al., 2009; Moe et al., 2010; Xu and Qin, 2020). On Lake Kariba, Nile tilapia (*O. niloticus*) dominates cage farming, while native species like Three-spotted tilapia (*O. andersonii*) and Greenhead bream (*O. macrochir*) show potential for diversification according to the Department of Fisheries in Zambia (Bbole et al., 2018, 2020; Hasimuna et al., 2020b, 2021, 2023). Since its introduction in the late 1990s, cage farming has expanded significantly, offering economic and food security benefits, particularly for smallholder farmers (Nsonga, 2014; Hasimuna et al., 2019; Muhala et al., 2021a; Maulu et al., 2024a). Raising aquaculture production in Lake Kariba and other lakes is poised to increase and enhance Zambia's economy in terms of employment, incomes, food and nutrition security benefiting especially the small-scale aquaculture farmers (Velde et al., 2022; Hasimuna et al., 2023).

To address the growing gap between fish demand and supply, the Zambian government has partnered with the private sector (Siavwapa et al., 2022; Hasimuna et al., 2023; Mphande et al., 2024) on initiatives such as the Zambia Aquaculture Enterprise Development Project (ZAEDP). Co-funded by the African Development Bank (AfDB) and the Zambian government, ZAEDP has a budget of $50.89 million and aims to support aquaculture entrepreneurs, improve infrastructure to facilitate industry, and strengthen project management and institutional capacity (African Development Bank, 2024). The President of the Republic of Zambia's recent directives to expand cage farming to Lakes Bangweulu, Mweru, and Mweru Wantipa underscore the government's ongoing commitment to advancing the aquaculture sector, as previously reported (Hasimuna et al., 2023; Siavwapa et al., 2022). Government-funded small-scale cage fish farming initiatives in Zambia, particularly in Siavonga District, aim to enhance food security, create employment, and drive economic growth. However, their long-term sustainability beyond the initial project funding remains uncertain. Challenges such as inadequate infrastructure, limited access to quality inputs, and weak market linkages have been identified as major constraints in many government funded projects (CapMad, 2024). In contrast, privately funded ventures often demonstrate greater adaptability to market dynamics but struggle with scalability due to limited initial capital (Kgosiemang and Oladele, 2012; Ya and Pei, 2022).

While previous studies have explored aquaculture's role in food security and economic development (Hasimuna et al., 2019; Maulu et al., 2024b), there is limited research comparing the long-term sustainability of government-funded and privately funded projects. Government-funded initiatives, such as those under ZAEDP, have improved livelihoods and increased fish production but often struggle to maintain operations once external support ends. Privately funded projects, though more adaptable, lack the resources to scale effectively. Addressing the sustainability challenges of government-funded small-scale cage fish farming projects requires a comprehensive understanding of their performance, the obstacles they face, and the opportunities available for improvement. This gap in understanding undermines efforts to ensure the long-term viability of aquaculture investments in Zambia and other similar regions.

This study focuses on Siavonga District, where government-funded small-scale cage fish farming projects under ZAEDP have been implemented to enhance food security, employment, and economic development. By assessing the performance, challenges, and opportunities of these initiatives, the study aims to provide insights for designing sustainable aquaculture strategies. To our knowledge, this is the first study to explore the long-term sustainability of government-supported small-scale cage fish farming in Zambia, offering valuable lessons for policymakers and stakeholders.

## 2 Materials and methods

### 2.1 Study area

The study was conducted in Siavonga, a town located in Zambia's Southern Province, positioned on the northern shore of Lake Kariba. Siavonga's geographical coordinates are 16°32' S latitude and 28°43′E longitude (16.533° S, 28.717° E), as shown in Figure 1. The town sits at an elevation of approximately 1,335 meters above sea level. Siavonga is 133 kilometers from Lusaka, the capital of Zambia, making it relatively accessible. According to the 2010 census, Siavonga has a population of

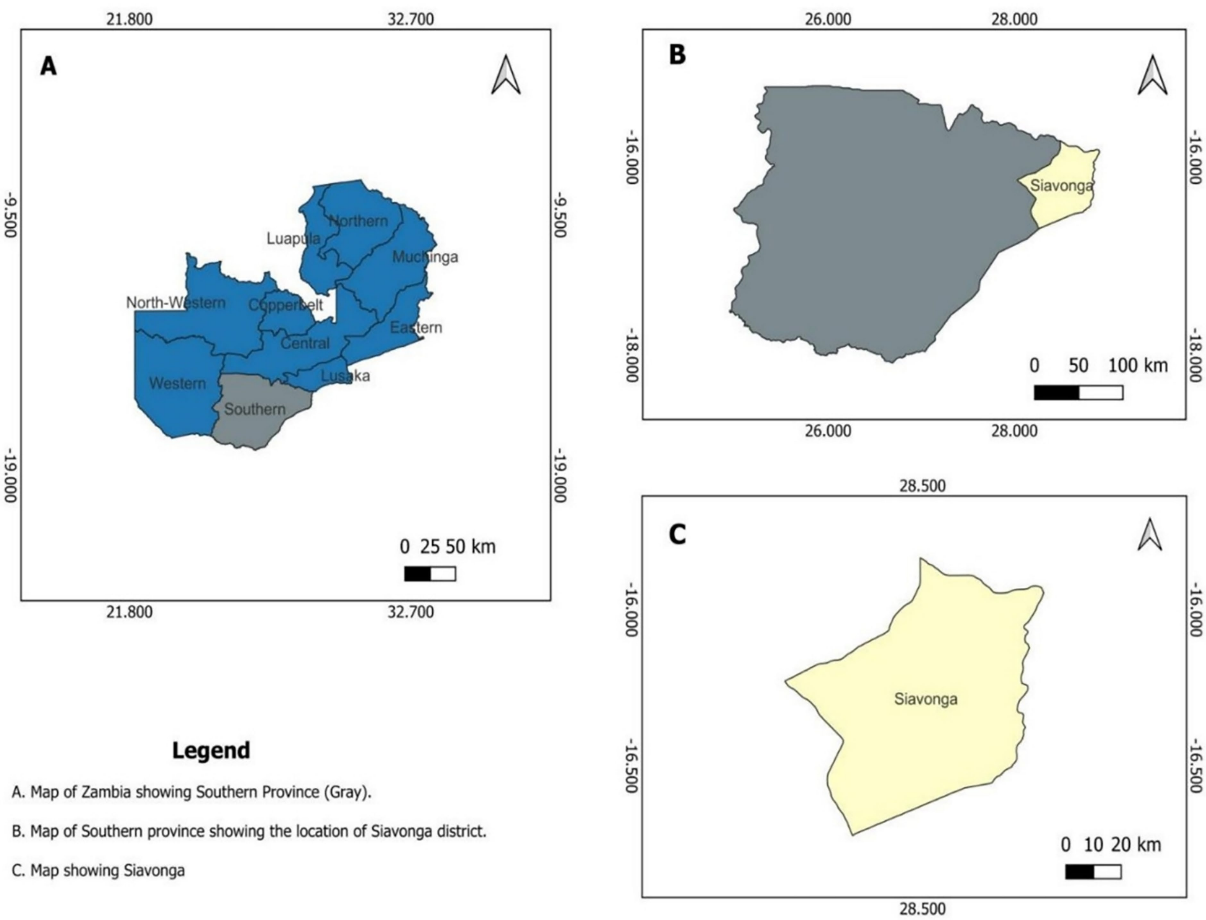


FIGURE 1
Geographical location of Siavonga District in Zambia and Southern Province.

more than 90,000 people. The primary economic activities in the district include fishing, hotel tourism and agriculture, reflecting the town's reliance on natural resources and its proximity to Lake Kariba.

## 2.2 Ethical approval

In this study, ethical approval was obtained from Kapasa Makasa University (KMU) Research and Ethics Board (REB) and was carried out in strict compliance with their guidelines. Furthermore, verbal consent was obtained from participants in line with the guidance from REB to facilitate and enhance direct interaction while minimizing potential discomfort between the researcher and participants. Accordingly, respondents who were interviewed face-to-face provided informed verbal consent and all respondents were informed of their right to opt out at any time without consequences, and confidentiality was assured to the respondents.

## 2.3 Data collection

Two distinct questionnaires were developed one targeting government-funded small-scale cage fish farmers and the other aimed at District Fisheries Officers. Both instruments were structured into five sections: Demographic Information, Performance, Challenges, Opportunities, and General Feedback. Draft versions were initially pretested with a subset of government-funded small-scale cage fish farmers (Mphande et al., 2023) to assess clarity, identify potential improvements, and ensure that the questionnaires would yield the desired outcomes. Feedback from this pretest led to modifications that enhanced clarity, eliminated redundant questions, and minimized ambiguity. A purposive sampling strategy was employed, selecting 30 farmers based on data from the Department of Fisheries office in Siavonga who at a time had a total of 40 government funded cage fish farmers. Although 40 participants were initially targeted, only 30 were accessible, which was deemed sufficient for the study. Purposive sampling was chosen to ensure that participants possessed the necessary knowledge and experience relevant to the research objectives (Siankwilimba et al., 2024). The data was collected between April to August 2024, via face-to-face interviews and supplemented with online questionnaires, with all responses subsequently entered into Google Forms.

## 2.4 Data analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) for Windows, version 23.0. Initially, all quantitative data were entered into Microsoft Excel for organization and preliminary checks before being exported to SPSS for cleaning and statistical analysis. Descriptive statistics, including frequencies and percentages, were employed to summarize key findings on the performance, challenges, and opportunities associated with government-funded small-scale cage fish farming initiatives in Siavonga District. Data visualization techniques, such as frequency tables, bar charts, and graphs, were used to enhance clarity and facilitate pattern recognition. In addition to quantitative analysis, qualitative data obtained through face-to-face interviews and open-ended feedback were analyzed using thematic content analysis. Responses were read carefully, coded manually to identify recurring themes and patterns, and then organized into categories that highlight the nuanced challenges faced by fish farmers, as well as perceived opportunities for improvement. This complementary qualitative analysis provided deeper insights that enriched the interpretation of the quantitative findings. Given the study's objectives and the mixed nature of the data, the combined descriptive and thematic analytical approach was deemed most appropriate, providing a structured yet comprehensive overview of the sector's dynamics.

# 3 Results

## 3.1 Socio-demographic and operational characteristics

The social-demographic and operational characteristics of farmers are shown in Table 1. Most respondents were males (76.7%), while females were the least (23.3%). The predominant age range among the farmers was 18–35 years (80%), with a smaller proportion aged between 36–45 years (20%). In terms of education, most farmers had attained tertiary education (63.3%), while 36.7% had attained secondary education. Notably, none of the respondents reported having primary or no education. Moreover, each participant engaged in farming for a period of 1–5 years. When considering employment, before receiving funding, a significant majority had no employees (93.3%), whereas only a small fraction had one employee (3.3%). Before receiving funding, most farmers had a monthly income of less than 5,000 ZMW (96.7%), with only a small percentage earning between 5,001–7,500 ZMW (3.3%). However, after receiving funding, a larger portion of these farmers reported monthly incomes in higher brackets, with 60% earning between 10,001–20,000 ZMW. In addition, most farmers (96.7%) have already begun repaying their loans, while a minority (3.3%) have yet to start. Regarding their operations, the farmers typically operated with one cage (66.7%), and the most common cage size was 6 m x 6 m (60%). Unfortunately, disease outbreaks were reported by 60% of the farmers, and a significant majority (86.3%) faced challenges in repaying the loan. Despite these challenges, an overwhelming majority of farmers (93.3%) express their willingness to recommend government initiatives to fellow farmers. Additionally, all respondents have confirmed that they received training from the government.

## 3.2 Feed source preferences among small-scale cage fish farmers

Among small-scale cage fish farmers who received government support, the primary feed type used was commercially pelleted feed.

TABLE 1 Social-demographic and operational characteristics of farmers in the district.

| Variable | Category | Composition (%) |
|---|---|---|
| Gender | Male | 76.7 |
| | Female | 23.3 |
| Age group | 18–35 | 80 |
| | 36–45 | 20 |
| | 46–55 | 0 |
| Highest education attained | None | 0 |
| | Primary | 0 |
| | Secondary | 36.7 |
| | Tertiary | 63.3 |
| Years in farming activity | 1–5 years | 100 |
| | 6–10 years | 0 |
| | 11–15 years | 0 |
| Number of employees after funding | 0 | 10 |
| | 1 | 16.7 |
| | 2 | 43.3 |
| | 3 | 16.7 |
| | 4 | 10 |
| | 5 | 0 |
| | 6 | 3.3 |
| Number of employees before funding | No employees | 93.3 |
| | 1 employee | 3.3 |
| Farmer's monthly income before funding (ZMW) | <5,000 | 96.7 |
| | 5,001–7,500 | 3.3 |
| | 7,501–10,000 | 0 |
| | >10,001 | 0 |
| Farmer's monthly income after funding (ZMW) | <10,000 | 20 |
| | 10,001–20,000 | 60 |
| | 20,001–25,000 | 6.7 |
| | >25,001 | 13.3 |
| Number of farmers who started paying back the loan | Started | 96.7 |
| | Not started | 3.3 |
| Number of cages | 1 | 66.7 |
| | 2 | 30 |
| | 3 | 3.3 |
| Sizes of cages | 3 m × 3 m × 3 m | 33.3 |
| | 6 m × 6 m × 6 m | 63.3 |
| | 7 m × 7 m × 7 m | 3.3 |
| Disease outbreak | Yes | 60 |
| | No | 40 |
| Percentage of farmers facing challenges paying back the loan? | No | 13.3 |
| | Yes | 86.3 |
| Percentage of farmers who would recommend this government support to other farmers | Yes | 93.3 |
| | No | 6.7 |
| Number of farmers who received training | Yes | 100 |
| | No | 0 |

TABLE 2 Feed preferences, employment changes, and gender distribution among government-supported small-scale cage fish farmers (*n* = 30).

| Variable | Category | Value |
|---|---|---|
| Feed source preferences | NOVATEK | 70% |
| | Aller Aqua | 30% |
| Total employees | Before government support | 7 employees |
| | After government support | 64 employees |
| Gender distribution | Male employees | 96.88% |
| | Female employees | 3.13% |

The majority of respondents (70%) reported using NOVATEK feed, while a smaller proportion (30%) indicated reliance on Aller Aqua feed (Table 2). This distribution suggests that NOVATEK feed is the predominant choice among farmers, possibly due to factors such as availability, cost, or farmer preference. In contrast, Aller Aqua feed is less commonly used, indicating its smaller market share within this group. These findings reflect the prevailing trends in feed selection among government-supported small-scale cage fish farming enterprises.

## 3.3 Total employees before and after receiving government financial support

Before receiving financial assistance from the government, the 30 farmers collectively employed only 7 individuals. However, after the allocation of government funds, the total number of employees increased dramatically to 64 (Table 2). This change illustrates the positive effect of financial support on employment opportunities within the fish farming value chain and industry as a whole.

## 3.4 Gender distribution of employees

The gender distribution of employees among small-scale cage fish farmers who received government funding for training and aquaculture inputs, such as feed and fish seed, reveals a pronounced gender imbalance. Male employees constitute the vast majority, accounting for 96.88% of the workforce, while only 3.13% are female (Table 2). This significant disparity highlights the under representation of women in employment within these small-scale cage fish farming enterprises, even after the allocation of government support. The results suggest that despite efforts to enhance productivity and promote aquaculture through funding, male dominance in the workforce persists, indicating potential barriers that limit female participation in these government-supported initiatives.

## 3.5 Aquaculture practices

Most farmers (60.3%) use 6 m × 6 m × 6 m cages, with stocking densities ranging from 19,000 to 22,000 fish and producing 3–5 tons per cycle (Table 3). A smaller group (33.3%) used 3 m × 3 m × 3 m cages, with stocking densities of 11,000 to 12,000 fish and producing 1.3–3 tons per cycle. Only 3.3% of farmers used 7 m × 7 m × 7 m cages, with a stocking density of 23,000 fish and a production of 5 tons per cycle. All farmers were producing *O. niloticus*.

## 3.6 Feeding of fish

The source of information used by farmers to administer feed to their fish are shown in Figure 2. The majority, 60.0%, follow the manufacturer's recommendations. The feed conversion ratio (FCR) guidelines were used by 26.7% of farmers. Personal experience and intuition, as well as professional advice from aquaculture experts, were each used by 6.7% of the farmers.

## 3.7 Challenges faced by the farmers

The challenges identified by the farmers are shown in Table 4. Some of the most significant challenges reported included theft and predation 14.0%, transportation of fish to market (12.8%), and fluctuation of local currencies (12.3%). Other notable challenges were the insufficient amount of funds received and conflicts with other resource users, both having 11.2%, whereas damage to facilities by weather accounted for 0.6%. Competition with big producers accounted for 8.9% while transport for inputs and equipment 7.8%. Late delivery of inputs impacts 3.4% of farmers. Less frequent challenges include lack of access to quality fingerlings (2.2%), late fund release by the government (2.2%), bad road networks (1.1%), and delays in feedback from government institutions (0.6%).

In response to an open-ended question on predation and theft was a challenge in the district, one farmer stated: *"We need to ensure that our cages are manned at all times, especially at night, because there are individuals who pretend to be just passing traveling from one part of the lake to another but sometimes these are potential thieves. Meanwhile, otters, birds, and crocodiles pose the biggest predation threats to our operation."* In response to a follow-up question on transport challenges, another cage fish farmer commented: *"It is challenging for us small-scale cage fish farmers to transport fish to major markets like Lusaka due to the lack of refrigerated trucks. Most of the time, we are forced to sell our fish at low prices to avoid losing the money we have invested in the business. The situation is made worse by the absence of cold chain facilities where we could store our fish after harvesting, especially when prices are low or demand is weak."*

## 3.8 Opportunities identified by the farmers

Farmers identified various opportunities in aquaculture, as summarized in Table 5. The most frequently highlighted opportunities included the availability of extension services (12.6%) and training programs offered by private stakeholders (11.6%). Other notable opportunities were access to water transport (10.6%), the profitability of fishing during the fishing ban (9.5%), networking and collaboration among fish farmers (9.5%), and access to quality fingerlings (9.0%). Additionally, the presence of large cage producers equipped with advanced tools (8.0%) and government support for aquaculture development (6.5%) were emphasized. Opportunities mentioned less frequently included access to quality feed (5.5%), timely delivery of inputs by the government (5.5%), reliable transport to markets (5.5%),

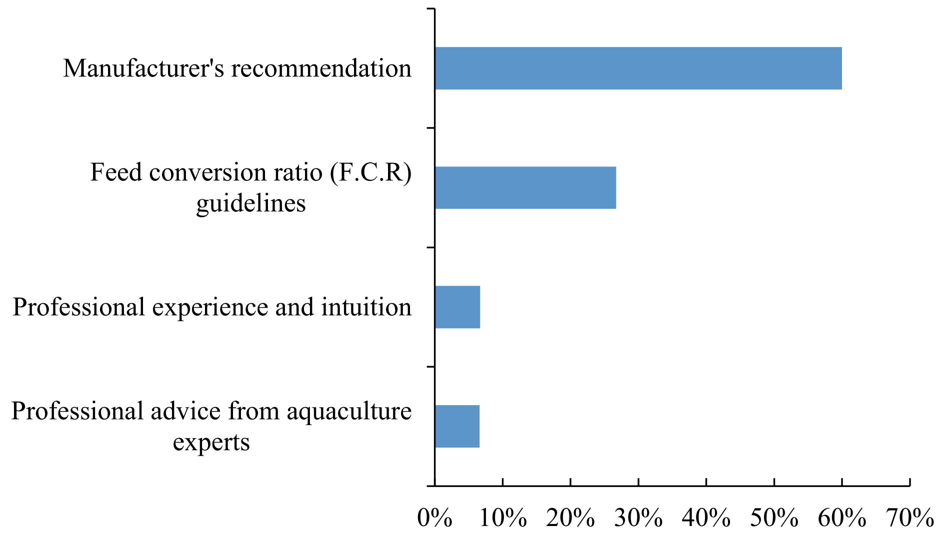


FIGURE 2
Percentage distribution of guides used by farmers to administer fish feed.

TABLE 3 Productivity and stocking density differences by cage size.

| Cage volume ($m^3$) | Stocking density (fish/$m^3$) | Production per cycle (MT) | Prevalence (%) | Significance |
|---|---|---|---|---|
| (3 × 3 × 3) | 11,000–12,000$^a$ | 1.3–3.0$^a$ | 33.3 | Low productivity baseline |
| (6 × 6 × 6) | 19,000–22,000$^b$ | 3.0–5.0$^b$ | 63.3 | Moderate productivity |
| (7 × 7 × 7) | ≥23,000$^c$ | >5.0$^c$ | 3.3 | High productivity outlier |

Superscript letters (a, b, c) denote statistically significant differences between groups as determined by one-way ANOVA followed by *post-hoc* tests ($p < 0.05$). Groups not sharing the same superscript letter differ significantly.

TABLE 4 Challenges faced by the farmers.

| Challenges | Percentage (100%) |
|---|---|
| Theft and predation | 14.00 |
| Transportation of fish to market | 12.80 |
| Fluctuation of local currencies | 12.30 |
| Insufficient amount of funds received | 11.20 |
| Conflicts with other resource users | 11.20 |
| Damage to facilities by weather | 10.60 |
| Competition with big producers | 8.90 |
| Transport for inputs and equipment | 7.80 |
| Late delivery of inputs | 3.40 |
| Lack of access to quality fingerlings | 2.20 |
| Late fund release by the government | 2.20 |
| Bad road networks | 1.10 |
| Delays in feedback from government institutions | 0.60 |

and the availability of markets (4.0%). Online market access (0.5%) and a well-developed road network (1.0%) were the least cited opportunities.

To add on, in response to a follow-up question on why extension services were considered an opportunity, one cage fish farmer remarked: "*The availability of District Aquaculture Business Extension Officers (DABEOs), who can be consulted at any time, makes it easy to get the technical help we need, as they are fully dedicated to providing both technical and operational support. Moreover, we are free to engage the district fisheries office whenever we need assistance or guidance regarding the running of our enterprise.*"

## 4 Discussion

### 4.1 Performance and challenges of government-funded cage fish farming

The present study has revealed that the government-funded small-scale cage fish farming in Siavonga district has contributed significantly to increased farmer income and employment opportunities. Through financial support and technical assistance provided under ZAEDP, small-scale farmers have been able to engage in commercial aquaculture. However, despite these benefits, the long-term sustainability of such initiatives remains uncertain due to persistent challenges, including loan repayment difficulties, theft, predation, and transportation constraints. Addressing these challenges is crucial for ensuring the continued success and expansion of small-scale cage aquaculture in the region.

TABLE 5 Percentage distribution of opportunities identified.

| Opportunity | Percentage (100%) |
|---|---|
| Availability of extension services | 12.60 |
| Training services from private stakeholders | 11.60 |
| Availability of water transport | 10.60 |
| Fishing ban for profitability | 9.50 |
| Networking and collaboration with other fish farmers | 9.50 |
| Access to quality fingerlings | 9.00 |
| Presence of large cage producers with equipment | 8.00 |
| Support from the government for aquaculture development | 6.50 |
| Access to quality feed | 5.50 |
| Early delivery of inputs by the government | 5.50 |
| Readily available transport to the market | 5.50 |
| Readily available markets | 4.00 |
| Good road network | 1.00 |
| Access to online markets | 0.50 |

## 4.2 Loan repayment and economic constraints

This study revealed that a significant proportion of fish farmers struggled with loan repayment, a challenge that has also been documented in other African aquaculture regions, such as South Africa and Nigeria (Madibana et al., 2020; Okonta et al., 2023). This issue can be attributed to several interrelated factors, including financial mismanagement, market volatility, and operational challenges such as theft and predation. Furthermore, fluctuations in currency exchange rates exacerbate these difficulties by increasing the costs of imported fish feed and other essential aquaculture inputs (Zhang et al., 2011; Hasimuna et al., 2019, 2025). Given that feed costs account for a substantial portion of total production expenses, such economic pressures place additional strain on farmers' financial stability. To mitigate these issues, it is imperative to implement integrated financial training programs while promoting policies that support local feed production, thereby reducing reliance on expensive imported feeds.

## 4.3 Theft, predation, and security challenges

Theft remains a significant challenge in cage fish farming, particularly in areas where artisanal fishers and commercial farmers operate in close proximity. This finding aligns with Hasimuna et al. (2019), who also identified theft as a major constraint for commercial cage aquaculture farmers in Siavonga. In some cases, conflicts between these groups have exacerbated fish theft, with stolen fish often being sold as legally caught stock. Additionally, low wages among farm workers may incentivize internal pilfering further compounding financial losses.

Beyond theft, predation by birds (Baleta et al., 2019; Hasimuna et al., 2019), otters, and crocodiles has been identified as another major challenge to fish farming in Zambia, Kenya, and the Philippines (Shitote et al., 2013; Roriz et al., 2017; Hasimuna et al., 2019). These losses not only reduce productivity but also impose financial strain on farmers. The situation is further worsened by limited access to funds needed for investment in protective measures. The revealed challenges require urgent, timely and appropriate actions if they are to be mitigated such as cooperative security initiatives, as well as cost-effective protective strategies net enclosures and scare tactics.

## 4.4 Market access and transportation constraints

Market access and transportation constraints are significant challenges for small-scale fish farmers in the present study. The absence of efficient transportation infrastructure particularly refrigerated transport reduces the shelf life of harvested fish, resulting in substantial post-harvest losses. Additionally, transporting essential inputs such as feed and fingerlings is hampered by poor road networks and high logistical costs, further limiting production efficiency. These challenges align with those reported by Mwanja and Nyandat (2013) in Eastern Africa, where limited access to quality fish seed, inadequate feed availability, and insufficient extension services persist. They also highlight underdeveloped aquaculture infrastructure and gender imbalances in resource control as key barriers to sector growth. Similarly, studies by Zhang et al. (2011) in China and Hasimuna et al. (2025) in Zambia underscore the influence of transportation and feed costs on the sustainability of aquaculture. These studies indicate that while small-scale systems can provide short-term benefits, they often face challenges in achieving long-term viability. Wealthier farmers with better market access typically produce higher volumes, whereas poorer farmers struggle to scale up. Despite increasing commercial production of fish seed and feed in East Africa, access to formal markets remains constrained by limited technical knowledge and inadequate infrastructure. To address these constraints, strategic interventions are needed which may include developing cooperative transport networks, promoting local feed production, and encouraging private-sector investment in cold-chain logistics. Mwanja and Nyandat (2013) further note that, although some policy and rural development efforts have shown promise, more focused attention is required. Therefore, strengthening infrastructure and improving access to inputs are essential for enhancing the sustainability, profitability, and overall viability of small-scale aquaculture.

## 4.5 Gender dynamics in small-scale cage fish farming

The present study on cage aquaculture in Siavonga reveals a shift in gender dynamics that contrasts with traditional patterns observed in existing literature. While studies by Hasimuna et al. (2019), Blow and Leonard (2007), and Medard et al. (2002) consistently highlight a gendered division of labor, with women mainly involved in post-harvest activities such as fish trading and processing, our findings suggest that women in Siavonga are increasingly participating in production roles, including managing fish cages and harvesting fish. This evolving trend challenges the more rigid gender norms seen in other sub-Saharan African countries like Ghana, Malawi, and Uganda, where women's involvement remains largely restricted to post-harvest sectors (Blow and Leonard, 2007). Moreover, while physical demands and cultural expectations continue to impose constraints on women's full participation, their growing presence in production activities indicates a shift toward more inclusive practices in aquaculture. Furthermore, gender-inclusive policies, such as those recommended by Blow and Leonard (2007), appear to have a positive effect in Siavonga. Targeted training programs such as ZAEDP through financial incentives have contributed to increased female involvement in both production and decision-making roles. Thus, continued policy support holds the potential to further advance gender equity in the sector, fostering a more sustainable and resilient aquaculture industry.

## 4.6 Opportunities for growth and sustainability

Despite the aforementioned challenges, several opportunities exist to improve the sustainability and resilience of small-scale cage fish farming in Siavonga.

### 4.6.1 Improved extension services and fingerling supply

The findings of this study highlight the crucial role of recent improvements in extension services in bridging technical gaps within small-scale cage aquaculture. The deployment of District Aquaculture Business Extension Officers (DABEOs) under the Zambia Aquaculture Enterprise Development Project (ZAEDP) has significantly enhanced farmers' access to technical support. For instance, DABEOs provided trainings, farm visits, demonstrations and facilitated for linkages to other stakeholders like input suppliers. The presence of DABEOs marked a departure from earlier reports in Uganda, where inadequate extension services hindered aquaculture development (Kwikiriza et al., 2018). Strengthened extension services help small-scale farmers improve production management, ultimately contributing to better livelihoods. This aligns with the observations of Munthali et al. (2024) who indicated that support to small-scale aquaculture is a vital strategy for rural income diversification and food security.

Despite improved access, gaps remain in fingerling distribution quality, frequency, and coverage which continue to limit productivity and profitability. In Zambia, the availability of high-quality fingerlings which was previously identified as a constraint (Hasimuna et al., 2019, 2025) has improved through government-supported hatcheries. To sustain these improvements, continued investment in hatchery expansion and rigorous quality monitoring are necessary to ensure a reliable supply of superior fingerlings. Moreover, strengthening input supply chains and enhancing extension support remain key priorities for improving farm management practices. Munthali et al. (2024) emphasize that well-functioning supply chains are essential for aquaculture sector growth, a recommendation that is equally applicable to Zambia. By maintaining and expanding these support systems, small-scale farmers can achieve greater productivity and long-term sustainability in the sector.

### 4.6.2 Digital marketing and cooperative networks

Notably, many farmers were unaware of the potential benefits of digital marketing platforms despite its growing significance in post-COVID-19 aquaculture markets (Siankwilimba et al., 2022, 2023). This contrasts with the findings from Omambala in Anambra State, Nigeria, where Nwoye et al. (2024) note that digital marketing tools can enhance visibility and market access, though they are underutilized due to factors such as lack of awareness, high technology costs, and insufficient knowledge. The above studies highlight the potential benefits of digital platforms for smallholder farmers if accompanied by appropriate training and infrastructure support, with the key difference being the level of digital literacy and infrastructure development. Additionally, both studies emphasize the importance of cooperative networks in improving market access, pooling resources, and ensuring financial stability. As Siankwilimba et al. (2023, 2024) demonstrate, collective action enhances bargaining power, facilitates knowledge exchange, and strengthens resilience. Importantly, cooperative networks can also serve as a conduit for digital marketing adoption by organizing training sessions, spreading awareness of digital tools, and lowering individual costs through shared access to technology.

Fostering cooperative structures can, therefore, improve access to credit, logistics, and emerging market opportunities while bridging the gap in digital marketing adoption.

In summary, government-funded small-scale cage aquaculture in Siavonga offers a promising pathway for enhancing climate resilience and improving rural livelihoods, especially in the face of recurring droughts and water scarcity affecting conventional aquaculture systems. However, realizing its full potential requires a balanced approach that prioritizes environmental stewardship, technical support, and policy enforcement. By addressing current challenges and safeguarding lake ecosystems from eutrophication risks (Hasimuna et al., 2019; Phiri et al., 2025), Zambia can sustainably scale up cage aquaculture as a climate-adaptive solution for the future of its fisheries sector.

## 4.7 Sustainable production and policy recommendations

To enhance the sustainability and profitability of small-scale cage aquaculture, several strategic interventions are recommended:

**Aligning fish harvests with seasonal fishing bans**: Implementing policies that incentivize fish harvesting during closed fishing seasons can enhance market stability while reducing pressure on wild fish stocks, contributing to long-term resource conservation.

**Promoting local feed production**: Reducing reliance on imported feed through investment in local feed production can significantly lower production costs and improve profit margins for farmers, making aquaculture more economically viable.

**Strengthening extension services and research**: Increased investment in extension services and research-driven innovations is essential to improve farmer knowledge, optimize production techniques, and enhance disease management strategies.

**Enhancing access to financial and technical support**: Expanding financial assistance programs and improving access to affordable credit will enable small-scale farmers to invest in better infrastructure, increasing productivity and resilience.

**Integrating climate resilience strategies**: Encouraging adaptive strategies, such as improved cage designs and water quality monitoring, can help mitigate the risks posed by climate variability and environmental changes.

By addressing these structural challenges, government-funded aquaculture programs can maximize their long-term impact, ensuring both economic resilience and ecological sustainability.

### 4.8 Limitations

When interpreting the results of this study, several limitations should be considered:

1 **Sample size**: The relatively small sample size may not fully capture the variability in aquaculture practices across different regions, potentially limiting the generalizability of the findings.
2 **Temporal scope**: This study primarily focuses on short-term and medium-term impacts, leaving uncertainties regarding the long-term sustainability and profitability of government-supported cage fish farming.
3 **Self-reported data**: Reliance on self-reported data for income, challenges, and operational changes introduces potential biases or inaccuracies, as participants may misreport or recall information inaccurately.
4 **Comparative analysis**: The absence of a comparative analysis between government-supported and non-supported farmers makes it challenging to isolate the true impact of financial assistance on aquaculture practices and outcomes.

These limitations underscore the need for further research to provide a more comprehensive understanding of the sector's sustainability and its broader economic effects.

## 5 Conclusion and recommendations

The government-funded small-scale cage fish farming initiative in Siavonga demonstrates significant potential to reduce Zambia's fish deficit, enhance food security, and stimulate rural economic growth. However, its effectiveness is constrained by persistent challenges including theft, predation, inadequate transport infrastructure, currency volatility, and gender disparities. Addressing these barriers calls for strengthened security systems, improved logistical networks, targeted financial education, gender-inclusive programming, and enhanced digital literacy and marketing skills among farmers. This study offers practical insights into optimizing public aquaculture investments to foster inclusive and climate-resilient aquatic food systems. Future research should explore the environmental sustainability of cage aquaculture, assess the effectiveness of extension services, and examine the scalability and impact of similar government-led initiatives. Furthermore, studies involving pond-based systems can provide a more comprehensive understanding of the broader aquaculture landscape in Zambia.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the patients/participants or patients/participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

## Author contributions

OH: Conceptualization, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. JM: Conceptualization, Data curation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. ML: Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Writing – original draft. SS: Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. HB: Data curation, Formal analysis, Software, Validation, Writing – review & editing. IN: Data curation, Validation, Visualization, Writing – review & editing. MMu: Resources, Validation, Visualization, Writing – review & editing. IB: Validation, Visualization, Writing – review & editing. ES: Methodology, Validation, Visualization, Writing – review & editing. IO: Validation, Visualization, Writing – review & editing. AJ: Data curation, Funding acquisition, Validation, Writing – review & editing. FM: Data curation, Funding acquisition, Validation, Writing – review & editing. EO: Data curation, Formal analysis, Software, Validation, Visualization, Writing – original draft. MMw: Data curation, Formal analysis, Software, Writing – review & editing. MC: Data curation, Resources, Validation, Visualization, Writing – review & editing.

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## Conflict of interest

IB was employed by IBAN Aquafish Solutions and Consultancy Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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