ASSESSMENT OF BIOSECURITY COMPLIANCE RATE AND FISH HEALTH MANAGEMENT PRACTICES OF FARMED FISH IN MALAWI

Yamikani Balaka
Department of Fisheries, Senga Bay Fisheries Research Centre,
P.O Box 316, Salima, Malawi.
yamebalakah@gmail.com

Supervisors:

Amanda Vang: amanda@firum.fo
Árni Kristmundsson: arnik@hi.is

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ABSTRACT

This study aimed to assess the biosecurity and fish health management practices of fish farms in Malawi to prevent the transmission of diseases both within and between farms. The study evaluated biosecurity compliance and adoption rate by investigating 61 fish farms in Malawi's northern and southern regions. The results revealed poor compliance with the biosecurity measures, with an overall average rate of 48.5%. Similarly, the adoption rate of biosecurity measures was unsatisfactory, with an overall average of 43%. Based on the compliance rate scale used in this study, 62.3% of the audited farms were in the category of poor compliance level, 36.07% were in the intermediate category, and only 1.64% were categorised as having good compliance with aquaculture biosecurity measures. The compliance rate differed across districts, with significant differences between Rumphi and Zomba ($p=0.026<0.05$). This study suggests that a substantial proportion of fish farmers in Malawi tend to respond to disease outbreaks in a reactive manner, which means that they only take action once the problem has surfaced. This approach is not proactive, and may lead to suboptimal disease prevention and control outcomes. The study also found that most fish farmers (73.77%) sourced their fingerlings from uncertified sources, such as fellow farmers, and did not quarantine new fish stocks. Furthermore, most fish farms do not have their own fish harvesting nets, suggesting that they share harvesting nets across different farms, facilitating the spread of fish diseases. Categorical principal component analysis (CATPCA) identified two critical dimensions, with dimension 1 explaining approximately 97.913% data variance. After a thorough review of all biosecurity factors considered in this study, it was revealed that the biosecurity measures that pose a great risk in the studied areas were associated with the source and movement of fingerlings (seed), sharing of materials such as harvesting nets, improper disposal of dead fish, transport vehicles, and persons either visiting farms or working on the farm. To prevent the spread of disease and protect fish health, fish farms in Malawi must increase their efforts to implement effective biosecurity measures. This will require collaborative effort between fish farms, government agencies, and other stakeholders to promote and enforce best practices in biosecurity measures. This study recommends training and education, collaboration and sharing of information, regular audits and feedback, enhancement of regulatory frameworks, and monitoring and surveillance of stakeholders in the fish farming industry in Malawi.

Keywords: Aquaculture, biosecurity compliance, fish health management, disease prevention, Malawi.

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1 INTRODUCTION

1.1 Background

Aquaculture, also known as aquafarming, involves the production of fish and other aquatic organisms under controlled conditions. The global aquaculture sector has recently grown tremendously with the increasing demand for aquatic products to feed the ever-increasing human population. With this, aquaculture is seen as an alternative to cope with food demand, as it relieves the pressure on capture fisheries (Zornu *et al*., 2023). It plays a crucial role in achieving various objectives such as food security, employment, and economic growth in different regions worldwide (FAO, 2018a). Consequently, the industry directly contributes to achieving several United Nations 2030 Sustainable Development Goals (SDGs), including SDG1 (ending poverty), SDG2 (ending hunger), SDG3 (ensuring healthy lives), SDG13 (taking action against climate change), and SDG14 (sustainable use and protection of life underwater).

Aquaculture is becoming an increasingly important sector in Malawi, contributing significantly to food security, economic growth, and poverty reduction. The potential of aquaculture has been acknowledged in other parts of sub-Saharan Africa, where the average annual growth rate of farmed fish production was 21% between 2004 and 2014 (Belton *et al*., 2018). Malawi boasts of a wide range of freshwater resources, including Lake Malawi and several rivers, providing excellent aquaculture development opportunities. The country's aquaculture industry focuses mainly on pond culture, utilising both earthen and concrete ponds (Munthali *et al*., 2022). The main species currently under culture for both small and large-scale aquaculture operations in Malawi are tilapia species, namely chilinguni (*Coptodon rendalli*), makumba (*Oreochromis shiranus*), chambo (*Oreochromis karongae*), and catfish, mlamba (*Clarias gariepinus*). Currently, there are 15,465 fish farmers, with 10,007 fishponds covering an area of 251.59 hectares. The production output of aquaculture in Malawi has been steadily increasing over the years, from 812 tons in 2005 to 9,948 tons in 2021 (Munthali et al., 2022; Government of Malawi, 2021a). Between 2001 and 2019, production increased by an average of 54% per annum, with almost 90% of the output comprising of tilapia (Government of Malawi, 2021a). As discussed in the following paragraph, several factors have contributed to this growth in aquaculture production.

Aquaculture development in Malawi has seen changes in its organizational structure, administration, and regulatory instruments. The formulation of the National Fisheries and Aquaculture Policy of 2001 and the National Aquaculture Strategic Plan of 2006 provided a clear environment for boosting the fisheries and aquaculture sectors. These two policy documents guided the delivery of aquaculture extension, research services, and operationalisation of the National Aquaculture Research Centre, with a central role in the production of good quality fingerlings (Government of Malawi, 2021a; Government of Malawi, 2016). These efforts were later augmented by the implementation of the Agricultural Technological Transfer Project, which promoted the mono-sex culture of tilapia, deeper pond technology, and the provision of inputs to fish farmers (Munthali *et al*., 2022; Government of

Malawi, 2021a; Donda & Zidana, 2015). In addition, public-private partnerships have been adopted and implemented in aquaculture, providing an environment for the private sector to participate fully by supporting the training of fish farmers, providing resources for pond construction, and sourcing fingerlings (Government of Malawi, 2016). Despite poor hatchery infrastructure, there has been a steady production of fingerlings amounting to 11 million from both government research centres and the private sector (Government of Malawi, 2021a). This has led to a positive increase in aquaculture production (Figure 1).

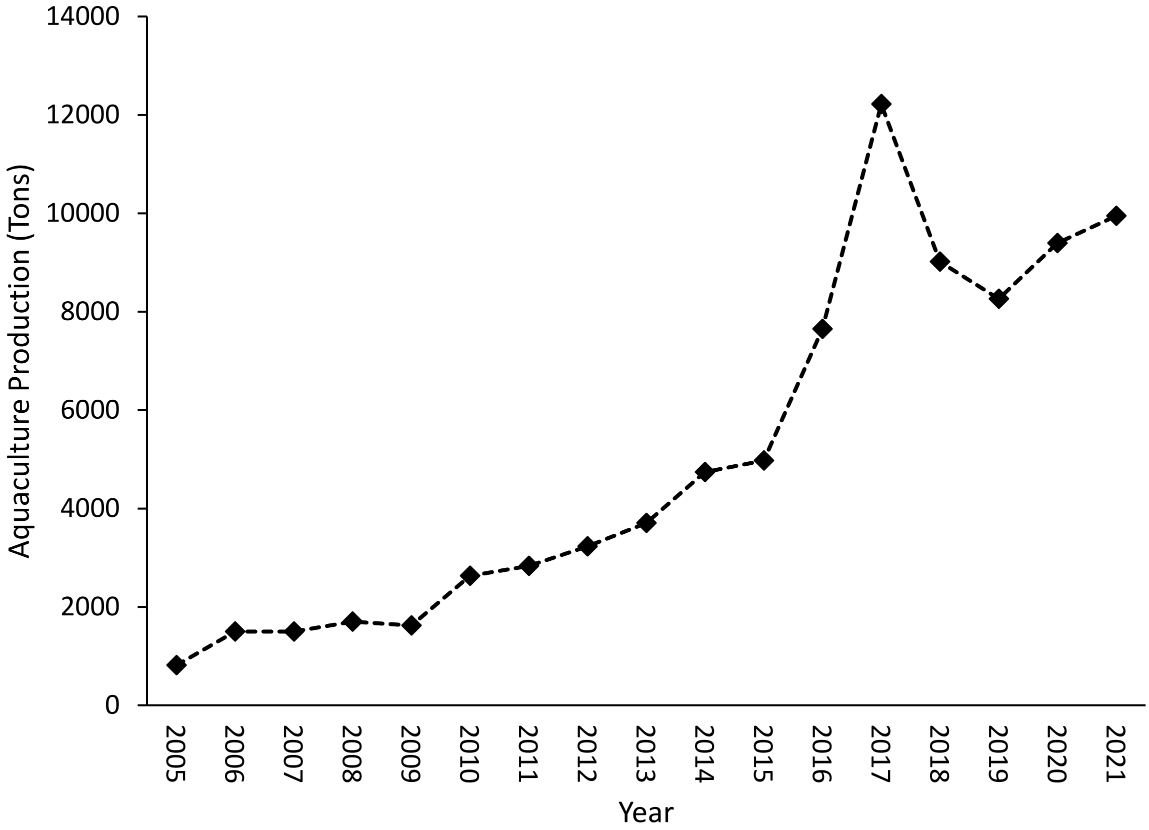

Figure 1. Aquaculture production in Malawi, Source: FishStatJ2023.

Despite this positive increase in aquaculture production, the industry in Malawi is facing a serious threat from a severe fish disease called Epizootic Ulcerative Syndrome (EUS). This disease is caused by a fungus known as *Aphanomyces invadans*, which causes red spots, lesions, or ulcers on the skin of fish (FAO, 2009). The first outbreak in Malawi was reported in 2020 in the Mchinji district bordering Zambia (FAO, 2020). The disease has high morbidity and mortality rates, which lead to significant losses in farmed fish. Munthali M. (2021) reported that the EUS outbreak will undoubtedly cause mass mortality, severely impacting the production of susceptible species, including catfish, tilapia, and straight-fin barb. Inevitably, these species will disappear from the market in many areas (The Chronicles, 2020), inflicting huge economic losses on the country and affecting efforts to improve food and nutritional security. If not adequately managed, fish disease outbreaks in Malawi will affect the implementation and attainment of the second National Aquaculture Strategic Plan (NASPII), which seeks to enhance production and productivity from aquaculture to increase household income, national economic growth, and regional trade. As the FAO (2019) suggested, controlling diseases and parasites is crucial in aquaculture to ensure the health and welfare of farmed organisms. In response to the outbreak of EUS in Malawi, the government has implemented several measures to contain the disease and protect the fish population and aquaculture industry. During the first outbreak, the government temporarily suspended the transportation and sale of live or dead fish in and around the infected areas and fish farms. Additionally, fishing in infected rivers and dams was suspended to prevent the further spread of the disease. Farmers were advised to avoid sharing fish-harvesting nets, as this can also contribute to the spread of the disease. Furthermore, communities were advised to avoid using water from infected rivers for fish culture. Moreover, the government took the initiative to sensitise communities to the signs and symptoms of the disease and how to prevent its spread. This education is crucial for preventing further outbreaks and ensuring the safety of fish populations and the aquaculture industry. Despite the different measures taken by the Government of Malawi to contain the disease, urgent and decisive action is imperative to safeguard the fish population and the thriving aquaculture industry from this deadly pathogen and other potential outbreaks.

1.2 Rationale

Despite its benefits, aquaculture also presents challenges such as disease management, environmental impact, and water pollution due to farming activities. Controlling diseases and parasites is crucial in aquaculture to ensure the health and welfare of the farmed organisms. In Malawi, there is a lack of established procedures and regulations regarding biosecurity in aquaculture. This means that there are no clear guidelines on how to implement preventive measures or react in the case of mass mortality events caused by infectious agents. The absence of such regulations has resulted in fish farmers being unsure about measures to mitigate the risk of infectious diseases. Furthermore, very little information is available regarding the current use of preventive measures against fish diseases in fish farms. This lack of data means that it is difficult to assess the effectiveness of the measures being implemented. The absence of established procedures and regulations for biosecurity in aquaculture is a significant challenge for the aquaculture sector in Malawi as it limits the ability of fish farmers to ensure the health and safety of their stock.

Moreover, the outbreak of EUS in Malawi has highlighted significant biosecurity risks at the farm, district, and national levels, which demands urgent attention. Zornu *et al*. (2023) noted that in many developing countries, including Malawi, inadequate or lack of fish health services stems from the perception that fish do not get sick. Addressing these misconceptions can ensure a safer and healthier environment for all fish species, leading to a more sustainable and prosperous aquaculture industry. Assefa and Abunna (2018) indicated that biosecurity measures are critical in preventing the entry of pathogens into farms. By investigating current biosecurity behaviours ‘locally,’ it is possible for regionally appropriate research to be undertaken or targeted education programs to be carried out, hence increasing the effectiveness of disease control and surveillance in the area.

The current project is the first small-scale aquaculture survey dealing with biosecurity measures in the two regions of Malawi. The results will help us understand how fish disease-preventive tools are being used and identify gaps to optimise their use. This project is of great importance, as it has the potential to significantly impact the aquaculture industry in Malawi. By gathering reliable data on biosecurity and fish health management practices, this project will assist the government and stakeholders in developing effective strategies for managing fish diseases in Malawi. This will result in better decision making and ultimately lead to an overall improvement in the health of farmed fish.

1.3 Research Objectives

1.3.1 Overall Objective

The main aim of this study was to comprehensively evaluate biosecurity and fish health management practices undertaken by fish farmers in Malawi to prevent disease transmission within and between farms. This study will elucidate essential ideas in aquatic disease management and provide practical insights to farmers, investors, and regulators in defining best practices, protocols, and mitigation methods to successfully manage existing and potential fish disease outbreaks.

1.3.2 Specific Objectives

The specific objectives of this study are as follows:

1. To assess farm-level biosecurity adoption rate across fish farms in Malawi
2. To evaluate the biosecurity compliance rate of fish farms in Malawi
3. To provide practical recommendations on biosecurity management measures for Malawi’s aquaculture industry.

2 LITERATURE REVIEW

2.1 Fish Disease Outbreaks in Farmed Fish

One of the biggest problems facing the aquaculture industry is disease outbreak. Globally, losses caused by fish diseases in the aquaculture industry are estimated by the FAO at approximately US$6 billion annually. The Infectious Salmon Anaemia (ISA) outbreak in the Chilean salmon-farming industry cost US$2 billion and 20,000 jobs (World Bank Group, 2014). Similarly, Brazil has reported a loss of up to US $ 84 million annually for approximately 16,100 fish farms (Tavares-Dias & Martins, 2017). Fish diseases have caused severe economic losses in fin fish aquaculture worldwide (FAO, 2020; Tavares-Dias & Martins, 2017; Verner-Jeffreys *et al*., 2018). Most aquaculture disease outbreaks have occurred in developing countries, where over 90 percent of aquaculture occurs, reducing revenues, eliminating jobs, threatening food security, and undermining development goals (World Bank Group, 2014). In Egypt and Ghana, there is evidence that fish diseases cause significant harm to the commercial aquaculture sector and broader value chain. Since 2010, Egyptian fish farmers have experienced considerable losses annually between March and September (Leschen & Immink, 2023). In 2015, 37% of fish farms were affected, resulting in an average mortality rate of 9.2% and an estimated loss of approximately US$100 million (Fathi *et al*., 2017). In Ghana, the private sector has suffered losses of over US$100 million due to large-scale tilapia deaths since 2016 (Verner-Jeffreys *et al*., 2018).

Epizootic ulcerative syndrome (EUS) (Figure 2) is a fish disease that affects African countries. The spread of EUS across Asia from Japan and Australia, where it was first identified in the early 1970s, Pakistan in 1996, and southern Africa in 2006, is a significant epizootiological phenomenon (FAO, 2009), demonstrating the significance of fish disease health management. According to FAO (2020), in Africa, EUS has spread from one nation to another in the following chronological order: Botswana (2007, 2010, 2020), Namibia (2007), Zambia (2008, 2014), Zimbabwe (2016), South Africa (2011; 2014; 2015; 2016; 2017), Democratic Republic of Congo (2015), and Malawi (2020).

Figure 2. Mlamba (*Clarius gariepinus*) infected with Epizootic Ulcerative Syndrome.

In Malawi, various fish diseases have been reported, including some that are not as fatal as the epizootic ulcerative syndrome. Cotton Wool disease (Flavobacterium columnare) is a documented bacterial infection. This type of infection mainly occurs because of stress caused by handling, particularly during fish transportation in hatcheries. It is characterised by white cottony growth on the fish skin and fins, eventually leading to death. Another disease, saprolegniosis, which is detected in farmed indigenous tilapias and catfish in ponds throughout the country, is caused by the fungal *Saprolegnia* species. These infections are more prevalent in the hatchery sector, where fish are cultured at high densities. The fungus, which is defined as an opportunistic pathogen, attacks the fish's weakened immune system owing to poor water quality and causes white cottony growth on the fish's body. If left untreated, the infection spreads, eventually leading to death.

Aquaculture in poor countries, such as Malawi, is typically small-scale and rural, which means that most diseases go undetected, untreated, and unrecorded. This places a heavy cost on communities trying to break free from poverty (World Bank, 2014). Hence, as fish farming continues to become more prevalent in the region, it is essential to address critical issues such as research gaps in the diagnostics of fish diseases, potential impacts of pathogens, and the need for an effective management framework for fish diseases. According to Racicot and Vaillancourt (2009), the primary cause of disease transmission and dissemination in fish farms is failure to adhere to hygiene and biosecurity protocols.

2.2 Fish Disease Biosecurity Measures

Aquaculture biosecurity includes controlling the spread of aquatic plant and animal diseases, invasive pests, and the production of products that are safe for consumption (FAO, 2007; Phu *et al*., 2016; OIE, 2018). The Aquatic Animal Health Code published by the OIE defines aquaculture biosecurity as a set of management and physical measures that are implemented to minimise the risk of introduction, establishment, and spread of pathogens into and out of an aquatic animal population (OIE, 2018). This broad definition recognises that a disease is a complex interaction between the host, disease-causing agent, and environment, as shown in Figure 3. As noted by Georges *et al*. (2023), biosecurity is an important tool for reducing the risk of diseases entering a farm, and suitable biosecurity practices can prevent emerging health issues, reduce the impact of disease, and improve the sustainability and profitability of production.

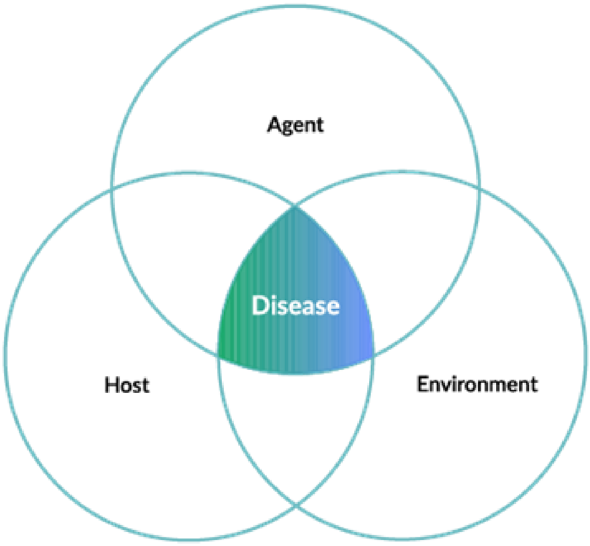

Figure 3. Interaction of host, agent (pathogen), and environment with disease outbreaks.

The outcome of an infection and the ability of a pathogen to spread within a population depend on several complex factors, which can be categorised into three main groups: pathogen-related, host-related, and environment-related (Figure 3). Pathogen characteristics that play a role in disease transmission include virulence, survival in the environment, species specificity, ability to persist in the host, and the strength and duration of the induced immune response following infection (Dewulf & Van Immerseel, 2018). Generally, pathogens with a broad host range are more difficult to control than are species-specific pathogens. This is particularly true for the causative agent of epizootic ulcerative syndrome (*Aphanomyces invadans*), because it can cause infections in different fish species (FAO, 2020).

Host-related factors include immune response, genetic background, host behaviour, and availability of susceptible hosts. Environment-related factors include climate, geography, and anthropomorphic activities, which influence the availability of vectors and hosts. Pathogens are highly adaptive and can evolve quickly in response to changing environmental conditions. Consequently, the established transmission patterns may not remain constant, and new transmission routes may emerge. Anthropomorphic activities such as deforestation, urbanisation, and global travel can significantly impact the spread of pathogens by altering the availability of susceptible hosts and vectors and the climatic and geographic conditions that favour pathogen transmission (Dewulf & Van Immerseel, 2018).

Thus, the effective management of disease risks in fish farms necessitates a complete understanding of all aspects that may influence the application of biosecurity measures. Although managing aquatic animal health and biosecurity governance can be challenging due to the diverse nature of the aquaculture industry (Ye, 2020), it presents an opportunity for continuous learning and improvement. Traditionally, fish health management has focused on a disease reaction approach (pathogen-disease-diagnosis-treatment), whereas currently, it is recognised that it should focus on a more integrated system approach, where surveillance, biosecurity, risk assessment, prevention, and welfare are key aspects that should be included (World Bank Group, 2014; Bernoth, 2008). As "prevention is better than treatment", it is advisable to focus on preventing the occurrence of disease rather than treating it (Romero *et al*., 2012; Dewulf & Van Immerseel, 2018), and this can only be achieved with suitable disease biosecurity measures and sound fish health management practices.

Biosecurity measures can be grouped into external and internal (Alarcón *et al*., 2021). External biosecurity, or bio-exclusion, comprises all measures adopted to prevent the introduction and spread of infectious agents from one farm to another (biocontainment). These measures are related to actions in which there is contact between the farm and the surrounding environment. On the other hand, internal biosecurity or bio-management includes all measures endorsed to prevent the spread of infectious agents within the farm (e.g., from one category or production group to another). In contrast to external biosecurity measures, which apply to both exotic and endemic diseases, internal biosecurity measures focus more on controlling endemic infectious diseases (Dewulf & Van Immerseel, 2018). Farm-level biosecurity measures involve the application of a combination of activities, including strict quarantine measures, sanitation of equipment, disinfection of eggs, traffic control, water treatment, use of clean feed, and disposal of dead fish (Assefa & Abunna, 2018). These measures are of utmost importance in aquaculture to prevent the introduction and spread of diseases, parasites, and other biological threats that can have catastrophic impacts on both aquatic organisms and the industry as a whole. Some of the critical fish disease biosecurity measures commonly applied at the farm level are discussed below.

2.2.1 Quarantine and health screening

To maintain the health of aquatic animals in aquaculture facilities, it is crucial to implement stringent quarantine protocols for all incoming animals. When newly acquired fish or other aquaculture species arrive, it is essential to isolate them and conduct thorough health screenings before introducing them into existing populations (Arthur *et al*., 2008). The quarantine period should be sufficiently long to allow for the detection of any potential diseases or infections that the animals may be carrying. During this period, diagnostic testing, visual observations, and health assessments should be conducted to ensure that the animals are healthy and disease-free (Dewulf & Van Immerseel, 2018). Diagnostic testing involves the use of various laboratory techniques to identify pathogens in animals (Assefa & Abunna, 2018). Visual observations involve examining animals for macroscopic signs of illness or abnormalities, such as unusual behaviour, lesions, or discoloration. Health assessments are conducted by qualified personnel, who evaluate the animals' overall health and assess their risk of transmitting diseases to other animals in the facility. By implementing a strict quarantine protocol and conducting thorough health screenings, aquaculture facilities can prevent the introduction of diseases into their populations, which can save considerable money and effort in the long run.

2.2.2 Stock Sourcing and Certification

It is crucial to work with reputable suppliers and certified hatcheries when sourcing fish and other aquatic organisms. These sources must adhere to strict health management protocols to minimise the risk of introducing pathogens into aquaculture systems. This is essential because pathogens can cause significant harm to animals and the environment, resulting in economic loss. By sourcing from trusted suppliers and certified hatcheries, you can ensure that the animals you introduce to your farm are of known health status and pose minimal risks of disease. This means that the need for antibiotics and other treatments that may harm the animals and the environment can be reduced. Moreover, it can help maintain the quality and safety of products, which is essential for building a loyal customer base.

2.2.3 Biosecurity Barriers and Restricted Access

Biosecurity measures are essential to maintain a healthy and safe environment in aquaculture facilities. Physical barriers and restricted access are effective measures that can be implemented to control the movement of people, equipment, and vehicles in and out of the facility. Foot baths are physical barriers that can be used to prevent the spread of diseases. These shallow containers are filled with disinfectants that people must use to clean their feet before entering the facility. This helps to reduce the risk of introducing pathogens into the facility on the soles of shoes. Controlled entry points are another measure that can also be used to restrict access to facilities. These are designated entry and exit points where people must check in and out of the facility. This helps to keep track of who is entering and leaving the facility, and can be helpful in the event of a disease outbreak. In addition to physical barriers, specific clothing and equipment protocols can be implemented to prevent the introduction of contaminants and pathogens into facilities. This can include wearing facility-specific clothing and using sterilised or disinfected equipment before use.

2.2.4 Animal Health Monitoring

Maintaining the health of aquatic animals is of utmost importance to farmers in the aquaculture industry. Regular monitoring of animal health can help detect diseases early, which is critical for preventing further spread of the disease within the aquaculture system (Dewulf & Van Immerseel, 2018). Visual inspection is an essential component of animal health monitoring as it can help identify any physical symptoms or abnormalities in animals. Health assessments are also conducted to evaluate the overall health of the animals, which can provide insights into their susceptibility to diseases. Diagnostic tools such as blood tests or genetic testing (PCR) can also be used to identify specific diseases or genetic predispositions in farmed species. By conducting regular health monitoring, farmers can take preventative measures and implement appropriate treatment protocols to ensure that their livestock remains healthy and disease-free.

This not only benefits the welfare of animals, but also helps to ensure the long-term sustainability of the aquaculture industry.

2.2.5 Record-Keeping and Traceability

Maintaining comprehensive and detailed records of stock movements, health status, treatments, and biosecurity practices is essential to ensure traceability and effective disease management in livestock operations. Accurate record-keeping can help identify potential sources of disease and track the spread of infections, which is critical in preventing and controlling disease outbreaks. For instance, keeping track of when and where animals move within the operation, as well as their health status and any treatments they receive, can help to identify the source of a disease outbreak and prevent its further spread. By maintaining complete and up-to-date records, animal health professionals can quickly trace the movement of potentially infected animals and take appropriate measures to contain the spread of the disease before it becomes a significant problem. Furthermore, maintaining detailed records of biosecurity practices is essential for reducing the risk of disease transmission within the operation. Recording details such as cleaning and disinfection schedules, visitor logs, and quarantine protocols can help identify potential weaknesses in biosecurity programs and enable corrective measures to be taken promptly.

2.2.6 Fallowing

Fallowing is a strategy used in aquaculture to maintain a healthy and balanced environment for fish farming. This involves leaving a fish farming area free of fish for a certain period of time, typically ranging from a few weeks to several months or even longer (United States Government, 2008). During this period, the absence of fish allows the environment to recover from the effects of fish farming and restore its natural balance. Fallowing is an effective biosecurity strategy that helps reduce the risk of disease outbreaks among fish populations (New Zealand Government, 2016). The absence of fish during the fallowing period allows for the removal of pathogens and parasites from the environment, reducing the likelihood of transmission to subsequent fish populations. The duration of the fallowing period depends on several factors, such as the specific farming system, environmental conditions, and the type of fish being farmed. Fallowing is a critical component of a comprehensive biosecurity plan, as it helps maintain the health of fish populations and minimise the use of antibiotics and other treatments. This is an essential practice for sustainable aquaculture and ensures the long-term viability of fish farming as a food source.

The increase in production also means an increased density of fish in culturing units, thereby predisposing fish to harsh environments, such as poor water quality and opportunistic infections. Compared to other countries, such as Norway, Iceland, and the Faroe Islands, the aquaculture industry in Africa has not received sufficient support for its growth. Specifically, there has been a lack of measures to address disease surveillance, control, and prevention, as well as quality feed provision, water quality analysis, and management practices (Kyule-Muendo, *et al*., 2022). This has made the African regions more susceptible to fish disease outbreaks. By being proactive and implementing effective biosecurity measures, we can prevent pathogens from entering the aquatic environment, thereby saving time and money in the long run.

2.3 Biosecurity Strategies/ Regulations for Aquatic Animal Health

The World Organisation for Animal Health, formerly known as the Office International des Épizooties (OIE), was established in 1924 to enhance animal health globally (FAO, 2018). As the competent authority for aquatic animal health, it seeks to prevent the importation of dangerous pathogens that are zoonotic in nature through trade by regularly publishing international standards and guidelines. In addition, OIE aims to strengthen veterinary services worldwide to improve surveillance and response capabilities. In Malawi, the Department of Livestock and Animal Health is the competent authority for managing animal health. However, there is a lack of capacity in the area of aquatic animal health, which results in fish diseases and aquatic animal health issues not being adequately addressed in the National Fisheries and Aquaculture Policy of 2016-2021 and the National Livestock Development Policy of 2021-2026. Moreover, most veterinarians in Malawi are not trained in aquatic animal health, which further exacerbates this issue.

Despite participating in different workshops organised by the Food and Agriculture Organization (FAO) since 2008 on the Development of an Aquatic Biosecurity Framework for Southern Africa, Malawi has yet to develop its own National Aquatic Animal Biosecurity strategy (FAO, 2018). Therefore, there is a pressing need for Malawi to develop its own strategy for aquatic animal health management to ensure that fish diseases and aquatic animal health issues are adequately addressed.

The current Malawi National Fisheries and Aquaculture Policy for 2016-2021 lacks comprehensive strategies for managing fish diseases in the country. Hence, the proposed project will also, to a higher extent, contribute to the development of a National Biosecurity Strategy for Aquatic Animal Health. This strategy would help in the management of fish diseases in Malawi, as highlighted in the policy analysis by Munthali (2021) which noted the absence of a National Biosecurity strategy for Aquatic Animal Health and a National Aquatic Animal Health Plan (NAAHP) as a significant challenge in the country's efforts to handle fish disease outbreaks.

This study aimed to obtain an overview of farm and fish health management, biosecurity measures, and health monitoring of farmed fish in Malawi. The data obtained will be used to conduct a descriptive analysis of the current situation and to provide practical recommendations on biosecurity management measures for Malawi’s aquaculture industry. By adopting a data-driven approach to biosecurity and fish health management, we can make informed decisions that will help protect the health of our fish populations and maintain the highest possible levels of biosecurity.

3 METHODOLOGY

This section provides details on the study area, study design, data collection tools, and data analysis.

3.1 Study Area

Malawi is divided into three administrative regions, namely, the Northern, Central, and Southern (Figure 4). Owing to logistical issues, the study covered two regions (Northern and Southern), targeting one district in each region. The districts were selected considering that these districts were the epicentres of the Epizootic Ulcerative Syndrome fish disease in Malawi. The selected districts included Rumphi in the Northern region and Zomba in the Southern region (Figure 4). Furthermore, the studied districts have high potential for aquaculture production in Malawi.

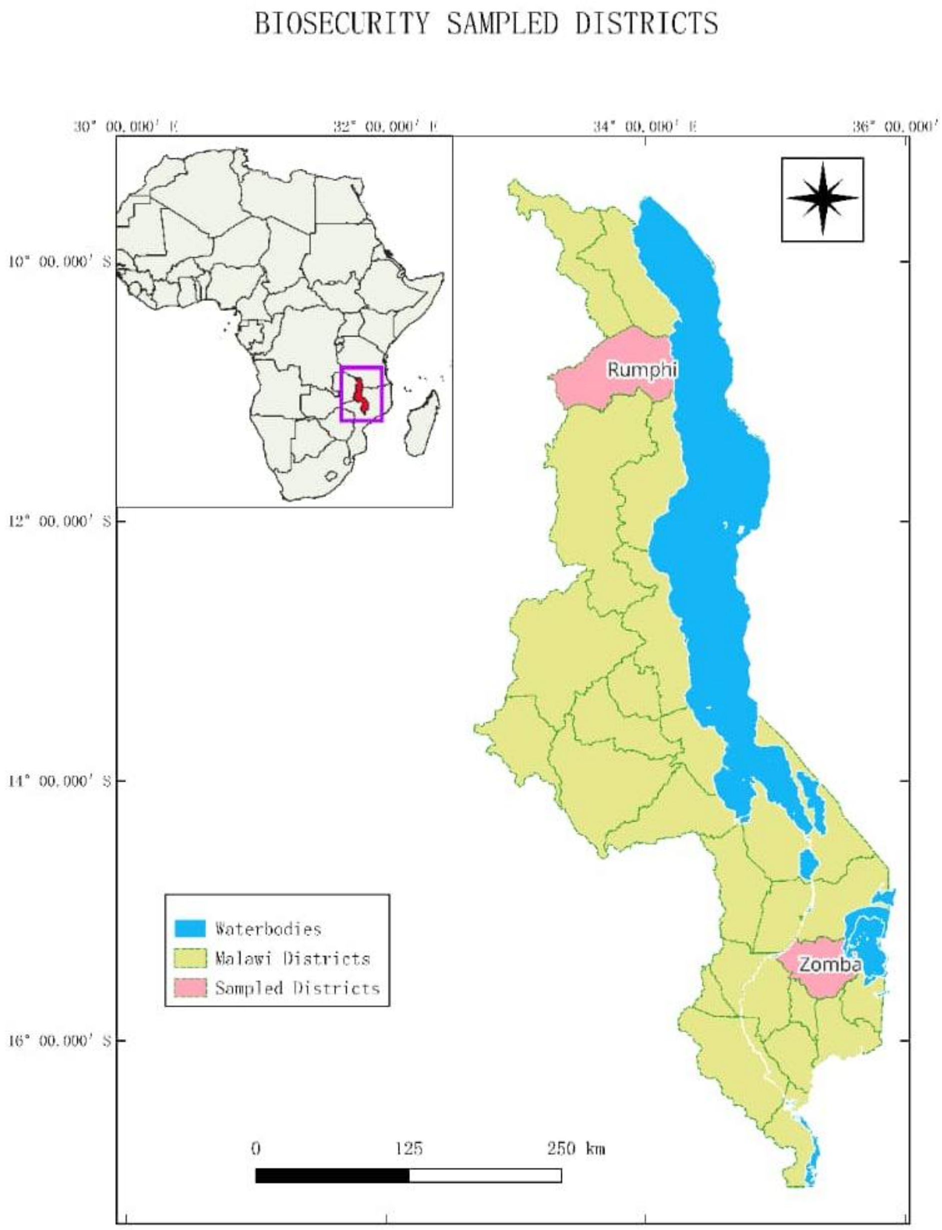

Figure 4. Map of Malawi showing locations of surveyed districts.

3.2 Data Collection Tools

The tools used in the current study included a questionnaire and a desk analysis. A semi-structured questionnaire was used for data collection using the Kobocollect mobile application data collection software. Pre-testing was conducted before starting the fieldwork to ensure the effectiveness of the questionnaire. The investigators pretested a small sample of fish farmers to gauge how well the survey questions were designed and whether they were understandable and relevant to the target audience. Adjustments were made to the questionnaire based on the feedback received during pretesting. Some words were replaced to make them clearer and more concise, irrelevant questions were deleted to avoid confusion and to make the questionnaire more focused, and some questions were reformulated and split to make them easier to answer and provide more detailed and accurate information. Adjustments made to the questionnaire were important to ensure that the survey results were reliable and relevant to the research objectives. The pretesting process helped identify potential issues and allowed for necessary improvements before the questionnaire was used in the main study.

The questionnaire included 112 questions and was divided into six sections: a) farm description, b) production statistics, c) water source and treatment, d) knowledge of disease management and biosecurity measures, e) practices of disease management and biosecurity measures, and f) fish health monitoring and management. The questions associated with farm characteristics consisted of farm type, farm size, fish species, farm capacity, production cycle, and stocking density. Second, a desk study was conducted to review the published and unpublished literature on fish diseases and biosecurity. During the desk study, documents such as government reports, fish disease biosecurity strategies and regulations, and journal articles on fish diseases and health management were reviewed.

3.3 Study Design and Sampling

A cross-sectional survey targeting small-scale aquaculture farms was conducted in two districts in Malawi. The lists of fish farmers were obtained from the respective District Fisheries offices. A one-to-one interview method was used to collect the desired data. No compensation was paid for the responses. To estimate the statistical sample size, the following formula was used to select the number of fish farmers (n).

$$n = \frac{N}{1+N*e^2} \qquad (1)$$

Where N is the total number of fish farmers in the district and e is the desired margin of error (Nguyen & Simioni, 2020). In this study, the error was fixed at 10%. Based on the statistical formula, the survey targeted a sample size of 61 fish farmers.

3.4 Data Handling and Analysis

3.4.1 Statistical Analysis

Data visualisation and analysis were conducted using Microsoft Excel and IBM Statistical Package for Social Sciences (SPSS) version 25. Numerical variables, such as stocking density and fish mortality rate, were subjected to Kruskal-Wallis and Mann-Whitney post-hoc analyses. Descriptive statistics are presented in tables, charts, and graphs. Multivariate analysis, particularly categorical principal component analysis, was performed to identify the crucial factors for biosecurity measures and fish health management.

3.4.2 Determination of Biosecurity Compliance Rate (CR) and Adoption Rate (AR)

The linear scoring or weighting system (0-1) was adopted and used to determine the biosecurity compliance rate (CR) for the implemented biosecurity measures (Georges, et al., 2023; Lestari *et al*., 2022; Dewulf & Van Immerseel, 2018). Each biosecurity measure was assigned a value of either 1 or 0 depending on whether it had been implemented. The final biosecurity measure score was calculated by adding up all the values (1 or 0) recorded for each farm.

$$CR = \frac{Number\ of\ measures\ applied\ by\ a\ farmer\ (Total\ scores\ of\ the\ farm)}{Total\ of\ recommended\ measures} * 100 \text{............. (2)}$$

The compliance rate with biosecurity measures for farmed fish refers to the extent to which specific biosecurity protocols and guidelines are followed and adhered to by individual fish farms (Dewulf & Van Immerseel, 2018). It assesses the degree to which farms are in alignment with established biosecurity regulations and standards. Fish farms were classified into Poor (0-50%), Intermediate (51-75%), and Good (76-100%) categories based on the modified compliance rate ranking (Table 1) proposed by Racicot and Vaillancourt (2009). Following the same principle, the biosecurity measure adoption rate was calculated as shown in Equation 3.

Biosecurity Adoption Rate

$$AR = \frac{Number\ of\ farms\ applying\ a\ biosecurity\ measure\ (Total\ score\ of\ the\ measure)}{Total\ of\ number\ of\ audited\ farms} * 100 \text{......... (3)}$$

This percentage represents the adoption rate of biosecurity measures among the studied fish farmers in the area. This provides an indication of the extent to which farms have embraced and implemented biosecurity measures as part of their operational protocols.

Table 1. Biosecurity compliance rate (CR) and adoption rate rankings.

CR	Implementation level	Biosecurity practice status	Risk Ranking
(0-50)	Low	Poor	Major
(51-75)	Intermidiate	Intermidiate	Moderate
(76-100)	High	Good	Minor

The adoption rate emphasises a broader quantitative aspect of biosecurity implementation, focusing on the prevalence and penetration of biosecurity measures within the fish farming industry as a whole. However, compliance rate emphasises the qualitative aspect of biosecurity implementation, focusing on the depth and accuracy of adherence to specific protocols within individual fish farms.

4 RESULTS

The study evaluated biosecurity compliance and adoption rates by conducting audits on 61 fish farms in the northern and southern regions of Malawi. Table 2 presents a summary of the survey resultsTable 2.

Table 2. Summary of survey results on categorical data.

Variable	**Category**	**Frequency (n)**	**(%)**
Gender of Respondent	Male	41	67.21
	Female	20	32.79
Role at Farm	Worker	3	4.918
	Owner	55	90.16
	Club Chairman	2	3.279
	Club Member	1	1.639
Level of Education	Primary school	29	47.54
	Secondary school	28	45.9
	Tertiary	3	4.918
	No formal education	1	1.639
Training in Aquaculture	Yes	48	78.69
	No	13	21.31
Farm Ownership	Family owned farm	57	93.44
	Club owned	3	4.918
	Government facility	1	1.639
The presence of other farms within 10km	Yes	56	91.8
	No	5	8.197
Water Source	Underground	40	65.57
	River	21	34.43
Treatment of farm effluent	No treatment	56	91.8
	Don’t know	5	8.197
Fish disease inspection on the farm	At least once a day	53	86.89
	Less than twice a week	5	8.197
	Once per month	3	4.918
Personnel responsible for inspection	Fisheries Worker	3	4.918
	Own farm personnel	44	72.13
	Not applicable	14	22.95
Submission of dead/dying fish for diagnosis	Yes	1	1.639
	No	49	80.33
	Not applicable	11	18.03
Source of fingerlings	Government facility	16	26.23
	Private hatchery	6	9.836
	Fellow farmers	27	44.26
	Own farm	12	19.67

4.1 Demographic Characteristics

In this study, 61 fish farms were enrolled, located in two administrative districts of Malawi-Rumphi (n=31) and Zomba district (n=30). The respondents who completed the questionnaire included farm owners (90.16%), workers responsible for general farm management (4.92%), chairmen of the fish farming club (3.28%), and 1.64% representing others, such as members of the club, secretary of the club, and treasurer. Of the participating fish farms, the majority (93.44%) were family owned, 4.92% were fish-farming clubs, and only 1.64% were government-owned. Male fish farmers were the majority of the total respondents at 67.21%, while the remaining 32.79% were females. In terms of education level, 47.54% of the respondents indicated that they had completed primary education, whereas 45.90% had education at the secondary level. Furthermore, 4.92% had attained tertiary education and only 1.64% had no formal education. The gender distribution and educational levels of the respondents are shown in Table 2. Regarding basic fish farming training, 78.69% of the respondents indicated that they had received training from government and non-governmental organisations, such as WorldFish, GIZ, and FAO, while 21.31% of respondents had no training in fish farming.

Farmers' experience has a significant impact on the success of fish farming. While exploring this relationship, the current study found that the extent of experience among respondents varied widely (Figure 5). Of all respondents, 27.87% had more than 10 years of experience in fish farming, indicating a high level of expertise in this field. Another 26.23% had between 5 and 10 years of experience, highlighting a moderate level of proficiency. Similarly, 29.51% of the respondents reported an experience of 2-5 years, showing that they had some knowledge and understanding of fish farming practices. Additionally, 14.75% of the respondents had an experience in the range of 1-2 years, which implies a relatively lower level of familiarity with fish farming practices. Finally, only 1.64% of the respondents had less than one year of experience in fish farming, indicating that they were beginning to learn about this field.

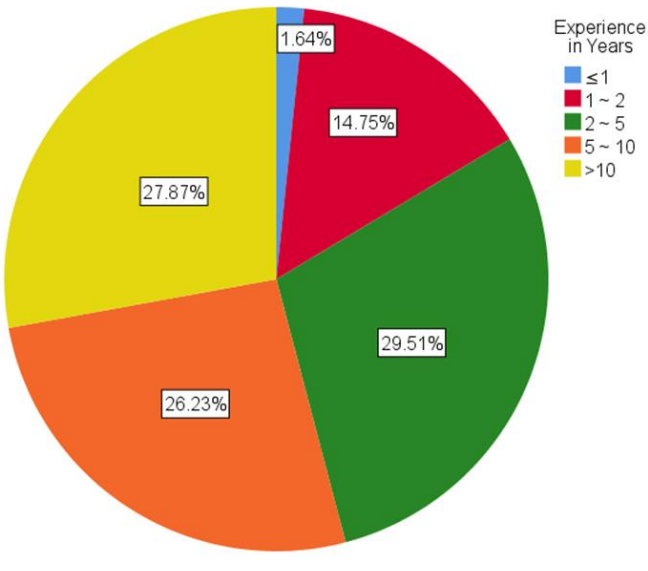

Figure 5. Experience of respondents in fish farming.

4.2 Production Statistics

Fish farming in Malawi is mainly conducted in small ponds of varying sizes and intensities. The survey results showed that *Oreochromis shiranus*, a tilapia species, was the most frequently raised fish species, accounting for 60% of all cultured fish. *Coptodon rendalli* was the second most commonly raised fish species, with a percentage of 30%, followed by *Clarius gariepinus* at 4% and *Oreochromis karongae* at 6%. The survey findings align with those of Munthali *et al*. (2022), who reported that *Oreochromis shiranus* constitutes approximately 57.2% of the cultured fish species in Malawi. This suggests that *O. shiranus* is particularly well-suited to Malawi's climate and farming conditions. The survey also examined the types of farms in operation, with 98.36% of the 61 surveyed farms being on-growing farms where fish are raised to maturity before being harvested. One farm was a government-owned fingerling production facility specialising in breeding and raising young fish for sale to on-growing farms. These findings provide valuable insights into the structure of the fish-farming industry in Malawi.

Table 3. Summary of production statistics for the surveyed fish farms.

	Number of stocked fish		**Production/Year (Kg)**		**Stocking Density (Pieces/m²)**		**Production Cycle (Months)**	
Species	Average	Std. D	Average	Std. D	Average	Std. D	Average	Std. D
Clarius gariepinus	833.33	1254.75	33.83	24.49	5.00	1.10	6.83	2.56
Oreochromis shiranus	1338.19	1320.66	78.29	166.78	4.25	1.08	7.33	1.85
Coptodon rendalli	1651.00	2040.15	102.65	271.81	4.19	1.10	7.68	2.21
Oreochromis karongae	1124.38	910.41	44.25	25.78	4.63	1.19	8.00	2.84

4.3 Water Source and Treatment

In the current survey, the primary water sources used for fish farming were permanent rivers (65.57%) and underground water (34.43%). It is worth noting that the underground water source referred to here is not a borehole. Rather, the fish ponds are intentionally dug in areas where there is a high water table and a good aquifer source. The process of locating and digging these ponds involves careful consideration of geological factors such as soil permeability to ensure that the water source is sustainable and reliable. Moreover, 70% of farmers did not treat their water before use, while 27.87% used simple sand filtration, and only the Government farm used chlorine (chemical treatment) before use. A few farmers (approximately 38 %) replenished or topped up their ponds when the water level fell below a specific level, whereas 61% did not adjust or refill the water in their fishponds during the production cycle. All audited fish farms revealed that no treatment was given to the wastewater generated by the farms, and in most cases, the effluent was dumped into surrounding farm fields.

4.4 Knowledge of Diseases Management and Biosecurity Measures

Many farmers in Malawi seem to have insufficient knowledge about the relevant authorities responsible for Aquatic Health Management. Although most respondents (98.36%) were aware of infectious diseases and 60% were aware of diseases caused by suboptimal farming conditions, 80.33% of the farmers indicated that they lacked knowledge about the local and international authorities in charge of Aquatic Health Management. The Animal Health and Livestock Department of Malawi is the primary authority responsible for animal health. However, some respondents indicated that the fisheries department is the main authority, which highlights the lack of knowledge about biosecurity and fish health management among farmers.

4.5 Fish Health Monitoring and Management.

Monitoring and inspection of fish health is a crucial management practice implemented in fish farms to ensure the health and well-being of fish. It involves regularly checking the fish for signs of poor health or disease outbreaks, allowing for early detection and timely intervention. In the current study which was conducted on 61 fish farms in Malawi, it was found that 86.89% of the farms monitored their fish at least once a day, whereas only 8.20% monitored their fish less than twice a week. A further 4.92% of the participants conducted monitoring and inspection once a month.

These findings indicate that most fish farms take fish health monitoring seriously and recognise its importance in maintaining the health of their fish. However, the survey revealed some concerning results. The majority of farms (72.13%) relied on unqualified personnel to conduct fish health monitoring (Table 2), which could lead to inaccurate assessments and inappropriate interventions. Only 4.92% of the farms surveyed involved fisheries extension officers in the monitoring process, while no veterinary officers or contracted fish health experts were involved on any farm. This lack of qualified personnel could lead to delayed detection of health issues and inadequate treatment, posing a significant risk to the fish and profitability of the farm.

Finally, the survey found that 22.95% of the respondents were unsure of who was responsible for fish health monitoring, indicating a lack of clarity in the roles and responsibilities of the farm personnel. This confusion could lead to inadequate monitoring and delayed intervention, further emphasising the need for clear guidelines and training of personnel involved in the monitoring process.

Fish inspection is crucial for maintaining the health and safety of fish farms. This involves the collection and submission of dying fish for diagnostic testing, which helps in identifying and containing the spread of fish diseases. However, the survey revealed that only government farms submit dead or dying fish for diagnostic testing. Specifically, 80.33% of respondents stated that they did not submit their dead or dying fish for diagnostic testing, while only the government farm did so at either the fisheries office or the veterinary clinic. Interestingly, about 18.03% of the respondents stated that this issue did not apply to their farms.

It is worth noting that proper disposal of dead fish is equally important to contain the spread of fish diseases. In this regard, the survey revealed that 67.21% of the audited fish farms buried dead fish off the farm, which is the recommended practice. However, 14.75% of the audited farms reported leaving dead fish in the pond as feed for other fish, which could lead to further contamination and the spread of fish disease to healthy fish populations. Additionally, 9.84% burned the dead fish, which could release harmful chemicals into the air. A total of 6.56%

reported collecting fish for discarding and use as animal feed, which is a good practice. However, the remaining 1.64% of farms indicated that they dispose of dead fish anywhere, which could lead to environmental contamination and the further spread of fish diseases.

4.1 Practices of Disease Management and Biosecurity Measures

4.1.1 Biosecurity Adoption Rate

This study evaluated the implementation and compliance rates of biosecurity measures across 61 fish farms using 24 individual measures. This study found that the most widely adopted measure among farms was to avoid stocking fish from farms with known fish disease outbreaks, with an adoption rate of 98.3%. This measure was closely followed by restricting fish movement between farms, which was adopted by 83.61% of the farms (Appendix i and Figure 6).

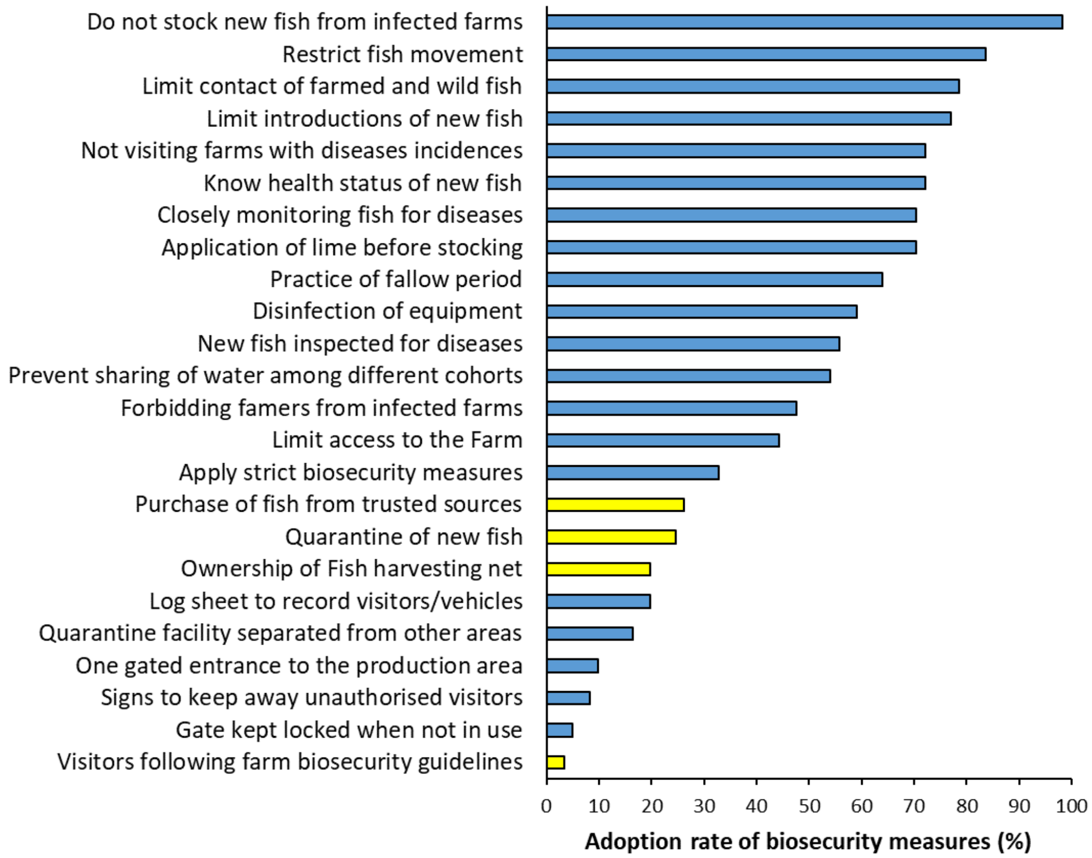

Figure 6. Adoption rates of biosecurity measures and key measures to limit fish disease transmission in Malawi are highlighted in yellow.

The study also found that most farmers (78.69%) were limiting the contact between farmed and wild fish. To prevent fish diseases from entering a farm, it is crucial to obtain fingerlings from reliable sources that provide healthy fish. The most dependable sources are certified government hatcheries, which are the only entities authorised to supply fish seeds to fish farmers in Malawi. According to the survey results, 44% of audited farms obtained fingerlings from other farmers (Figure 7). Although this may be a convenient option, it is important to note that the health status of fingerlings from these sources is uncertain. In contrast, 26.23% of the farms surveyed sourced their fingerlings from government facilities. This is a more secure option, as fingerlings are bred under regulated conditions and are likely to be healthy. Moreover, 19.67% of the surveyed farms sourced their fingerlings from their own farms. Although this may seem to be a cost-effective option, it can be risky, as the fingerlings may have been exposed to diseases or environmental factors that could affect their health. Finally, 9.84% of the surveyed farms obtained fingerlings from private hatcheries.

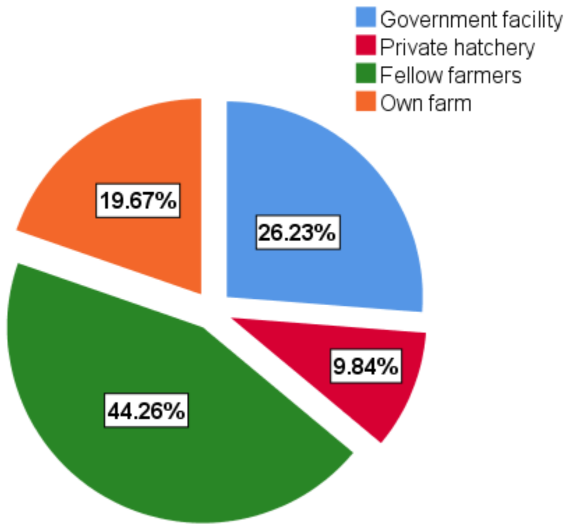

Figure 7. Various sources of fingerlings for pond stocking.

These measures are important for preventing the spread of diseases between fish farms and surrounding ecosystems. However, the study also revealed that certain biosecurity measures had lower adoption rates, with less than 50% of farms adopting them. These measures included the purchase of fingerlings from a trusted source, the presence of a gate, a locked gate, quarantine of new fish, ownership of fish harvesting nets, signs to keep away unauthorised visitors, a log sheet for visitors and vehicles, and visitors not following farm biosecurity guidelines.

4.1.2 Biosecurity Compliance Rate

The data presented in Figure 8 highlight that only government farms out of the 61 audited farms were found to have good compliance with biosecurity measures. However, approximately 36.07% of the farms had an intermediate level of compliance, while the majority of farms (62.30 %) were found to have a poor compliance rate. Such a low level of compliance might be attributed to a lack of knowledge among fish farmers in Malawi regarding fish health management and biosecurity practices. This lack of knowledge might have arisen because of insufficient training and education in these areas.

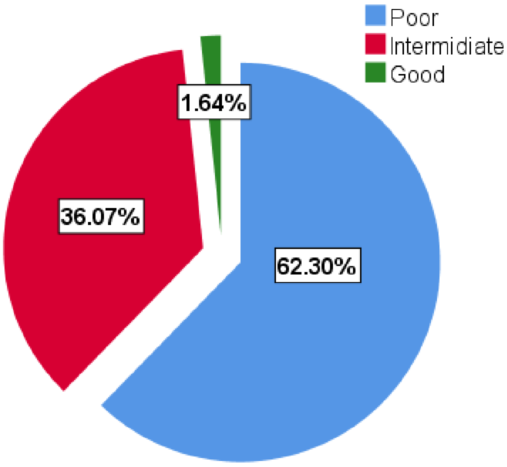

Figure 8. Percentage of fish farms across different categories of biosecurity compliance rate.

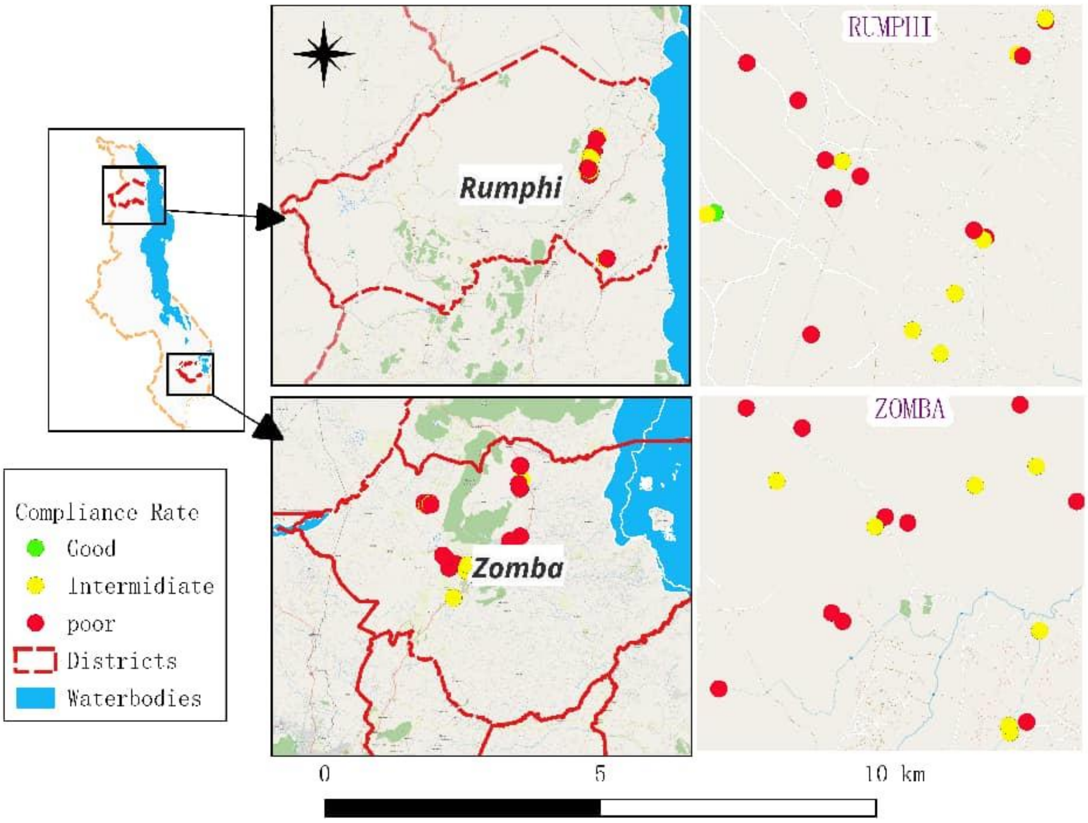

Figure 9. Map of farms symbolized with biosecurity compliance level across the two districts.

The data presented in Figure 9 indicate that a significant number of fish farms did not meet compliance standards. Specifically, most farms were found to have low levels of compliance. On the other hand, only one fish farm located in Rumphi has a good compliance rate, indicating that the farm operates following the regulations and guidelines set forth by the relevant authorities. It is important to note that despite the lack of compliance, fish farmers in Malawi may be aware of the importance of biosecurity measures. However, the implementation of these measures might be challenging for various reasons such as inadequate resources, lack of infrastructure, and/or lack of support from the government or other stakeholders.

Furthermore, it is interesting to note that as per Figure 10, there was no significant relationship (R=0.17, $p>0.05$) between the level of self-reported knowledge of fish disease management and biosecurity measure compliance rates. This could be due to various reasons, such as lack of practical training or insufficient awareness of the importance of biosecurity practices. Therefore, it is essential to address these factors and improve the knowledge and awareness of fish farmers in Malawi regarding fish health management and biosecurity practices to ensure better compliance and improve the overall health and safety of the fish farming industry in the region.

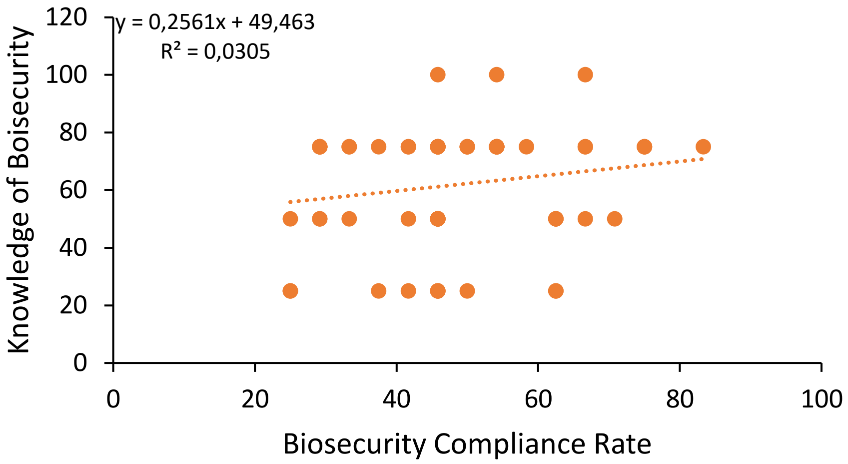

Figure 10. Correlation of knowledge of fish disease management and biosecurity compliance rate.

In the present study, biosecurity compliance rates varied significantly across the two districts studied. The compliance rates ranged from a minimum of 25%, which is poor, to a maximum of 83.33%, which is considered good. However, the overall mean compliance rate for the two districts was 48.50%, which falls within the category of poor compliance. Upon analysing the data, Figure 11 shows that the biosecurity compliance rate was not the same across the district categories, indicating significant differences ($p=0.026<0.05$). Rumphi had an intermediate mean compliance rate of 52.42%, whereas Zomba had a poor mean compliance rate of 44.44%. It is interesting to note that no significant differences were observed in knowledge of disease management across the districts. This suggests that, while biosecurity compliance rates differed across districts, knowledge of disease management was more consistent.

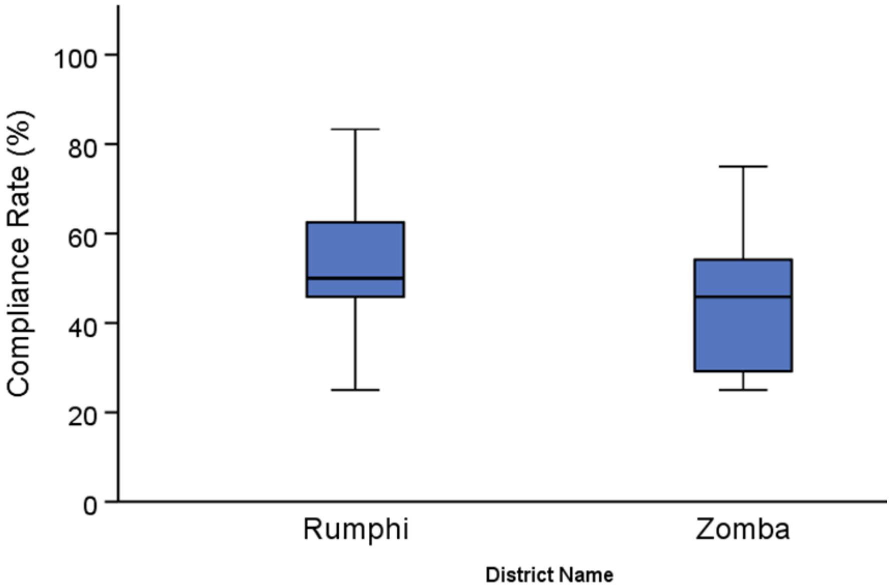

Figure 11. Box-and-whisker plot of biosecurity compliance rate by district.

4.1.3 Multivariate Analysis CATPCA

The results of the CATPCA analysis revealed some interesting insights. Two dimensions were identified, with dimension 1 having the highest eigenvalue of 23.499 and explaining about 97.913% of the variance in the data. This suggests that dimension 1 is the most significant dimension. The biosecurity compliance rate had the highest ellipse area (0.854), engulfing almost all biosecurity measures. It was also strongly associated with dimension 1. The ellipses of most biosecurity measures had values of zero, indicating shared similarities between the variables (Figure 12 and Appendix ii).

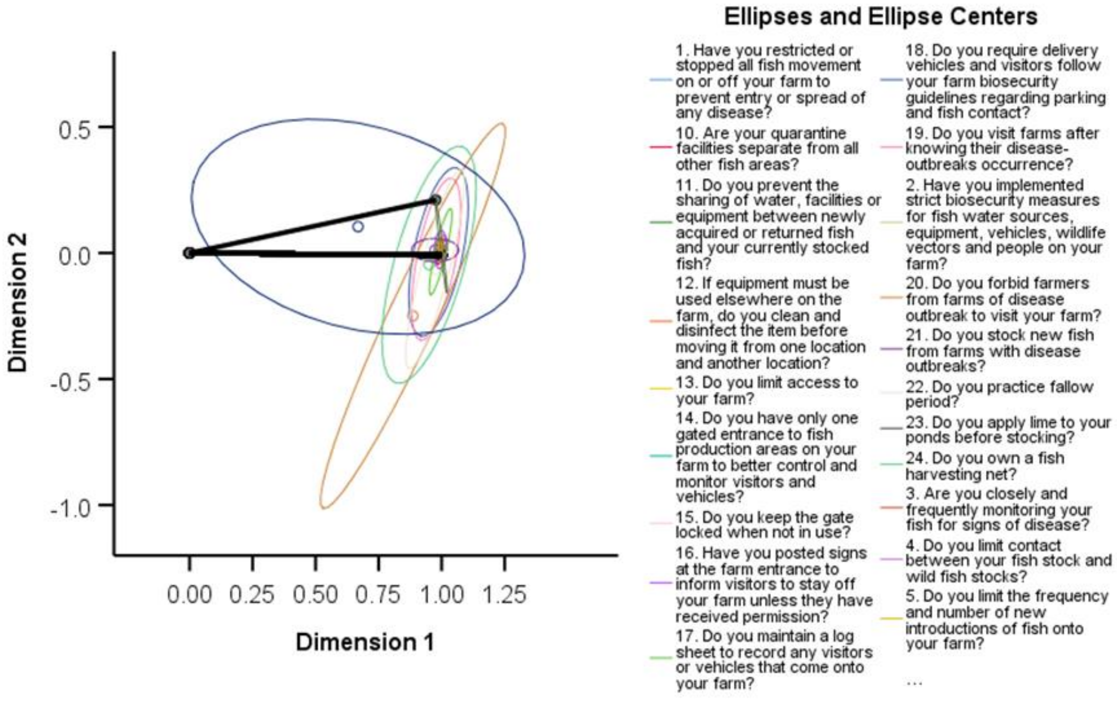

Figure 12. Categorical principal component analysis with two dimensions.

This is an important finding as it suggests that some underlying factors may influence these measures. Furthermore, larger ellipse values indicate higher variability in the data, which means that the biosecurity compliance rate had the highest variability, followed by forbidding farmers from infected farms to visit the farm, ownership of fish harvesting nets, visitors following farm biosecurity guidelines, visiting farms after knowing their disease outbreaks, and practice of the fallow period. Overall, these findings could be useful for improving biosecurity compliance rates and ultimately reducing the risk of disease outbreaks.

4.2 Identified Possible Disease Transmission Routes

Upon thorough review of all biosecurity factors considered in this study, it was revealed that the biosecurity measures that pose a great risk of disease transmission are associated with the source and movement of fingerlings (seed), sharing of materials such as harvesting nets, transport vehicles, and persons either visiting farms or workers on the farm. These findings align with those of Boklund (2008), who highlighted that the high-risk disease transmission routes include live animals, transport vehicles, persons, clothing, hands, and materials, as shown in Figure 13. Therefore, it is crucial to prioritise and implement effective biosecurity measures to mitigate the risks associated with these transmission routes and ensure the safety of farms and individuals involved.

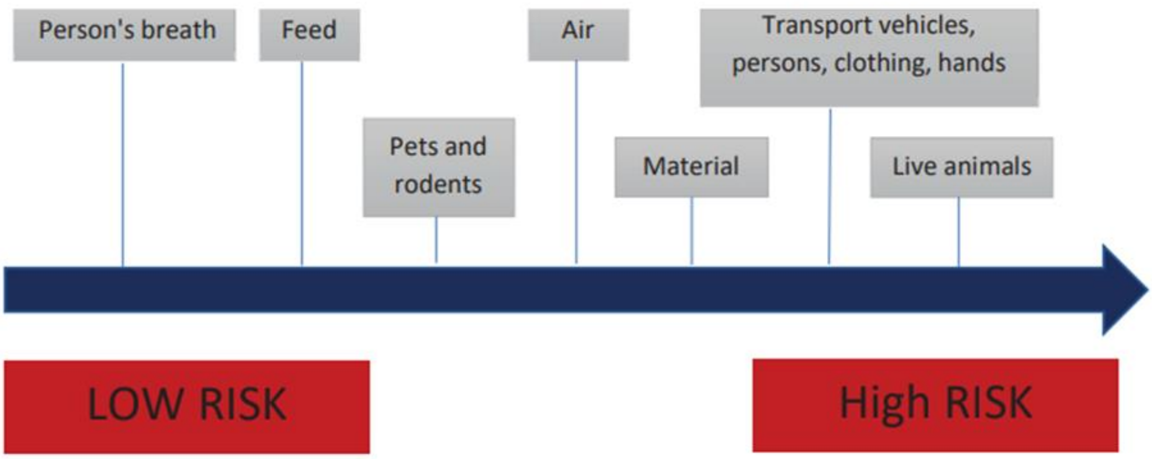

Figure 13. Theoretical ranking of different routes for disease transmission from low to high (after Boklund, 2008).

5 DISCUSSION

5.1 Technical Aspects of Farmed Fish Biosecurity Measures in Malawi

Over the past three years, Malawi has experienced an increase in annual outbreaks of epizootic ulcerative syndrome, a disease that affects fish and causes significant economic losses in the aquaculture industry. The recurrence of these outbreaks has highlighted the need to implement good biosecurity practices in fish farms to prevent and control the spread of the disease. To establish effective control programs for future infection incursions and endemic diseases, it is crucial to understand the current level of biosecurity compliance and adoption rate in fish farms. Biosecurity measures, such as quarantine procedures, disinfection protocols, and restricting access to farms, are essential in preventing the introduction and spread of diseases. Assessing the adoption rate of biosecurity measures in fish farms can help to identify gaps in compliance and develop targeted interventions to improve biosecurity practices. The successful implementation of biosecurity measures will prevent the spread of epizootic ulcerative syndrome and protect the sustainability and economic viability of fish farms.

The present survey was conducted to analyse the compliance rate of farm-level biosecurity measures in Malawi. This study found that the overall average compliance rate was 48.50%, which is generally considered poor. Similar results were reported by Zornu *et al*. (2023), who noted that despite the implementation of aquaculture and biosecurity regulations in different African countries, biosecurity compliance was notably low. In another study conducted in Kenya (Wanja *et al*., 2020) reported that despite the significance of biosecurity, only 1% of the respondents reported practising partial biosecurity measures, including disinfection and traffic control. This suggests that adherence to aquaculture biosecurity measures is a widespread issue in many African countries. This lack of compliance could have serious consequences, as it may promote the spread of transboundary diseases between neighbouring countries. Such diseases can cause significant harm to aquatic ecosystems and threaten the livelihood of those who depend on them. Therefore, it is essential to promote and enforce stricter biosecurity measures to prevent the transmission of diseases and to maintain the health and sustainability of aquaculture in the region.

The current study focused on two districts in Malawi, Rumphi and Zomba, and discovered a significant difference in compliance rates between the two districts. According to the survey results, some farms that claimed to be practising biosecurity measures showed partial compliance. For instance, although most farms reported that they did not stock fish from infected farms, none of them tested the fish for infections, and only a few quarantined the new stock. This failure to adhere to biosecurity measures is the main cause of fish disease outbreaks, which could be the case with the currently observed outbreaks of epizootic ulcerative syndrome outbreaks in Malawi. Failure to comply with biosecurity measures or hygiene has been declared as the origin of the transmission and spread of diseases in fish farms (Racicot & Vaillancourt, 2009). Hence, improving the compliance rate of biosecurity measures in Malawi is essential to prevent fish disease outbreaks.

Furthermore, this study also found that only a few biosecurity measures had an adoption rate greater than 71%. This indicates the need for more awareness campaigns to promote the adoption of biosecurity measures among fish farmers in Malawi. One of the most critical points to note was the difference in compliance rates between the two districts studied. Rumphi District registered a slightly higher compliance rate of 52.42% compared to Zomba District, which registered a compliance rate of 44.44%. The study suggests that the main reason for the disparity in compliance rates between the two districts is that Rumphi district was among the first districts to report an outbreak of epizootic ulcerative syndrome fish disease between 2021 and 2022. Hence, the farmers in Rumphi district received much of the awareness campaigns on biosecurity measures and containment of the epizootic ulcerative syndrome outbreak, unlike Zomba district, which reported the outbreak in mid-year 2023. According to Brennan *et al*., (2016), farmers tend to adopt more rigorous biosecurity measures in the event of an outbreak. This heightened awareness is, however, not enough to ensure that diseases are kept at bay. It is particularly difficult to maintain high biosecurity levels during periods of apparent inactivity in disease transmission. This assertion is supported by Garforth *et al*. (2013), who noted that maintaining a consistent level of biosecurity measures is challenging even during disease-free periods. Therefore, farmers must be vigilant and maintain a high level of biosecurity measures during and after outbreaks to keep diseases at bay.

Available evidence suggests that a significant proportion of fish farmers in Malawi tend to respond to disease outbreaks in a reactive manner, which means that they only take action once the problem has surfaced. However, this approach is not proactive, and may lead to suboptimal disease prevention and control outcomes. The underlying reasons for this reactive approach may be related to the prevailing approach to health management in African aquaculture, which is primarily focused on disease control and treatment, rather than disease prevention (FAO, 2018). This reactive approach may be attributed to various factors, such as the lack of effective disease surveillance systems, inadequate knowledge of disease prevention and control measures, limited access to diagnostic facilities, and high cost of disease management.

The findings of this study indicate a lack of coordinated efforts by various stakeholders, including government and non-governmental organisations, to provide fish farmers with comprehensive knowledge and skills regarding the implementation of biosecurity measures at the farm level. Although most respondents reported receiving training in fish farming, the training programs lacked components that covered farm-level biosecurity measures and disease management. This lack of coverage raises concerns as these measures are crucial for the prevention, management, and control of diseases in fish farms. Training programs mainly focused on site selection, species selection, pond construction, feeding, stocking, and general farm management. Consequently, farmers may not have adequate knowledge and skills to implement effective biosecurity measures (Georges *et al*., 2023), which could lead to disease outbreaks and significant economic losses. Therefore, stakeholders must revise and improve training programs to incorporate comprehensive on-farm biosecurity measures and disease management. This would ensure that fish farmers are equipped with the necessary knowledge and skills to maintain healthy and profitable farms.

The results of this study align with the research conducted by Zornu *et al*. (2023), which highlights the lack of knowledge about biosecurity measures as one of the key factors responsible for preventing fish farmers from implementing rigorous farm-level biosecurity measures. The current study also found no significant relationship between knowledge about disease management and compliance with biosecurity measures. This indicates the need for more intensive training that focuses on disease management and biosecurity protocols. This study emphasises the importance of robust biosecurity measures because weak or poor biosecurity measures can result in a high risk of disease outbreaks (Georges *et al*., 2023), making fish farms more vulnerable to infections. Therefore, it is essential to implement strong biosecurity measures to minimise the risk of disease outbreaks and protect the fish-farming industry from potential risks.

Biosecurity measures are important to prevent the spread of disease-causing agents in fish farms. However, the present study highlights critical gaps in the adoption of some measures as much as they should be. These include not having a fish harvesting net, visitors not following farm biosecurity measures, no log sheet to record visitors and vehicles, new fish not being quarantined, quarantine facilities not being separated from other production areas, no gated area or fence for the main farm, no limited access for visitors, and no signs to keep unauthorized visitors away. The absence of these measures increases the risk of disease-causing agents being introduced, emerging, or spreading on farms. For instance, if visitors do not follow biosecurity measures, they can carry disease-causing agents and introduce them to farms. Similarly, when new fish are not quarantined, they can carry diseases that can infect healthy fish on farms. Traffic control biosecurity is an essential component for preventing the entry of such agents into a farm by controlling the movement of personnel and equipment between farms. With a robust traffic control system, farms can prevent the introduction of disease-causing agents on farms and from one region to another.

Fish harvesting nets are an essential tool for fish farmers, as they enable them to collect fish efficiently and safely. However, this study found that most fish farms do not own harvesting nets. Instead, fish farmers share nets among farms, which is a concern for biosecurity. This practice is mainly due to the poverty level and low purchasing power of small-scale fish farmers (Wanja *et al*. 2020). Most farmers cannot afford to purchase fishing gear, making sharing a necessity. Sharing nets can transfer fish diseases from one farm to another, particularly if the nets are not properly disinfected. Unfortunately, this study found that disinfecting nets before use on another farm was not a common practice among fish farmers in Malawi. This is a significant concern, as contaminated nets are a common source of pathogen transmission between fish populations in different water bodies. Anderson *et al*. (2014) reported that contaminated nets can introduce pathogens into fish populations and spread them across different water bodies.

One of the primary issues resulting from improper site selection and spatial layout in aquaculture is the emergence of disease. Salama and Murray (2011) presented several studies showing how serious pathogens, such as sea lice and infectious salmon anaemia (ISA), can spread between hydrodynamically coupled farms. Regretfully, in the current study, 91.8% (n=56) of the audited farms had at least one facility within 10 kilometers. This close proximity could result in the spread of illness to neighbouring facilities and impacted fields. Because moving the farm is usually not an option, site selection and spatial organisation must be thoroughly considered.

Maintaining good biosecurity practices is crucial for ensuring the success of any aquaculture operation. One of the key aspects of these practices is obtaining healthy stocks and optimising their health and immunity through proper animal management. The results provide valuable insights into the importance of stocking healthy fingerlings and the risks associated with obtaining fingerlings from unreliable sources. The study found that 98.36% of the respondents surveyed would not purchase fingerlings from farms with known fish disease outbreaks. This indicates that audited farms understand the value of stocking healthy fingerlings in their ponds. Unhealthy fingerlings can introduce diseases to fish populations and reduce growth rates, leading to losses (Dewulf & Van Immerseel, 2018).

To mitigate these risks, it is crucial to obtain fingerlings from a reliable source. A trusted source will provide fingerlings that are disease-free or have a low disease burden, thereby reducing the risk of outbreaks and mortality rates in adult fish. High-quality fingerlings from reputable sources are less likely to harbour diseases or pathogens. It is important to note that this study found that no farm reported sourcing fingerlings from the wild. Farmers sourced fingerlings from fellow farms, own farms, private hatcheries, or government facilities. However, the survey observed some critical issues with the low number of farmers receiving fingerlings from government-certified facilities compared to those receiving fingerlings from fellow farmers. Lack of access to quality fingerlings is a major constraint affecting sub-Saharan African fish farming (Hishamunda and Manning, 2002). This could compromise production because the health status of fish from local farmers is not thoroughly assessed by competent individuals.

The availability of skilled fish health diagnostic and extension services affects the outcome of disease outbreaks (Ndashe *et al.*, 2023). According to the findings of this study, the majority of farmers rely on unskilled farm personnel for disease monitoring and inspection, supplemented by limited technical assistance from fisheries extension workers. Unfortunately, these farm personnel lack adequate knowledge of fish health and disease management, resulting in many diseases going undetected and exacerbating the severity of infections. Additionally, this study highlights that most farmers do not submit deceased or ailing-fish for diagnosis. This problem is exacerbated by the fact that most veterinary specialists in Malawi lack the skills and knowledge of aquatic health and disease management. The aquaculture sector in other countries, such as Zambia and Kenya, has also reported low access by farmers to disease diagnosis services because of the unavailability of specialised personnel (Ndashe *et al*., 2023; Kyule-Muendo *et al*., 2022; Opiyo *et al*., 2018). In light of these issues, it is essential to develop comprehensive training programs for personnel involved in fish health management. Such programs could equip them with the necessary skills and knowledge to effectively diagnose and manage fish diseases. Additionally, it is crucial to increase access to specialised personnel who can help diagnose and manage fish diseases, especially in regions where the aquaculture sector is vital to the economy. By taking concrete steps to address these challenges, we can ensure the sustainable growth of the aquaculture sector and food security for the population.

5.2 Policy Implications of Farmed Fish Biosecurity Measures in Malawi

The results of this study have important implications for policies that need to be addressed. The low rates of biosecurity compliance and adoption identified in this study undermine the progress made by the Malawian government to improve the aquaculture industry, as outlined in the Malawi National Aquaculture Strategic Plan II and Fisheries and Aquaculture Policy of 2016-2021. The study also notes a lack of coherent planning in these two documents to address fish disease problems, aquatic animal health, and farm-level biosecurity management. Additionally, there is a need to optimise and further integrate authority agencies and their functions. Too many authority agencies create complexity and inefficiency in government management, making it difficult for producers to seek help or guidance. Therefore, it is crucial to streamline the regulatory framework and ensure that the relevant authorities work together in a coordinated and collaborative manner. This will help improve the overall performance of the aquaculture industry and ensure that it can meet its potential as a vital source of food and income for the people of Malawi.

6 RECOMMENDATIONS

This study highlights the pressing need to improve the management of fish health and implementation of biosecurity measures in fish farms across Malawi. According to this study, the compliance rate of biosecurity measures in fish farming is currently inadequate, and this poses a significant risk of disease outbreaks, which can severely impact the sustainability of the aquaculture industry. To address this issue, this study recommends that Malawi's fish farming industry prioritise compliance with biosecurity measures. This can be achieved by addressing the following recommendations.

Education and Training: Ensuring that fish farmers have adequate knowledge and skills to effectively manage their farms is crucial for the success of their business. To achieve this, it is necessary to provide regular training and workshops for fish farmers on best biosecurity practices, disease recognition, and emergency response plans. Training sessions should cover various aspects related to biosecurity, including the importance of disease prevention, methods of disease detection, and the appropriate use of vaccines and treatments. Training should emphasise the importance of developing emergency response plans to mitigate the impact of disease outbreaks. Fish farmers should also be trained on how to identify and report any potential biosecurity risks on their farms to avoid the spread of diseases. By providing regular and comprehensive training, fish farmers can manage their farms better, reduce the risk of disease outbreaks, and improve the overall quality of their products.

Regular Audits and Feedback: Implementing regular biosecurity audits is a crucial step towards ensuring the safety of the aquaculture industry and the environment. As such, it is recommended that the responsible authority conduct these audits periodically, as is being done in other countries such as the Faroe Islands and Iceland. During these audits, authorities should thoroughly evaluate the biosecurity measures in place and identify potential areas of concern. Once the audit is complete, authorities should provide constructive feedback to fish farmers to help them improve their biosecurity practices. This feedback should be specific and actionable, highlighting areas that need improvement, and offering recommendations to address these issues.

Collaboration and Effective Communication: Effective management of fish farming biosecurity requires collaboration and open communication between farmers, veterinarians, and other stakeholders. The government plays a key role in fostering this collaborative culture by providing a supportive environment. To this end, the government should establish platforms for knowledge exchange between fish farmers, research institutions, and government agencies. These platforms can take various forms, including regular forums, workshops, and information dissemination through the local media. Through these channels, stakeholders can share knowledge and best practices, thus enhancing their understanding of fish-farming biosecurity management. For example, farmers can learn about the latest biosecurity measures and how to effectively implement them. Veterinarians can share their expertise in disease diagnosis and treatment, and researchers can provide insights into emerging risks and how to mitigate them.

Regulatory Framework Enhancement: Policymakers should prioritise the development and enforcement of robust regulations that specifically address biosecurity practices within the aquaculture industry. These regulations should be comprehensive, clear, and adaptable to the evolving challenges. The lack of comprehensive policies to address biosecurity and fish health management is a significant concern in the aquaculture industry in Malawi. For instance, the National Aquatic Animal Health Plan and Biosecurity Management Strategy for Aquatic Animals are not yet in place, posing a significant risk to the safety and health of aquatic animals. Therefore, it is crucial to enhance the regulatory framework to ensure that the aquaculture industry in Malawi maintains high standards for biosecurity and fish health management.

Monitoring and Surveillance: Effective monitoring and surveillance are vital for maintaining the health and safety of fish farms. By regularly monitoring and collecting data, fish farmers can ensure that their operations comply with biosecurity regulations and prevent the spread of disease. This is particularly important in the case of disease outbreaks, where early detection and rapid response are critical to minimise the impact on aquatic animal health and the environment. Policymakers should allocate resources for systematic monitoring to track compliance and assess the effectiveness of biosecurity measures. This could involve the use of advanced technologies such as remote sensing, drones, and computer-aided data collection tools, such as kobo.collect. In addition, regular inspections by trained professionals can help to identify potential risks and ensure that farmers take appropriate measures to maintain biosecurity.

7 CONCLUSION

This study is the first of its kind and it evaluates the biosecurity measures of fish farms in Malawi. The study found that compliance and adoption rates of biosecurity measures on audited fish farms were categorised as poor. This means that fish farms do not implement adequate measures to prevent disease outbreaks, which can have severe impacts on fish health, environment, and economy. This study highlighted the need for immediate action to improve the status quo. Fish farms in Malawi must increase their efforts to implement biosecurity measures that can effectively prevent the spread of diseases and protect fish health. This will require a collaborative effort between fish farms, government agencies, and other stakeholders to promote and enforce best practices in biosecurity measures.

After performing a detailed evaluation of the preliminary operational biosecurity questionnaire obtained from farms, the study identified several critical points that can significantly amplify the risk of disease introduction and spread. First, the absence of fences on farms leaves fish vulnerable to external factors such as stray animals, wildlife, and people who might carry infectious agents. Second, the lack of control over the entry of visitors or vehicles can increase the risk of accidental introduction of pathogens. Visitors not following on-farm biosecurity measures can also pose a significant threat to the health of animals. Third, farmers sharing equipment such as harvesting nets can spread diseases, especially if they are not adequately sanitised. Fourth, farmers not following fish quarantine measures can introduce pathogens into the farm. The improper disposal of dead fish is another critical factor that can lead to the spread of diseases. If dead fish are not disposed of correctly, they can contaminate the surrounding environment, leading to the spread of diseases to other fish farms. Finally, the lack of skilled personnel to conduct fish health inspections can lead to delayed diagnosis and treatment of diseases, leading to significant losses for farmers. Therefore, it is crucial to address these critical points to minimise the risk of disease introduction and spread on and between farms.

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9 APPENDICES

9.1 Appendix i: Adoption Rate (AR) External and Internal biosecurity measures

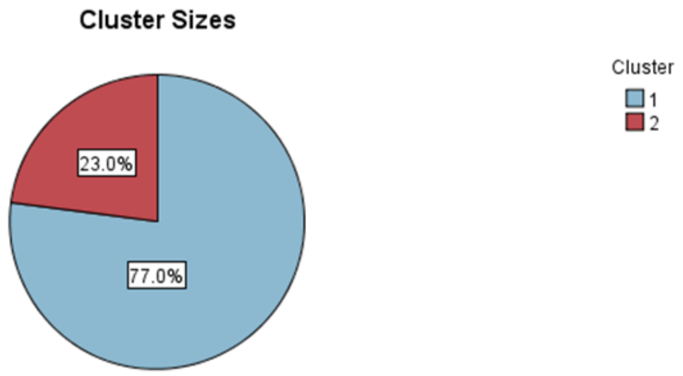
External Biosecurity Measures	**AR (%)**
Visitors following farm biosecurity guidelines	3.28
The gate kept locked when not in use	4.92
Signs to keep away unauthorized visitors	8.20
One gated entrance to the production area	9.84
Log sheet to record visitors/vehicles	19.67
Quarantine of new fish	24.59
Purchase of fish from trusted sources	26.23
Limit access to the Farm	44.26
Forbidding farmers from infected farms	47.54
New fish inspected for diseases	55.74
Know the health status of new fish	72.13
Not visiting farms with disease incidences	72.13
Limit introductions of new fish	77.05
Limit contact with farmed and wild fish	78.69
Restrict fish movement	83.61
Average Adoption Rate	**41.86**

Internal Biosecurity Measure	**AR (%)**
Quarantine facility separated from other areas	16.39
Ownership of Fish harvesting net	19.67
Apply strict biosecurity measures	32.79
Prevent sharing of water among different cohorts	54.10
Disinfection of equipment	59.02
Practice of fallow period	63.93
Closely monitoring fish for diseases	70.49
Application of lime before stocking	70.49
Do not stock new fish from infected farms	98.36
Average Adoption Rate	**53.92**

9.2 Appendix ii. Summary of categorical principal component analysis of biosecurity measures.

	Component Loadings		
Biosecurity measure	**Dimension 1**	**Dimension 2**	**Ellipse Area**
Restrict fish movement	1	-0.009	0
Apply Strict biosecurity	1	-0.009	0
Closely monitoring fish for diseases	1	-0.009	0.001
Limit contact of farmed and wild fish	1	-0.009	0
Limit introductions of new fish	1	-0.009	0.001
Purchase of fish from trusted sources	1	-0.009	0
Know health status of new fish	1	-0.009	0
New fish inspected for diseases	0.978	0.211	0.003
Quarantine of new fish	1	-0.009	0
Quarantine facility separated from other areas	1	-0.009	0.004
Sharing of water and facilities between different cohorts	1	-0.009	0.001
Disinfection of equipment	1	-0.009	0
Limit access to the Farm	1	-0.009	0.001
One gated entrance to the production area	1	-0.009	0
Get kept locked when not in use	1	-0.009	0.001
Signs to keep away unauthorized visitors	1	-0.009	0.006
Log sheet to record visitors/vehicles	1	-0.009	0.012
Visitors following farm biosecurity guidelines	1	-0.009	0.103
Not visiting farms with disease incidences	1	-0.009	0.079
Forbidding farmers from infected farms to visit your farm	1	-0.009	0.252
Do not stock new fish from infected farms	1	-0.008	0.014
Practice of fallow period	1	-0.009	0.072
Application of lime before stocking	1	-0.009	0.001
Ownership of Fish harvesting net	1	-0.009	0.212
Compliance Rate	1	-0.009	0.854
Eigenvalue	**23.499**	**0.271**	
%Variance	**97.913**	**1.129**	

9.3 Appendix iii: Dimension reduction analysis results (Two step cluster analysis)



Size of Smallest Cluster	14 (23%)
Size of Largest Cluster	47 (77%)
Ratio of Sizes: Largest Cluster to Smallest Cluster	3.36

9.4 Appendix iv: Questionnaire used for data collection

GRO FTP Malawi Survey on Biosecurity Compliance Rate and Fish HealthManagement Practices of Farmed Fish

Yamikani Balaka

The purpose of this questionnaire is to gather information about the biosecurity measures, and fish health management practices of farmed fish in Malawi. The questionnaire focuses on the current practices used on the farms. The information collected will be used to analyse the current situation of these aspects at the national level and to develop risk assessment tools specifically adapted to Malawi's conditions. The aim is to reduce the risk of introducing and spreading infectious fish diseases in these farms and the surrounding regions.

Please note that the information provided will be kept confidential and no data from this report will identify any specific farm or individual. We appreciate your participation in the survey.

A. Current Activity Description

1. Interviewer Name ___________________________________
2. District Name ________________________________
3. EPA_______________________________________
4. Farm Name ________________________________
5. Date of interview (DD/MM/YYYY)_______________________________
6. What is your role in this facility?
(Tick all that apply)
□ Owner □ Manager □ Worker
□ Other (specify):________________
7. Academic education
❑ Primary school ❑ Secondary school ❑ Tertially
❑ No formal education
8. Have you received any training in fish farming?
❑ Yes, please specify________________________
❑ No
9. Experience in aquaculture
❑ ≤1 ❑ 1 ~ 2 ❑ 2 ~ 5
❑ 5 ~ 10 ❑ ＞10 (Years)
10. What type of business is the farm? □ Family owned farm □ Company owned farm
□ Government farm □ Other (specify):_______________
11. What is the main type of production activity at this farm?
(Tick all that apply)
□ Fingerling Production □ On-growing
12. What type (tank/pond/cage) of fish holdings do you have on this site?
□ Tank □ ponds □ Cages
13. Environmental exposure? □ Indoor □ Outdoor sheltered (covered) □ Outdoor exposed (not covered) □ Other (specify):_______________
14. Are there any other aquaculture farms within 10 km of this facility?
□ Yes □ No □ Don't know
□ Other (specify):________________
15. If yes to the previous question, what is the type and the number of the facilities?

□ Fingerling production/Number:_____________
□ On-growing/Number:_____________ Check there are no options on question 16. On kobo

B. Current Production statistics

1. What fish species do you produce on this facility and the approximate percentage of the stocked species?
□ Catfish Percent: ________________ □ Oreochromis Shiranus Percent:________________
□ Coptodon rendalli Percent: ________________ □ O. karongae Percent: ________________

2. How many of each of the stocked species do you produce per year?
(Tick and provide number of fish)
□ Catfish number: ________________ □ *Oreochromis Shiranus* number:________________
□ *Coptodon rendalli* number: ________________ □ O. karongae Percent: ________________

3. How much of each stocked species do you produce per year?
(Tick and provide the amount in Kg)
□ Catfish Kg: ________________ □ *Oreochromis Shiranus* Kg:________________
□ *Coptodon rendalli* : Kg___________ □ O. karongae Kg: ________________

4. What is the maximum stocking density in number of fingerlings/m²?
(Tick and provide the maximum density)
□ Catfish fingerlings/m²: ________________ □ *Oreonchromis Shiranus* fingerlings/m²:________________
□ *Coptodon rendalii* fingerlings/m²: ________________ □ *O. Karongae* fingerlings/m²: ________________

5. How long is the production cycle?
(Tick and provide number in months on average
□ Catfish months: ________________ □ *Oreochromis Shiranus* months:________________
□ *Coptodon rendalli* months : ________________ □ *O. karongae* months: ________________

C. Water sources and treatment

1. What are the sources of water for the fish-rearing facility?
□ Borehole □ Underground □ River □ Open Lake water □ Spring
□ Others: specify ____

2. Treatment applied to the intake of water
(Tick all that apply)
This question applies to all operations on the site including quarantine, if applicable.
□ Filtration □ Chemical □ No treatment □ Not applicable □ Others: specify
____

3. Is there a treatment applied to the wastewater (effluent)?
□ Yes: specify____
□ No treatment □ Don't know □ Not applicable□ Others: Specify
____

D. Knowledge of Disease Management and/or Biosecurity

1. Have you heard of any infectious disease in farmed fish in Malawi?
❑ Yes ❑ No ❑ Not sure

2. Have you heard of any fish diseases related to suboptimal environmental conditions such as poor water quality, too low temperature and so on?
❑ Yes ❑ No ❑ Not sure

3. Have you ever heard of epizootic ulcerative syndrome fish diseases
❑ Yes ❑ No ❑ Not sure

4. Have you heard of any Aquatic Health Management agencies (International and/or Local ones (Malawi))?

❑ OIE ❑ Malawian agency, please specify__________________

❑ Other, please specify__________________ ❑ No

E. Practices of Disease Management and/or Biosecurity Measures

1. Have you restricted or stopped all fish movement on or off your farm to prevent entry or spread of any disease?

❑ Yes ❑ No ❑ Not sure

2. Have you implemented strict biosecurity measures for fish water sources, equipment, vehicles, wildlife vectors, and people on your farm?

❑ Yes ❑ No ❑ Not sure

3. Are you closely and frequently monitoring your fish for signs of disease?

❑ Yes ❑ No ❑ Not sure

4. Do you limit contact between your fish stock and wild fish stocks?

❑ Yes ❑ No ❑ Not sure

5. Do you limit the frequency and number of new introductions of fish onto your farm?

❑ Yes ❑ No ❑ Not sure

6. Do you limit purchases of fish to a few sources with known and trusted fish health programs?

❑ Yes ❑ No ❑ Not sure

7. Do you know the health status and the source of the fish brought onto your farm?

❑ Yes ❑ No ❑ Not sure

8. Do you only bring fish onto your farm, that have been inspected or tested to be free of fish diseases?

❑ Yes ❑ No ❑ Not sure

9. Do you require that newly acquired or returned fish for your farm are quarantined for at least 3 weeks upon arrival?

❑ Yes ❑ No ❑ Not sure

10. Are your quarantine facilities separate from all other fish areas?

❑ Yes ❑ No ❑ Not sure

11. Do you prevent the sharing of water, facilities or equipment between newly acquired or returned fish and your currently stocked fish?

❑ Yes ❑ No ❑ Not sure

12. If equipment must be used elsewhere on the farm, do you clean and disinfect the item before moving it from one location and another location?

❑ Yes ❑ No ❑ Not sure

13. Do you limit access to your farm?

❑ Yes ❑ No ❑ Not sure

14. Do you have only one gated entrance to fish production areas on your farm to better control and monitor visitors and vehicles?

❑ Yes ❑ No ❑ Not sure

15. Do you keep the gate locked when not in use?

❑ Yes ❑ No ❑ Not sure

16. Have you posted signs at the farm entrance to inform visitors to stay off your farm

unless they have received permission?

❑ Yes ❑ No ❑ Not sure

17. Do you maintain a log sheet to record any visitors or vehicles that come onto your farm?

❑ Yes ❑ No ❑ Not sure

18. Do you require delivery vehicles and visitors follow your farm biosecurity guidelines regarding parking and fish contact?

❑ Yes ❑ No ❑ Not sure

19. Do you visit farms after knowing their disease-outbreaks occurrence?

❑ Yes ❑ No ❑ Not sure

20. Do you forbid farmers from farms of disease outbreak to visit your farm?

❑ Yes ❑ No ❑ Not sure

21. Do you stock new fish from farms with disease outbreaks?

❑ Yes ❑ No ❑ Not sure

22. In the last three years, has there been any major mortality due to infectious disease on this farm?

□ Yes □ No □ Not sure

23. Do you practice fallow period?

❑ Yes ❑ No ❑ Not sure

24. Do you apply lime to your ponds before stocking?

❑ Yes ❑ No ❑ Not sure

F. Fish health monitoring and management

1. How often are the fish on the facility inspected?
(Tick one)

□ At least twice a day □ At least once a day □ At least every other day
□ At least twice a week □ Less than twice a week
□ Other (specify):_______________________________________ □ Never

2. What is the purpose of the fish inspection?
(Tick all that apply)

□ Monitor overall health of stock □ Identify signs of disease in stock
□ Identify any dead fish □ Check for presence of wild fish
□ Check for presence of predators □ Monitor status of cage and net
□ Monitor feeding tools, if used □ Monitor feeding behaviour
□ Other (specify): _______________________________________
□ Not applicable as fish are never inspected.

3. Who is in charge of regular fish health inspection?
(Tick all that apply)

□ Own farm personnel
□ A contracted fish health specialist
□ Assistant Veterinary Officer
□ Fisheries Extension Worker
□ Not applicable

4. How often are dead fish stocks in this facility logged?

□ Daily □ Weekly □ Monthly □ Only if there is a big outbreak.
□ Other (specify):_______________________________________ □ Don’t know

5. If dead fish are logged, what categories for mortality are used?
(Tick all that apply)
☐ No categorization ☐ Predation (e.g. , otters, birds, cannibalism)
☐ Infectious diseases ☐ Parasites ☐ Runts ☐ Production diseases
☐ Other (specify):____☐ Don't know
6. Are dead or dying fish promptly removed?
☐ Yes ☐ No ☐ Don't know
☐ Not applicable
7.Are dead or dying fish submitted for diagnostic testing or necropsy to determine the cause of death?
☐ Yes ☐ No ☐ Don't know ☐ Not applicable
☐ Others: specify ____
8. Enter any methods used for disposing of dead fish at the farm.
☐ Buried on the farm ☐ Buried off the farm ☐ Burned ☐Collected for discarding ☐ Discarded in a water body
☐ Sold for animal feed ☐ Not applicable
9. What is the mortality of fish per production cycle______?
10. What is the source of your fingerlings?
(Tick all that apply)
☐ Own farm
☐ Private hatchery
☐ Government facility
☐ Fellow farmers
☐ Wild source