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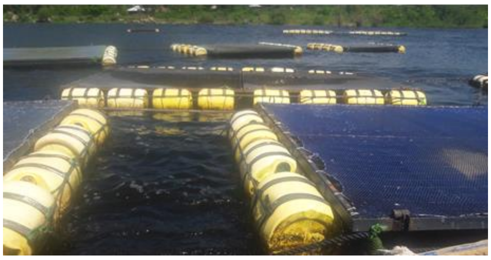

A KNOWLEDGE ATTITUDE AND PRACTICES (KAP) ANALYSIS OF BIOSECURITY AND WATER QUALITY EFFECTS IN NILE TILAPIA (OREOCHROMIS NILOTICUS) CAGE AQUACULTURE IN LAKE VICTORIA, KENYA.

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ABSTRACT

As aquaculture intensifies, maintaining conducive conditions becomes a key priority. The expansion in farm number and per-farm production puts pressure on the environment and increases susceptibility of the cultured fish to disease, leading to production loss by the investors. This study was designed to investigate the combined role of biosecurity and adherence to best management practices by looking at the Knowledge Attitude and Practices (KAP) of the cage aquaculture farmers. Additionally, it looked at the effects of cage aquaculture on water quality and the link between KAP in biosecurity and water quality all in the context of promotion of fish health and prevention of fish kills in the cage aquaculture of Nile tilapia in Lake Victoria, Kenya. The study was undertaken in representative cage aquaculture systems in 3 riparian counties within Lake Victoria, Kenya both in the gulf and open waters. It made use of available literature, qualitative and quantitative data. A semi structured questionnaire was used to gather qualitative information on the KAP of biosecurity and Best Management Practices (BMPs) in the cage aquaculture farms while water quality data spanning a period of 9 months was used for the quantitative analysis. Results showed that the farmers had a positive attitude towards various biosecurity and BMP concepts and a moderate level of knowledge, but the practices on the farm were not in concurrence with both their attitudes and knowledge. The water quality parameters were not significantly different between the cage sites and control sites. However, there was better water quality in the open waters as compared to the gulf and sheltered areas and the seasons had an impact on the water quality parameters. A good aquaculture performance index score was noted in only 8% of the farms under investigation, while 24% had an average score and the majority (68%) had a poor score. Findings also showed that a good aquaculture performance index score was inversely related to ammonia levels. The study proposes the need for capacity building on the importance of adopting biosecurity and BMPs in the cage aquaculture of Nile tilapia in the lake for enhanced productivity and sustainability of the lake ecosystem.

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1 INTRODUCTION

1.1 Background

In developing nations, fishing and aquaculture are important for ensuring food security and establishing alternative sources of income (FAO, 2020). With estimates for global population growth indicating that there will be 10 billion people on the planet by the year 2050, demand for an inexpensive high-protein diet is expected to rise (United Nations, Department of Economic and Social Affairs, Population Division , 2015). Thus, the development of aquaculture has increased, with most of the produce going toward human consumption (FAO, 2020). Aquaculture business growth and technological improvements have caused cultivation techniques to become more intense to boost yields and meet demand (Rico, et al., 2012). Due to this intensification, stress on both cultured fish and the environment are increasing, pointing to a likelihood that aquatic animal diseases will grow and spread.

In Kenya, aquaculture has rapidly expanded because of numerous government interventions to promote it. Additionally, several donor-funded programs have been running to meet the rising demand for fish in the country (Orina, et al., 2018). In the last decade, there has been significant intensification of cage aquaculture of the Nile Tilapia (*Oreochromis niloticus)* in Lake Victoria, Kenya (Aura, et al., 2022). Investors of both small scale and large scale have penetrated the market to benefit from this culture system which has resulted in enhanced productivity for the nation and made the resource accessible to many families. However, as aquaculture has expanded, fish commerce and transportation have increased, raising the possibility of introducing species with unknown health status at the global and local scale (Opiyo, et al., 2018). This is due to the translocation of fish diseases between nations and continents through the transfer of live fish for brood stock and seed (fry/fingerlings) (Bondad-Reantaso & Subasinghe, 2008). Future markets could be impacted by the risks of endemic, emergent, and re-emerging fish diseases, which could also have an impact on livelihoods and, in the case of zoonotic infections, human health.

There is a scarcity of knowledge on fish disease outbreaks in Kenya which could be due to several reasons. Lack of reporting, poor channels of reporting, lack of information on the signs of sick fish among other reasons have in the past resulted in fish health not being given adequate attention (Opiyo, et al., 2021). As a result, most studies and research focused on only parasitic diseases of fish and a few on bacterial and fungal infections (Mwainge, et al., 2021). However, with advancement in aquaculture and a growth in commercialization and intensification, there is a progressive shift in focus to the other disease groups (bacterial, fungal, and viral). A lack of skilled personnel for fish disease diagnostics, laboratories, and quarantine facilities has been a problem in Kenya in addition to a lack of specific policies and initiatives addressing fish health (Akoll & Mwanja, 2012). Concerns about the condition of Lake Victoria and the growth of cage fish farming provide possible hazards that call for further research. The development of comprehensive fish health management systems is necessary given the expansion of global fish farming.

As this global fish farming increases, the need for both skilled and unskilled labour becomes significant considering the need to employ systems in place to counter disease threats. Such systems include the adoption of best management practices, proper biosecurity and the utilisation of both probiotics and prebiotics. In the case of Lake Victoria, Kenya cage fish farming began before the policies were ready to guide this culture, hence efficient uptake, practice and adoption of both BMPs and biosecurity is still wanting. Implementation of these systems by the industry could result in fewer instances of mass mortalities, which have been an issue lately. By building the capacity of the farm owners and farm managers working in the industry, sustainability can be promoted, considering that the lake is a shared resource with multiple users.

The laborers in this culture system are mostly male. According to the World bank (World Bank, 2012), gender is referred to as the social, behavioural, and cultural attributes or expectations and norms associated with being a woman or a man. In the context of cage aquaculture of *O. niloticus* in Kenya, surveys have found it to be a male dominated activity (Aura, et al., 2018) (Githukia, et al., 2020), though women's roles are spread through the value chain from production, processing and marketing. Women are specifically involved in seed production in hatcheries, processing, and fish distribution to the markets (Orina, et al., 2018). Studies in Homabay county within the riparian counties of Lake Victoria pointed to the fact that out of 827 cages, only 29% were owned by women (Abwao & Awuor, 2019). Another case study in Siaya county (Namaemba, Sibiko, & Ogello, 2022) found that ownership by men and women was 87% and 13% respectively. Various reasons have been put forth for the low involvement of women in both aquaculture in general and cage aquaculture specifically, including limited rights, labour intensiveness, lack of capital, long payback time, poor aquaculture perception by women, and inadequate information on aquaculture (Nabayunga, Matolla, Shittote, & Kawooya Kubiriza, 2022).

1.2 Rationale

Disease and parasite occurrence on aquaculture farms cause, on average, close to 50% of the output loss (Assefa, 2018). To prevent the losses, there is a need to establish feasible disease mitigation strategies. In the last 3 years within the context of Lake Victoria, Kenya, where this study was executed, reports of Nile tilapia (*O. niloticus*) dieoff in Lake Victoria have increased. Studies have shown that water quality compromises (mainly low Dissolved Oxygen) due to the annual water mixing events have been the main causes of the kills. However, the issue of biosecurity and BMPs have not been adequately addressed. This study was designed to assess the link between the BMPs in place, adherence to biosecurity and the relationship with the water quality parameters in line with health of the fish cultured in the cages by adopting the Knowledge, Attitude, and Practices theory in biosecurity. This is guided by the role played by the environment, virulent pathogens, and immunocompromised living organisms on fish disease occurrence.

1.3 Research objectives

1.3.1 General objective

To assess the Knowledge, Attitude, and Practices of biosecurity, BMPs and water quality effects in Nile tilapia cage aquaculture in Lake Victoria, Kenya.

1.3.2 Specific Objectives

- To assess the level of knowledge, attitudes, and practices of biosecurity and BMPs of *O. niloticus* cage aquaculture farmers in Lake Victoria, Kenya.
- To establish whether cage fish farming influences select water quality parameters.
- To determine whether there is an association between water quality and biosecurity and BMP compliance.

1.4 Research Questions

- What is the extent of Knowledge, Attitudes and Practices of fish farmers on biosecurity and BMPs in the cage aquaculture of *O. niloticus* in Lake Victoria, Kenya regarding prevention of fish diseases and fish kills?
- Are there water quality effects due to the cage aquaculture of *O. niloticus*?
- Is there an association between water quality and biosecurity and BMPs?

1.5 Hypotheses

Socio economic

H_0: The knowledge, attitude, and practices (KAP) of cage fish farmers to biosecurity are sufficient to address fish health.

H_0: The cage fish farmers are compliant to select Best Management Practices (BMPs) in cage fish farming.

Water quality

H_0: There is no effect of cage aquaculture on water quality in Lake Victoria, Kenya.
H_0: There is no seasonal effect on the water quality in Lake Victoria, Kenya.
H_0: There is no effect of cage location (sheltered or open water) on water quality.

1.6 Expected Output

- ✓ Report on the levels of Knowledge Attitude and Practices of cage aquaculture farmers to biosecurity in the cage aquaculture of *O. niloticus* in Lake Victoria, Kenya.
- ✓ Report on the effects of cage aquaculture on select water quality parameters, nutrients, and primary productivity in Lake Victoria, Kenya.
- ✓ Proposed areas of intervention for capacity building of the farmers in the biosecurity and BMPs in the cage aquaculture of *O. niloticus* in Lake Victoria, Kenya.

2 LITERATURE REVIEW

2.1 Global trends in Aquaculture

Global production of aquatic animals was estimated at 178 million tonnes in 2020, which showed a slight decline from 2018 (179 million tonnes). Of the total production, aquaculture accounted for 88 million tonnes (49%) while capture fisheries accounted for 51% (FAO, 2022) (Figure 1). A slight decline was also noted in the per capita consumption of fish from 20.5Kg in 2019 to 20.2Kg in 2022.

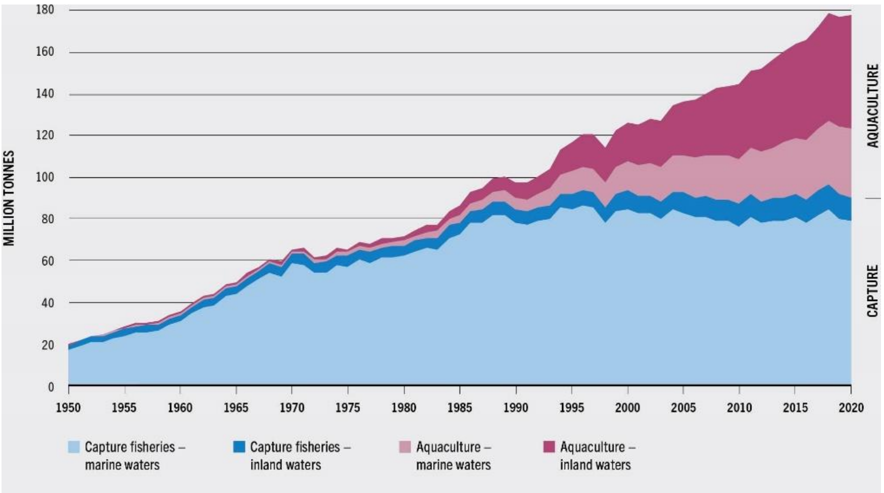

***Figure 1**: World capture fisheries and Aquaculture production from 1950 to 2020. FAO, 2022 State of Fisheries and Aquaculture report.*

Globally, aquaculture is often stated to be the solution to the increasing demand in fish and fishery products in the face of dwindling fish stocks (Orina, et al., 2018). Moreover, it has been said to be the fastest food producing sector globally, and contributes to food and nutrition security, and employment opportunities, and is a key income source to millions of people (FAO, 2020). Despite its steady growth, aquaculture has been faced by various challenges including aquatic pollution, genetic degradation of aquaculture species, decline of comparative profitability, lack of knowledge on market risks, financial crises and diseases (Xuepeng, et al., 2011). Fish diseases can result in significant economic losses as has been experienced by various industries and companies globally. The role of the interactions between the aquaculture environment, the well-being of the fish stock and the existence of pathogens are key in the establishment and proliferation of an aquatic animal disease (Hedrick, 1998).

2.2 Aquaculture in Kenya

Aquaculture in Kenya has grown rapidly over the last decade accounting for 12.8% of the total country’s fish production (Munguti, et al., 2021). The Government of Kenya has been instrumental in the rapid growth of aquaculture by continuously investing towards intensification of this sector. The government through the former Ministry of Fisheries, a project dubbed Fish Farming Enterprise Productivity Programme (FFEPP) under the National Economic Stimulus Program (ESP) that was initiated in 2009, resulted in enhanced vibrancy of the aquaculture value chain (Orina, et al., 2018). This programme resulted in the significant expansion of aquaculture production from 4218MT in 2006 to a peak of 24,096MT in 2014 (Obiero, et al., 2019).

In Kenya, mariculture is still at its infancy stage of development, while freshwater aquaculture is thriving, involving various culture systems. Ponds, RAS, Raceways, and cages are the main systems of culture in Kenya and are done in varying intensities (extensive, semi-intensive and intensive systems) (Opiyo, et al., 2018). Cage aquaculture of tilapia of the species *Oreochromis niloticus* within the Lake Victoria region, Kenya, has rapidly grown with the current estimates pointing to 3,000 cages (Aura, et al., 2022). The main species cultured in Kenya are Nile Tilapia (*Oreochromis niloticus*), Rainbow trout (*Oncorhynchus mykiss*), African catfish (*Clarias gariepinus*) and Common carp (Opiyo, et al., 2018). Aquaculture in the sub Saharan Africa has been growing at an average of 11% annually but since the beginning of 2015, fish diseases triggered by poor water and farm management practices, the high cost of local production, and competition from cheap fish imports coupled with the COVID-19 pandemic have all resulted in stagnation of production levels (Ragasa, Charo-Karisa, & Ruragwa, 2022). Therefore, there is a need to address these challenges to keep production growing. As the aquaculture industry focuses on creating a vibrant industry that is both profitable and environmentally sustainable, there is a need to utilise up to date information that is able to support the sector expansion, guide the regulatory processes, reassure the public, and conduct direct research aimed at improving the sector (Price, Black, Hargrave, & Morris, 2015).

2.3 Nile tilapia (*Oreochromis niloticus*) as an aquaculture species

Tilapia is considered the “aquatic chicken” due to their high growth rates, adaptability to a wide range of environmental conditions, ability to grow and reproduce in captivity, as well as their ability to thrive in low trophic levels (El-Sayed, 2006). Moreover, they are hardy, able to withstand low dissolved oxygen (1ppm), high ammonia levels (2.4 to 3.4mg/L unionized) and can grow in water with pH ranging from acidic (pH5) to alkaline (pH 11) (Chervinsky, 1982). Their ability to readily spawn in large numbers and undergo selective breeding make them the most attractive species for aquaculture (Watanabe et al. 2002). Various culture methods have been applied in the domestication of tilapia including ponds, tanks and raceways, recirculation systems and floating cages (El-Sayed, 2006), making it an attainable practice in almost any available environment on earth. A survey by Obiero and collegues (2014) on the consumer preference and marketing of Nile Tilapia (*Oreochromis niloticus)* and African Catfish (*Clarias gariepinus)* in Vihiga and Kirinyaga counties established that tilapia is the main species of culture in Kenya preferred by most households.

2.4 Best Management Practices (BMPs) as a tool in the management of aquaculture

Best Management Practices (BMPs) are methods utilized for production while at the same time reducing the environmental impact through pollution (Boyd, Lim, De Queiroz Queiroz, Salie, & Lorens de Wet, 2008). BMPs have been reported to be an effective and practical tool aimed at reducing the environmental impact levels to those compatible with resource management goals (Hairston, et al., 1995). Studies have shown that BMPs are site and species specific and there is also a need for regular updates to account for developments in the industry. According to Boyd and collegues (2008) and Howerton (2001), BMPs should address four main areas: water quality, site selection, farm operation and effluent management. Rich conceptual frameworks have been developed for BMPs in aquaculture by various organizations and researchers, most of which highlight lists of guiding principles on how management and other operational activities ought to be conducted (Boyd, Lim, De Queiroz Queiroz, Salie, & Lorens de Wet, 2008) (Henriksson, Dickson, Allah, Al-Kenawy, & Phillips, 2017). In their study on benchmarking the environmental performance of best management practice and genetic improvements in Egyptian aquaculture, Henriksson and collegues (2017) used life cycle assessment (LCA) to show that with the adoption of better management practices and genetically improved strains of tilapia, eFCRs could be reduced by a quarter, improving the economy of farmers and reducing environmental impacts of tilapia farming.

In cage aquaculture, the application of best practices enhances sustainability by safeguarding biodiversity and ecosystem services in the recipient waters, avoiding conflicts between the resource users while at the same time benefiting the farmers (Musinguzi, et al., 2019). A study by Portinho and collegues (2021) produced an integrated indicator for the assessment of BMPs in tilapia cage farming called the APOIA-Aquaculture indicator system, which aimed at providing objective measures, syntheses, interpretations and analyses of data by focusing on BMPs in tilapia cage aquaculture in 6 fish farms in Southeast Brazil. At the local level, the application of best practices in the cage aquaculture has been contrary to what is expected since most installations are close to the shoreline, in shallow sites (< 5M average depths) in eutrophic and hypertrophic waters (Musinguzi, et al., 2019). With increased investments in cage aquaculture, the industry requires the adoption of BMPs to ensure sustainability.

In Lake Victoria, Kenya, the assessment of site suitability before installation of cages has been inadequately regulated, resulting to most of the cages being poorly located (within 200m of the shoreline) in areas that are close to or within the fish breeding grounds and in areas conflicting with other resource users (Njiru, Aura, & Okechi, 2019). Poor location in areas without proper flushing enhances the effect of waste feed and fish wastes which increases eutrophication and enhances proliferation of nuisance species of algae and water hyacinth. In his study on the extent of cage aquaculture, adherence to best practices and reflections for sustainable aquaculture on African inland waters, Musinguzi and collegues (2019) studied 18 water bodies which were home to cage aquaculture systems and assessed adherence to BMPs by using chlorophyll a as a proxy of nutrients, depth of the holding body or site installation, proximity to protected areas and distance of installations from the shoreline. Their findings showed a spatial expansion of cage aquaculture in the water bodies and partial adherence to best practices.

2.5 Fish health and biosecurity management in cage Aquaculture systems

The FAO Biosecurity Toolkit (2007) defines biosecurity as a set of preventive measures designed to reduce the risk of transmission of infectious diseases and pests, living modified organisms and their products, and invasive alien species. Biosecurity for aquaculture has 5 main stages: Definition of the risks of introducing infectious agents, Identification of hazard points for introduction, Drawing up plans for control of hazard points, Putting the plans into effect, and Verification that the plans are followed (FAO, 2007). Due to increased productivity per farm unit, fish farming is quickly spreading into new areas, opening new infection routes. The stress reaction of fish to the conditions of their rearing exacerbates this (Murray, 2009).

Pathogens can be introduced through infected seed from hatcheries, food, contaminated equipment, personnel, vessels, and water currents (Arechavala-Lopez, Sanchez-Jerez, Bayle Sempere, Uglem, & Mladineo, 2013). Monitoring the health of aquatic animals, establishing biosecurity policies, and establishing surveillance areas are intended to reduce the transmission of illnesses along the various channels (Arthur, Bondad-Reantaso, & Subasinghe, 2008). If the implementation of biosecurity, environmental, and zoning regulations is improved, cage aquaculture systems, which are very productive, can be a significant driver of sustainable aquaculture growth (Ragasa, Charo-Karisa, & Ruragwa, 2022). For improved health management of farmed fish kept in cages, it is essential to have a complete grasp of the pathogens, disease processes, diagnosis, epidemiology, and control methods. A poor or compromised habitat, the presence of a virulent virus, and a susceptible host interact to cause fish illnesses (Figure 2) (Hedrick, 1998). They are divided into four categories based on the agents that cause them: bacterial, viral, fungal, and parasitic disorders. Except for South Africa, fish infections in Africa as a whole and especially in sub-Saharan Africa have not received much attention until recently (Hecht & Endemann, 1998), which has been attributed to the region's sparse aquaculture.

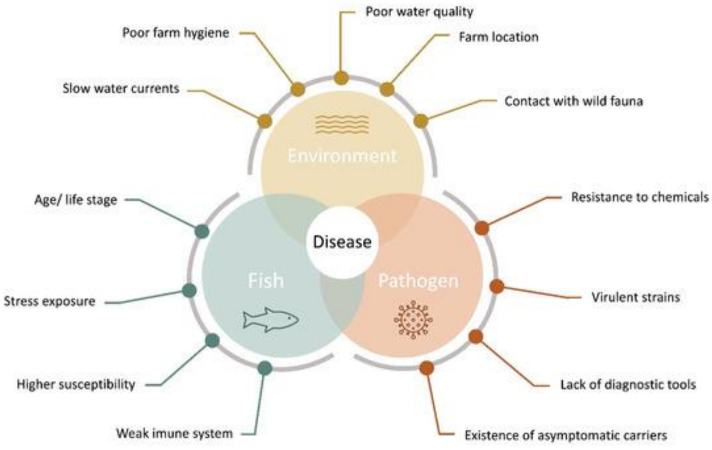

Figure 2*: Main factors for the evaluation of the pathogen and host pathogen interactions in the development of a disease (Adopted from Sitja - Bobadilla, 2017)*

Although many existing cage installations are only partially compliant with good practices (Aura, et al., 2022; Ragasa, Charo-Karisa, & Ruragwa, 2022), they are frequently poorly regulated and situated close to shore waters that are either eutrophic or susceptible. Ignoring proper standards while setting up and operating cage aquaculture is not only detrimental to the environment, but it may also disrupt and further discourage investment once farmers suffer fish kills and significant financial losses as a result. For a cage aquaculture operation, an understanding of the characteristics of the bodies of water is crucial since it will determine whether the fish cultured will be affected by poor water quality and especially by thermal de-stratification (Aura, et al., 2022) (Boyd, Lim, De Queiroz Queiroz, Salie, & Lorens de Wet, 2008). Other critical factors include the effect of the cage aquaculture operation on the surrounding water including enhanced eutrophication, conflicts with other resource users, effects of storms on the cages and other potential sources of pollution (Boyd, Lim, De Queiroz Queiroz, Salie, & Lorens de Wet, 2008). Governments must exert major influence over the development of cage aquaculture. Continuous disease monitoring and surveillance both inside and outside of borders, rapid disease diagnosis, and improved biosecurity in hatcheries and breeding facilities are all positive measures toward the control of diseases affecting aquatic animals.

2.6 The role of Water quality environmental management in fish health and Biosecurity

The development, establishment, and spread of a disease depend greatly on the fish environment. Important water quality characteristics include temperature, salinity, dissolved oxygen content, suspended particulate matter, and others. Any unfavorable changes can make fish more susceptible to illness. Boyd and Tucker (1998) state that any aquaculture system must take the water's quality into account. Environmental factors (availability of iron, osmotic force, oxygen levels, pH, salinity, and temperature) as well as the effects of poor management practices (inadequate nutrition, overcrowding, and overfeeding) can stress farmed fish, increasing their susceptibility to disease outbreaks. Fish farming can have significant impacts on nearby bodies of water through enrichment with phosphorous, ammonia, copper, organic matter and other nutrients and the consequent decrease in dissolved oxygen (Simoes, Moreira, Bisinoti, Gimenez, & Yabe, 2008). Accumulation of waste and a combination of other geological processes can consequently result in massive fish kills.

Massive fish mortalities in natural marine, freshwater and estuary systems as well as aquaculture systems have been widely reported (Svircev, et al., 2016). Hypoxia or anoxia, sudden temperature changes, acidification from sulfide mineral oxidation, toxic algal and cyanobacterial blooms, microbial pathogens (bacteria, protozoa, fungi, viruses), agricultural pollutants (such as pesticides, fertilizers, and animal waste), industrial pollutants (such as metals and hydrocarbons), municipal wastewater, and transportation have been reported as some of the common causes of fish kills.

Contrary to closed systems, cage aquaculture has a higher chance of pathogen incursion through water contaminated with pathogens, and it is very challenging to control this method of infection (Vijayan, Rajendran, Sanil, & Alavandi, 2015). The presence of *Streptoccocus agalactiae* in cage-grown red hybrid tilapia, *Oreochromis niloticus*, and *Oreochromis mossambicus* was found to be significantly correlated with water temperature, clarity, and pH in the Lake and ammonia, temperature, and dissolved oxygen in the river, according to a study conducted in Malaysia (Amal, Zamri-Saad, Siti-Zahra, & Zulkafli, 2015). They concluded that in field conditions, a variety of stresses affect the presence of and susceptibility to disease. The impact of the environment on the pathogen's ability to survive in the environment or on the host defensive mechanisms are two additional ways that the environment might affect the disease mechanism (Reno P. , 1998).

The influence of water temperature on fish health can be varied. Any alteration from the optimum for the species can induce stress in the animal, affecting feeding, growth, reproduction, and disease susceptibility (Lawson, 1995). For example, vibriosis, enteric redmouth, and furunculosis occur at temperatures above 10°C, while marine flexibacteriosis and freshwater cold-water illness occur at temps below 10°C. Temperature also has a significant effect in the development of other diseases (Roberts, 1986). With fast flow rates either shortening the interaction between a host and pathogen or better disseminating pathogens than slow flow rates, other water properties including water flow and water chemistry might influence the emergence of disease. Additionally, some sensitive agents may become inactive under the influence of certain chemical components (Reno P. , 1998). A further study on the effect of water temperature on the susceptibility of fish to vibriosis in a marine cage aquaculture system in Malaysia found a strong positive correlation ($p<0.01$) between temperature, presence of *Vibrio* and fish mortality (Albert & Ransangan, 2013). They established that water temperature can enhance susceptibility of cultured marine fish species to vibriosis. Considering that it is not practical to control temperature in an open water system, adherence to good aquaculture practices like frequent removal of biofilm on net cages and floating structures may help minimize *vibriosis* outbreaks and thus reduce fish mortalities in net cage aquaculture establishments.

Proper site selection is key in establishing a cage aquaculture system since it is impractical to control water quality parameters in such systems (Perez, Ross, Telfer, & Brguin, 2003). Locating cages close to the shore can have detrimental effects as far as fish health is concerned. Wastes discharged from cage aquaculture farms can have potential negative environmental effects which could limit development of the industry in some places due to environmental degradation. This has been seen in some areas, while in regions like northern Europe, the industry has learned from those mistakes and improved by ensuring lower environmental effects per unit of production mainly through a combination of improved feeds and proper cage setting (Grøttum & Beveridge, 2007). It is important to utilize the lessons learned to develop a framework for setting and operating cage aquaculture farms which maximizes production while minimizing the impacts on water quality (Price, Black, Hargrave, & Morris, 2015). Runoff from the adjacent land can introduce clay particles, nutrients and silt, increasing turbidity and causing growth of plankton which can be detrimental to fish. Excess turbidity can result in clogging of gills or trigger stress responses which then make the fish susceptible to disease (Lawson, 1995). Urban sewage discharges can also negatively impact fish health since it contains metals, oils, grease, detergents, and industrial wastes which could contain enteric bacteria, viruses, and the eggs of internal parasites (Perez, Ross, Telfer, & Brguin, 2003).

2.7 Fish health management and biosecurity systems in cage aquaculture of *Oreochromis niloticus* in Kenya

In the last 2 decades, the government of Kenya has made conscious efforts to promote fish farming in the country to be able to meet the growing demands for fish. Farmers within the Lake Victoria region have begun to invest heavily in the cage aquaculture of Nile tilapia (*Oreochromis niloticus*). This has resulted in increased population of cages with the latest statistics indicating more than 3,000 cages of varying sizes in the Kenyan portion of Lake Victoria (Aura, et al., 2022). Cage aquaculture systems in Kenya are grow-out systems and source their seed from hatcheries. Most hatcheries in the country use preventive measures to reduce the chances of infection and due to their ease of application and use, disinfection of farm equipment and aquaculture facilities is included in the health management system in hatcheries (Opiyo, et al., 2018). There are no quarantine facilities and the existing biosecurity measures are inadequate to monitor new introductions which has been blamed on the lack of personnel who are skilled in fish diseases (Lewo & Obwonga, 2017). Without quarantine facilities, the translocation of fish disease in the case of transboundary live fish trade becomes much more likely (Nzeve, Muendo, Opiyo, Odede, & Leschen, 2022). Proper biosecurity is key in the reduction of economic losses through fish mortalities and elevated and unnecessary treatment costs (Bhujel, 2014). A study conducted on the biosecurity systems practised in Siaya, Busia and Kakamega counties found that most fish farmers were not practicing biosecurity measures to prevent fish diseases and infections, probably due to a lack of awareness (Kyule-Muendo, et al., 2022). For those practicing biosecurity, the various attempts included timely removal of dead fish and water quality monitoring. The study established that only a small percentage (<2%) of the studied farms (n=504) practised disinfection to prevent introduction of pathogens into the system.

With the background provided, and considering that cage aquaculture is still rapidly expanding, this study made use of select sites to generate information about biosecurity and BMP systems in place by analysing the knowledge, attitude and practices of cage fish farmers which would then inform about their characteristics, the farming practices, which may consequently affect the occurrence and transmission of fish diseases, fish survival and suitability of the environment for the farming practices for sustainability and profitability of the aquaculture industry in the country. This study will make use of a quantitative approach to link some selected biosecurity and BMPs with water quality parameters and provide information to guide management.

3 METHODOLOGY

3.1 Study Design

3.1.1 Study Area

Lake Victoria is one of Africa's great lakes and the second largest freshwater lake in the world, occupying a surface area of 68,000 Km^2 . The lake is shared by 3 countries, Uganda (43%: 31, 000 Km^2), Tanzania (51%: 33,700Km^2) and Kenya (6%: 4,100 Km^2) (Aura et al. 2013). This study will be done in Kenya's portion of the Lake that has 5 administrative units (counties) by the names; Kisumu, Siaya, Busia, Homabay and Migori counties (Figure 3).

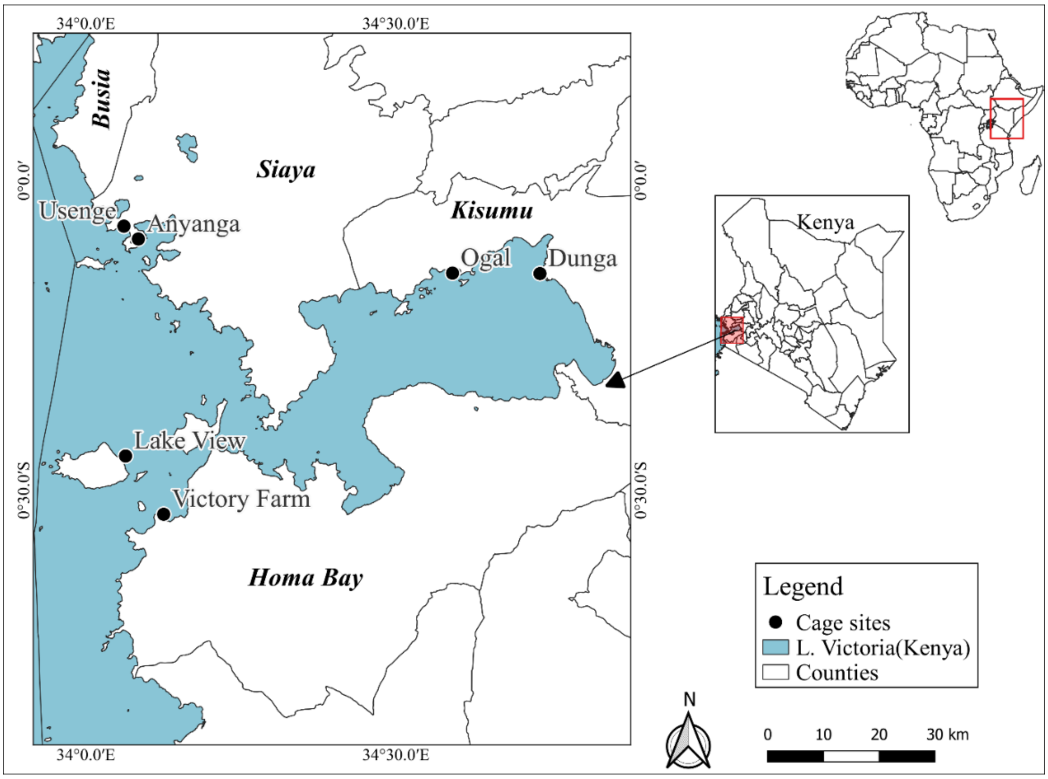

Figure 3: Location of Lake Victoria, Kenya showing the administrative counties where the data collection was conducted (Adapted from Aura et al., 2018)

This study focused on aquaculture systems in 3 counties: Kisumu, Siaya and Homabay. These were selected based on the criteria shown in Table 1. Pre-selected cage aquaculture establishments raising *O.niloticus* were used to provide the relevant information for this study.

Table 1: Justification for the counties and cage establishments chosen for this study.

County	Cage establishments	Justification
Kisumu	Dunga, Ogal	Cages located in the Nyanza gulf. The gulf has a lot of influence from the catchment and surroundings; water mixing is not so high; frequent cases of algal blooms; fish kills experienced.
Siaya	Anyanga and Usenge cages	This county has the highest number of cages in the Kenyan bit of Lake Victoria; densely aggregated together; site is in a sheltered area; fish kills experienced.
Homabay	Lake View, Victory farms	Cages located in the open waters; impact of flushing / supposed cleaner environment; individually owned; no cases of fish kills reported.

3.2 Data collection

This study utilised both primary and secondary data sources. The secondary data included reviews of existing literature for Lake Victoria, Kenya in relation to cage aquaculture of *Oreochromis niloticus*. The study also used primary data which was both qualitative and quantitative.

3.2.1 Socio economic data collection

For the qualitative data collection, 25 questionnaires were administered to cage farmers/ managers in proportion to the densities of the cages in the Lake in the 3 counties of Siaya, Kisumu and Homabay. 80% of the respondents were obtained from Siaya county while 12% were from Kisumu County and 8% from Homabay county. All respondents were interviewed with a structured questionnaire consisting of both close ended and open-ended questions assessing their knowledge, attitude, and practices (KAP) regarding on-farm biosecurity and farm management (Appendix 4). The KAP questions were modified from the aquatic animal survey conducted by Jia and collegues (2017) and a seaweed aquaculture analysis survey conducted by Kambey and collegues (2021). The questionnaires were administered physically to the farm owners/ managers with the aid of field assistants by using the kobo collect software (using the KoboToolbox, which is a data collection, management, and visualization platform).

3.2.2 Water quality sample collection and sample analysis

Quantitative data on water quality, nutrients, and primary productivity was gathered during a nine-month period between November 2018 and July 2019 on 4 cage farms and corresponding control sites (approximately 1Km away from the cage sites) in the counties of Kisumu, Siaya, and Homabay counties in Lake Victoria, Kenya. This data captured 4 seasons (Dry, Rain, Wet and Slightly Wet) and included both cage and control sites. This information was used to investigate if there were any potential effects of the cages on the water quality within the specified time, if there were seasonal influences, whether there were effects with respect to location (gulf/sheltered and open waters) or to stocking densities. Chlorophyll-a values were used as a proxy to determine if there were potential effects of elevated algae on the health state of the fish.

Physicochemical parameters were determined in situ at 1 m depth using a YSI multi parameter meter. They were measured in triplicate and included: pH, dissolved oxygen (DO), temperature, turbidity, conductivity, total dissolved solids (TDS), chlorophyll-a, alkalinity, and oxidation–reduction potential (ORP). Water transparency (photic depth) was determined by using a Secchi disk of 20 cm diameter. For nutrient analysis, three replicate water samples for were taken at 1 m depth and fixed using sulphuric acid (H2SO4) and kept at 4°C until laboratory analysis and final quantification. The following nutrient concentrations were determined; total nitrogen (TN), total phosphorous (TP), ammonium ($NH_4{}^+$), nitrates (NO_3) and nitrites (NO_2), using standard procedures (APHA, 2005; Wetzel & Likens, 1991). The levels of Chlorophyll-a in the samples were also determined using standard procedures with concentrations estimated using the Talling and Driver (1961) equations.

3.3 Data analysis

3.3.1 Water quality analyses

Statistical analysis was conducted using R version 4.1.2 (R Core Team, 2021) where a value was said to be significant at $p < 0.05$ in all statistical tests. A linear regression model was used to test for:

- Significant differences in key water quality parameters (WQPs) by season (Dry, rainy, wet, and slightly wet).
- Significant differences in key water quality parameters between cage and control sites.
- Significant differences in key water quality parameters by location (Gulf vs. open water).

3.3.2 Socioeconomic data analyses

Demographic parameters were extracted from questionnaires to provide a descriptive analysis and summary of socioeconomic features of the respondents. Additionally, various aspects of biosecurity were analysed to show the differing levels of knowledge, attitudes and practices and application of biosecurity in the cage aquaculture farming of Nile tilapia. The three sampled counties did not have equal representation (2 of the counties do not have enough cage farmers to provide the minimum number required for statistical analysis), so it was not feasible to compare them statistically. This study adopted some aspects of the APOIA-aquaculture indicator system (Portinho, et al., 2021) to rank the cage establishments for compliance to biosecurity and BMP aspects and propose some areas of intervention. According to this system, 68 APOIA – Aquaculture environmental performance indicators have been categorised into 5 dimensions of sustainability. The indicators were based on a scaling checklist which was then converted into utility values ranging from 0-1 where 0 was the lowest score, 0.5 the average score, and 1 was the highest score. The reference points for compliance were extracted from the East African Community Cage Aquaculture Guidelines (LVFO, 2016). The performance indices per category were then aggregated to compose an overall performance index. Based on the weights of importance of the various factors under investigation and their impacts to the aquaculture systems, the firms were divided into the following categories: Good: 69-100, Average: 50-69 or Poor: 0-49. This index was used to point to the level of BMP and biosecurity compliance and propose areas of intervention to the aquaculture cage firms. The chosen indicators for this study were:

- Minimal annual depth
- Distance to shore

- Disinfection
- Procedures of vaccination and prophylaxis
- Stocking density
- Control of predators
- Control and record of fingerling origin
- Control and record of behavioural symptoms
- Bookkeeping of fish mortalities
- Procedure for disposal of dead fish

Pearson’s correlation analysis was used to determine the effect of age (years) and experience in fish aquaculture activity (years) on the biosecurity compliance score.

4 RESULTS

4.1 Status of biosecurity and BMPs in cage aquaculture

4.1.1 Demographic characteristics of the questionnaire respondents

Demographic characteristics of the respondents have been summarised in Table 2. A total of 25 respondents were interviewed from 3 counties surrounding Lake Victoria, Kenya: Kisumu, Siaya and Homabay. Of those, 92% were male while 8% were female, reflecting the gender disparity that exists within the aquaculture sector for this geographic region. The majority of respondents (40%) were in the 36 to 45 age group and most (60%) had completed at least some secondary level education. Of the interviewed fish farmers, majority (84%) had other sources of income besides fish farming while only 16% had fish farming as their main source of income. Other economic activities included fishing, small scale businesses and agricultural farming. Majority of the respondents (68%) had between 1-5 years of experience in farming tilapia, which is in line with the period in which the number of fish cages in the Kenyan part of Lake Victoria expanded.

Table 2: Demographic characteristics of respondents from the study including gender, age, highest education level, main income source and experience in cage aquaculture.

Variable	Category	N	Proportion
Gender	Female	2	8%
	Male	23	92%
Age	18-25	2	8%
	26-35	5	20%
	36-45	10	40%
	46-55	7	28%
	>56	1	4%
Highest Education	Primary	6	24%
	Secondary	9	36%
	Some primary	4	16%
	Some secondary	3	12%
	Some tertiary	1	4%
	Tertiary	2	8%
Fish farming main income	Yes	4	16%

	No	21	84%
Experience (years)	1-5	17	68%
	6-10	7	28%
	>10	1	4%

4.1.2 Compliance to select BMPs & biosecurity practices and knowledge of biosecurity

By using the customised biosecurity performance index tailored for this study, the farms were ranked based on their scores (expressed as a percentage) as seen in Table 3. Out of the 25 sites sampled, 2 ranked Good (69% -100%), 6 ranked Average (50 – 69%) and 17 ranked poor (0-49%). The sites that scored "good" were both located in the open waters where there are more currents hence better circulation of water. An overall evaluation (Figure 4) of the various categories captured within the Aquaculture performance index score showed that all the farms had the right stocking density according to the regulations in place. Additionally, the farms were on good course with regards to control of predators which were mainly birds. However, key biosecurity areas including disinfection procedures, water quality monitoring, recording origin of fingerlings, mortalities and quarantine procedures for new stocks are the areas that need to be addressed moving forward.

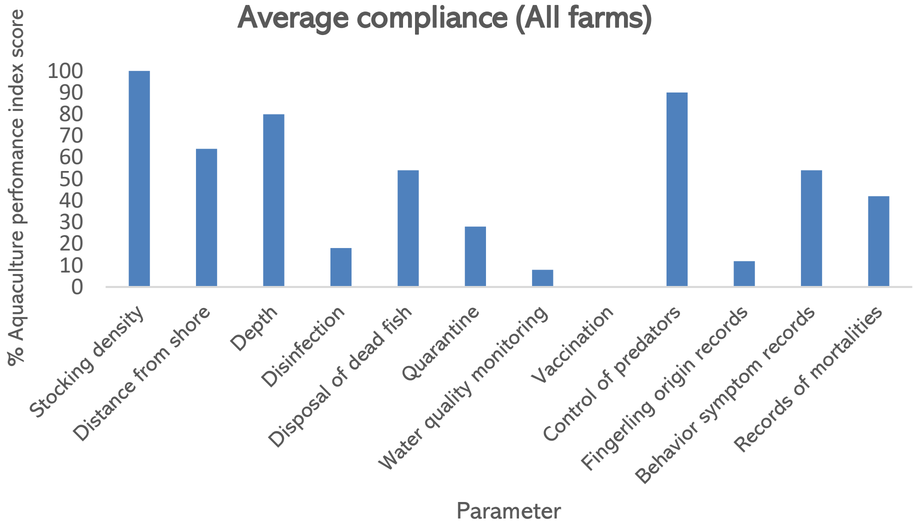

Figure 4: Summary of performance scores across studied aquaculture farms in Best Management Practice categories.

The Pearson's correlation analysis found that neither age nor experience had a significant effect (*p >0.05, Appendices 1&2*) on the biosecurity score. Literacy levels among cage aquaculture farmers was moderate with most of them having completed at least some secondary education (60%). Only 32% had some training relevant to fish culture from which 28% was from extension services and (8%) had received the training from tertiary education.

Table 3*:* Breakdown of BMP compliance scores by farm for the 12 categories of compliance adapted from the APOIA performance indicators *(Portinho, et al., 2021)*.

Farm ID	Stocking density	Distance from the shoreline	Depth	Disinfection	Procedure for disposal of dead fish	Quarantine and monitor new fingerlings/ broodstock	Water quality monitoring	Vaccination and prophylaxis	Control of predators	Record of fingerling origin	Record of disease symptoms	Mortality records	Score (%)	Biosecurity compliance
1	1	1	1	1	1	1	1	0	1	1	1	1	91.67	Good
2	1	0	1	0	0	0	0	0	1	0	0.5	0	29.17	Poor
3	1	0	1	0	0	0	0	0	1	0	0.5	0	29.17	Poor
4	1	0	0	1	0	1	0	0	0.5	0	0.5	0.5	37.50	Poor
5	1	1	1	0	0	0	0	0	1	0	0.5	0	37.50	Poor
6	1	1	1	0.5	0	0	0	0	1	0	0.5	0	41.67	Poor
7	1	0	1	0.5	1	0	0	0	1	0	0.5	0.5	45.83	Poor
8	1	1	1	0	0	0	0	0	1	0	0.5	0	37.50	Poor
9	1	0	1	0.5	1	0	0	0	1	0	0.5	0	41.67	Poor
10	1	0	1	0	0	0	0	0	1	0	0.5	0.5	33.33	Poor
11	1	0	1	0	0	1	0	0	1	1	0.5	1	54.17	Average
12	1	1	1	1	1	1	1	0	1	1	1	1	91.67	Good
13	1	1	0	0	1	0	0	0	1	0	0.5	0.5	41.67	Poor
14	1	0	1	0	1	1	0	0	1	0	0.5	0.5	50.00	Average
15	1	1	1	0	0	0	0	0	1	0	0.5	0.5	41.67	Poor
16	1	1	1	0	1	0	0	0	1	0	0.5	0.5	50.00	Average
17	1	1	0	0	0	0	0	0	1	0	0.5	0	29.17	Poor
18	1	1	1	0	1	1	0	0	1	0	0.5	0.5	58.33	Average
19	1	1	1	0	0	0	0	0	1	0	0.5	0.5	41.67	Poor
20	1	1	1	0	1	0	0	0	0.5	0	0.5	0.5	45.83	Poor
21	1	0	0	0	1	1	0	0	0.5	0	0.5	0.5	37.50	Poor
22	1	1	1	0	1	0	0	0	1	0	0.5	0.5	50.00	Average
23	1	1	0	0	1	0	0	0	1	0	0.5	0.5	41.67	Poor
24	1	1	1	0	1	0	0	0	1	0	0.5	0.5	50.00	Average
25	1	1	1	0	0	0	0	0	0	0	0.5	0.5	33.33	Poor

4.1.3 Knowledge of and attitude towards biosecurity measures in fish farms

An analysis of the correlation between the Aquaculture performance index score and various practices of the study indicated a positive correlation and significant differences ($p<0.05$) between the scores and disinfection procedures, proper disposal of dead fish, monitoring of new fingerlings of brood stock, water quality monitoring, keeping records of; the origin of fingerlings, behavioural symptoms, and mortalities (Appendix 1). The respondents for this study showed varying levels of knowledge of biosecurity practices in their aquaculture systems. Categories considered most important in biosecurity by the respondents were: the need for taking precaution before introducing new fingerlings on the farm, removing all the old stock and restocking with only the new stock of fish (53.8%), leaving the farm empty/fallow for some time before restocking (30.8%), and removing and sun-drying nets for two weeks before restocking (15.4%). The majority of surveyed farmers assess fish health daily (20%) or weekly (24%) but do not vaccinate the fish (100%). Vaccination is a way of reducing or preventing the clinical manifestation of disease and dependence on antibiotics which eventually improves the economics of the fish farming enterprise (Thorainsson & Powell, 2006). With the current trends of intensification of this aquaculture system, vaccination can be explored as an option to boost the immunity and survival of farmed fish.

Respondents had a generally positive attitude to various biosecurity activities included in Best Management Practices (Figure 5).

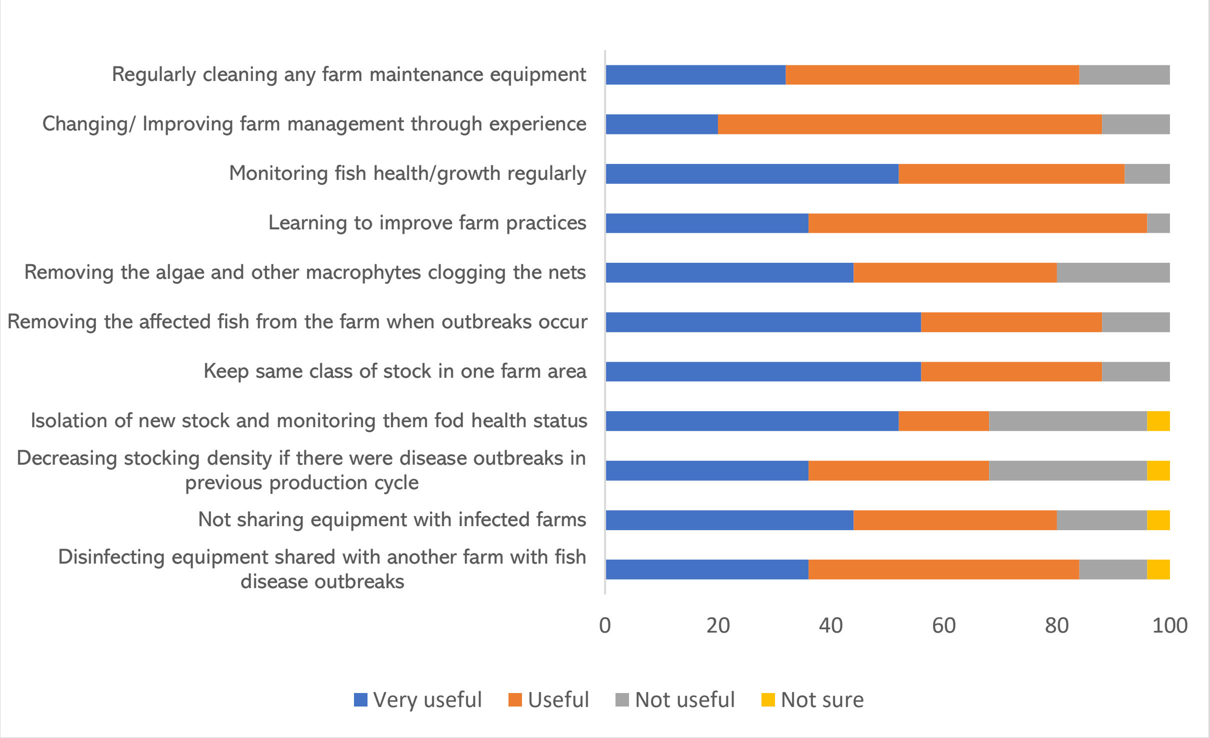

Figure 5: Responses of fish farmers to the perceived usefulness of different biosecurity measures from very useful to not useful or unsure.

4.2 Impacts of cage fish farming on physical chemical parameters, nutrients, and productivity

4.2.1 Seasons, Station, and Site effects on the water quality

This study investigated the effects of location (gulf vs open water), season, and fish cage presence on water quality. A linear regression analysis indicated that there were no significant differences ($p>0.05$) between areas with cages and those without cages for all water quality variables investigated (see exact values in Appendix 3). Figure 6 shows box plots of Dissolved oxygen and Chlorophyll-a concentration, showing the large spread of the data. A similar spread was seen in the other water quality parameters between the cage and non-cage sites.

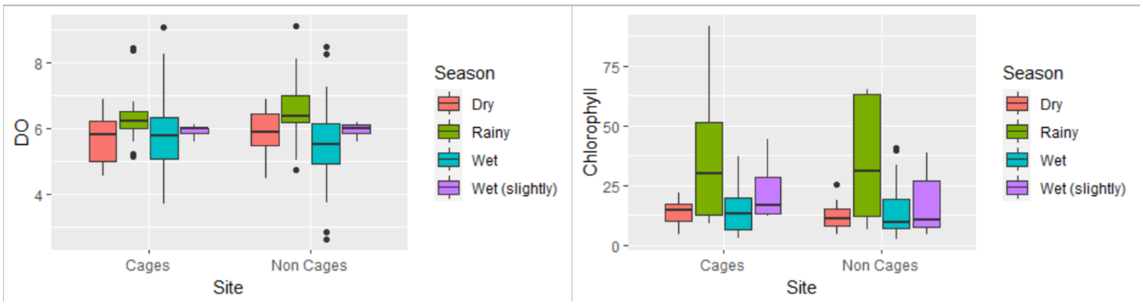

Figure 6: Boxplot representations of the data for Dissolved oxygen and Chlorophyll-a concentration between cage sites and non-cage sites, by season.

However, significant differences were noted ($p<0.05$) in some water quality parameters between the 4 seasons (Dry, Rainy, Wet, Slightly wet) as summarised in Appendix 3. Station effects (gulf or open water) were also noted, with various parameters showing significant differences between the gulf and open waters ($p<0.05$). Seasonal effects with respect to the 4 seasons investigated were noted (Dry, Wet, Wet-Slightly and Rainy) and significant interactions between the stations and seasons for 9 out of the 18 parameters investigated. Most of the water quality parameters complied with the recommended ranges in cage aquaculture, according to the E. Africa Cage Aquaculture Guidelines ((LVFO, 2016). However, deviations from the recommended values were noted in some parameters in the gulf; TDS values for some of the gulf sites were up to twice the recommended values (>40mg/L) including Secchi depth ranges (<70cm), Total phosphorous (>100µg/L) and chlorophyll (>75µg/L). Details from the model are included in Appendix 3.

Significant differences were noted in some physical chemical parameters including Turbidity, TDS, and Secchi depth (Figure 7). From this figure, the general trend was that in the gulf, there was more turbidity and TDS as compared to the open waters. Additionally, as expected the rainy season had higher values for these 2 parameters within the gulf, and little to no effect on the open water locations. Secchi depth also followed this trend, showing lower depths in the gulf as compared to the open waters.

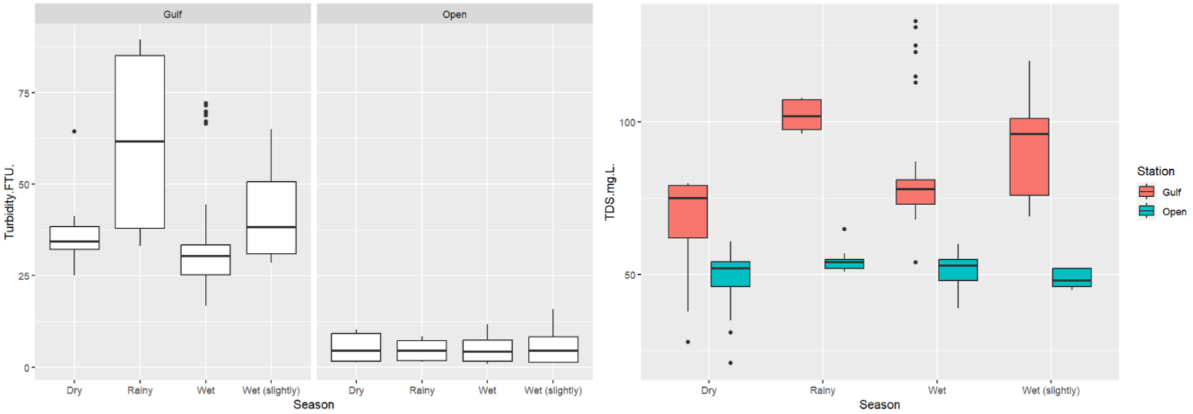

Figure 7: Differences between seasons by station in Turbidity (FTU), Total dissolved solids (mg/l) and Secchi depth (m) showing the medians, first and third quartiles.

4.2.2 Seasons, Station, and Site effects on Nutrient variations

The study found that generally, nutrients were more concentrated in the gulf as compared to the open waters but again were within the recommended values (Figure 8). Nitrite values were lower as compared to the nitrate values and had higher concentration in the dry season as compared to the nitrates whose highest value was at the slightly wet season.

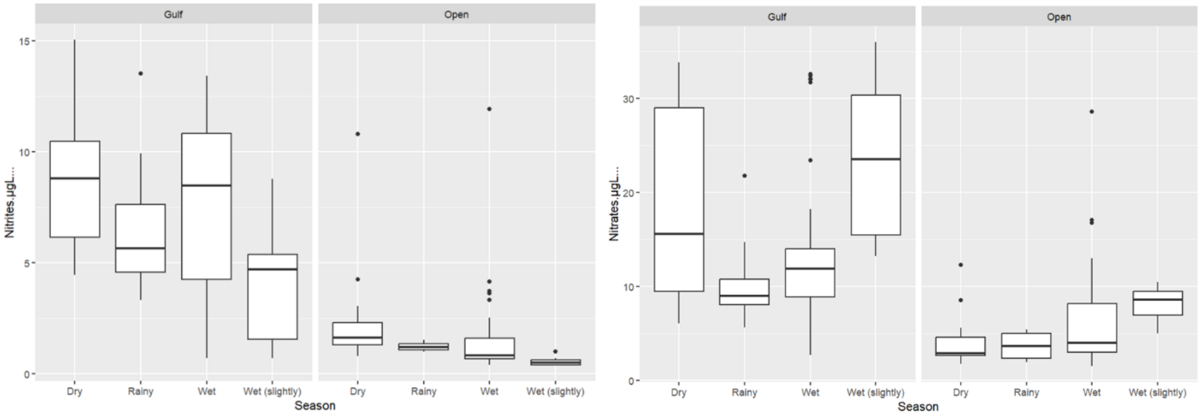

Figure 8: Box plots showing representation of the spread of data in Nitrites and Nitrates (µg/l) for the open and gulf stations in the 4 seasons.

4.2.3 Seasons, Station, and Site effects on Primary productivity

Primary productivity showed similar trends as those observed in the nutrients and physical chemical parameters.

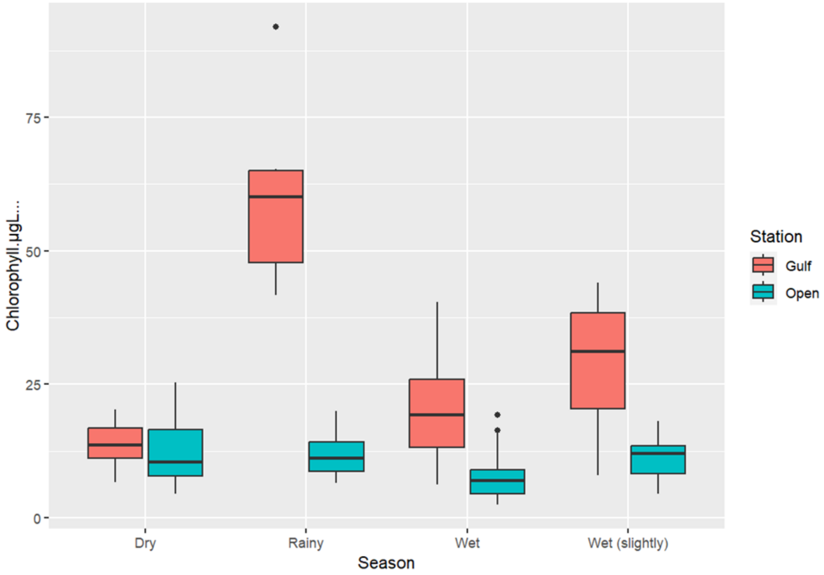

Figure 9: Box plot of primary productivity (Chlorophyll a) between the 4 seasons by station (Open water and gulf).

A plot to determine the relationship between Total Dissolved Solids and chlorophyll-a concentration showed that the relationship explained 79% of the variation during the rainy season (Figure 10).

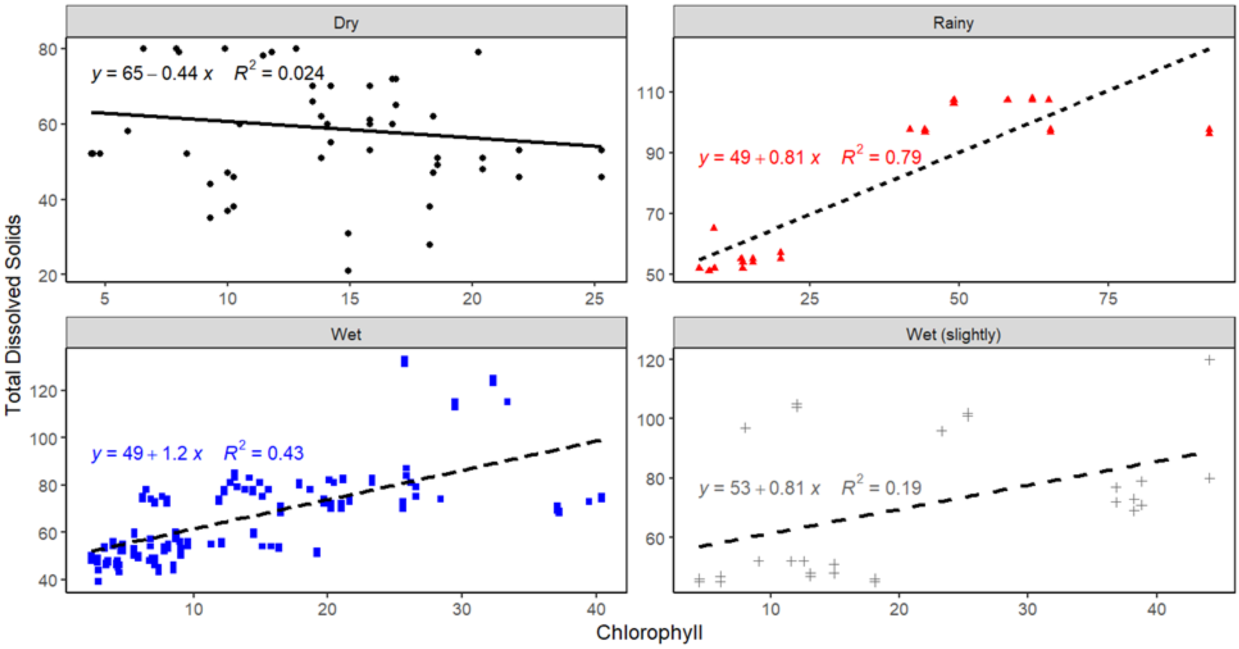

Figure 10: Multiple gg plot showing the relationship between TDS and chlorophyll in the 4 seasons (Dry, Rainy, Wet and Wet (slightly). The high effect size (R^2=79%) in the rainy season points to the strong inter relationships of the 2 variables.

4.3 Relationship between water quality and the biosecurity and BMP performance score

Pearson's correlation analysis results from this study (Appendices 1&2) found that there were minimal correlations between various water quality parameters under investigation (Figure 11).

4.3.1 Performance score vs physico chemical parameters

Results from the correlation analysis showed that the Aquaculture performance index score (% score) had a positive correlation with secchi depth (Figure 11), showing that farms with higher water clarity had a higher performance score.

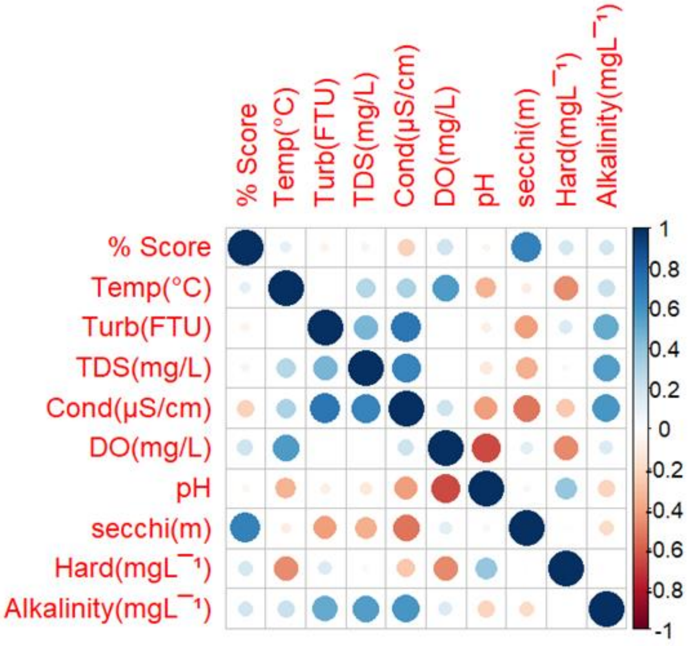

Figure 11: Pearson’s correlation between the % performance score and water quality parameters investigated in the study showing positive correlation between the performance score and the secchi depth values.

4.3.2 Performance score vs nutrients and primary productivity

Additionally, looking at the correlation between the Aquaculture performance index score (% score) and the nutrients and primary productivity (Figure 12), there is a distinct negative correlation between the % score and the ammonia values. This shows that the farms that had a high performance score were those with low ammonia levels.

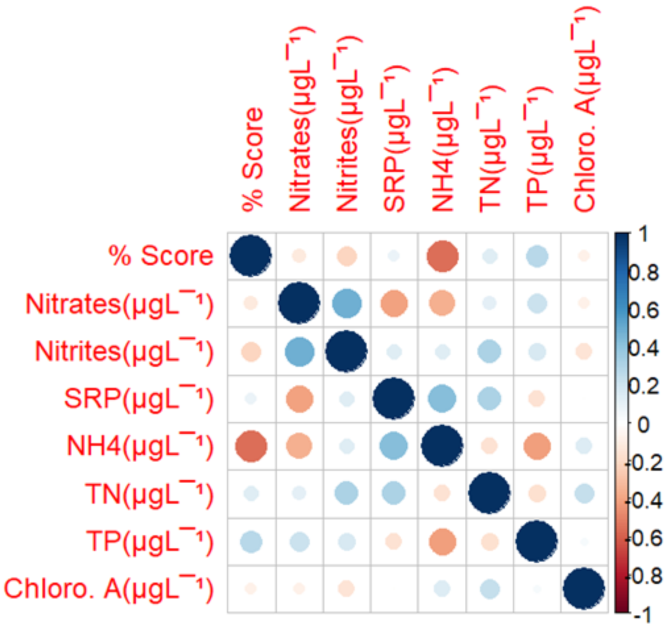

Figure 12: Correlation between the % performance score and the nutrient parameters, showing a strong negative correlation between the score and ammonia values.

5 DISCUSSION

This study was conducted to assess the knowledge, attitudes, and practices (KAP) of biosecurity and best management practices (BMPs) of Nile tilapia cage aquaculture farmers in the Lake Victoria region of Kenya, to determine if there were effects of cage aquaculture on water quality and to establish if there was a link between water quality and biosecurity compliance. Findings indicated that the attitudes and knowledge of the farmers were not in line with the best practices. Additionally, cage aquaculture did not show any effects on the studied water quality parameters and lastly, it was established that ammonia was higher in farms that had little biosecurity compliance, showing the need to incorporate biosecurity into the fish farming system.

5.1 Socio demographic characteristics of the respondents

The study identified gender disparities in ownership and management of the aquaculture systems, which is something that has been found by others within the same regions (Aura, et al., 2018; Githukia, et al., 2020; Namaemba, Sibiko, & Ogello, 2022). Among the reasons for this disparity is the fact that the labour intensiveness of cage culture operations tends to keep women out of the active rearing process in the cages. Women are more likely to work in other areas of the value chain, for instance processing and marketing. However, studies conducted in Nigeria attributed this to the growing demands on males in families that are required to look for additional sources of income (Adah, Saidu, Oniye, & Adah, 2023). The fact that the majority of the respondents had other business ventures aside from fish aquaculture could have a downside in that not enough attention would be given to their farms, hence inadequate management which would then compromise the growth, performance and health of their stocks. An interesting observation from the study was that neither age nor experience influenced the overall score obtained by the respondents. This is contrary to findings by Omitoyin and Osakuade (2021) who found that younger people tended to be more productive in comparison to the elder people since they were more energetic, and more flexible to improvements/ changes in the sector which is necessary for growth. Nonetheless, the blend of the respondents in this study could suggest that aquaculture is now being embraced by even the younger age bracket which is in line with studies by Kumar and collegues (2015) who found a shifting pattern from the older to younger generation of fish farmers.

5.2 Knowledge, Attitudes and Practices of fish farmers on biosecurity and BMPs in line with prevention of fish diseases and fish kills

Our findings showed that the Knowledge, Attitudes and Practices (KAP) of biosecurity by the farmers in this study was relatively moderate, showing compliance to some biosecurity practices in line with the set standards according to the East African Community cage aquaculture guidelines (LVFO, 2016). To develop and implement a biosecurity plan, knowledge of the aim of biosecurity with regards to preventing fish diseases is key. Along those lines, knowledge of the symptoms of sick and unhealthy fish and their causes and modes of transmission is vital. From the survey, a majority of the farmers reported knowing symptoms of fungal infections, though most lacked any knowledge of the characteristic presentations of bacterial, parasitic, and viral infections pointing to the need to provide aquaculture farmers access to diagnostic and independent disease control advisory services. These findings are like those noted in a study in hatcheries and fish cages in Western Kenya where the farmers also saw that fungal infections were the most abundant in their systems occurring mostly in the cold/ rainy season (Kyule-Muendo, et al., 2022). Additionally, in as much as they knew the presentations of some of these diseases, they were limited in knowing the causes of the infections. Similar findings were noted in an assessment of the KAP of the yellow catfish aquaculture in China, pointing to gaps in knowledge (Jia, Hilaire, Singh, & Gardner, 2017).

Among the key components of biosecurity are disinfection procedures and processes. This study found that the farmers downplayed the role of disinfection of materials after a production cycle in the prevention of possible disease transmission. This survey established that only 20% of the interviewed farmers practiced disinfection after completion of a production cycle. The main mode of disinfection was washing and sun drying while chlorine and table salt were used by some proportion of the farmers. Similar modes of operation were used in cage aquaculture farms in Cat Ba Island, Vietnam (Chi, Clausen, Van, Tersbol, & Dalsgaard, 2017), where farmers cleaned their nets using high pressurized marine water and then air dried them in-between production cycles unlike in their pond systems which use chemical disinfectants. According to that author, pond systems in Vietnam apply chlorine-based compounds to disinfect water in storage ponds, often without knowledge of the type of disinfectants and their mode of action. A review of literature found that most biosecurity practices are executed at the hatcheries, while little to no biosecurity is done at the grow out stages of fish culture (Kyule-Muendo, et al., 2022). The significance of the annual upwelling events in the Lake in causing massive mortalities was affirmed by most of the respondents (88%) some of whom stated that they had encountered losses (60%) from it. Massive mortalities have happened in the lake lately and the reasons have been varied including climate change effects (Seafood source, 2022). The effects of this phenomenon on stocks can be aggravated by poor management and practices. Considering that most of the respondents in this study were in sheltered areas and in the gulf, it is important that this culture system is promoted in the open waters where such effects are minimal to ensure productivity and profitability of the fish farmers and again to ensure sustainability of the lake ecosystem.

Nevertheless, the study established that there was a relatively good score on the attitude of the respondents to the various aspects of biosecurity and BMPs in cage aquaculture. However, the attitudes did not support what the farmers claimed to be practicing on biosecurity. This was like what was observed in the evaluation of the KAP of yellow catfish aquaculture (Jia, Hilaire, Singh, & Gardner, 2017) and in a study conducted on commercial finfish recirculating facilities in the United States and Canada, which then points to a need for further focus on capacity building. Another approach to this would be in conducting further research on developing a cost benefit analysis of the adoption of biosecurity systems in cage fish farming (Delabbio, et al., 2005). This would be able to provide fish farmers with empirical evidence on the usefulness of incorporating biosecurity into their systems of operation. However, the study found that there was uncertainty in several key elements of biosecurity for instance the role of the government in its control of the fingerlings, risks of sharing equipment between farms, the importance of knowing the source of fingerlings, quarantine of new stocks, decreasing stocking density, record keeping and regular disinfection of farm equipment.

However, considering the intensification of this culture system to meet the demand for fish in the region, investors are out to get the best seed stock to optimise in productivity and profits in the long run. A previous study found that investors can get seed stock from the neighbouring country without much trouble (pers. comm) pointing to gaps which could result in cross transmission across the borders. Additionally, with growing global trade, the risks of translocation of diseases through seed and brood stock needs to be addressed (Opiyo, et al., 2018; Akoll & Mwanja, 2012; Bondad-Reantaso & Subasinghe, 2008). This can be done through strict government controls of imports and quarantine of new stock. Considering that the cages are all located within the same water body, a compromise by one investor can multiply and result to huge losses to many investors hence the need to ensure strict compliance.

Generally, this study established that there are gaps in the implementation of biosecurity practices on cage aquaculture farms. This was also found in a study by Kyule-Muendo and collegues (2022) and Obiero and collegues (2019) who stated that a lack of technical skills can hinder the uptake of biosecurity practices and adoption of best management practices in an aquaculture farm. Water quality monitoring is another key pillar in biosecurity and BMPs, but it was established that only a few farmers did this. Of those monitoring water quality, the majority monitored for clarity of the water some using standard equipment (secchi disc) while others used unconventional means (dipping the hand to check for clarity). Dissolved oxygen, a key parameter, was assessed by only a small fraction of the farmers. The use of chemicals for disease treatment and control is not allowed in the lake due to various reasons including the fact that it is a multi-use resource, there is a risk of anti-microbial resistance etc. The study established that sodium chloride was the most used prophylactic for any abnormalities noted in the fish. A small fraction of the respondents stated that they allowed for natural healing to take place. The need for an understanding of the roles played by the environment, pathogens and the fish hosts are key and could result to better adoption of biosecurity practices on aquaculture farms (Sitja-Bobadilla & Oidtman, 2017).

The survey established that sharing of equipment across farms was not considered as a breach of biosecurity protocol. It is important to make the farmers realise that by sharing equipment between farms, there is a risk of transfer of infections from one farm to the next. Removing affected fish from the farm when outbreaks occur and keeping the same class of stock in one area was a very useful aspect of biosecurity by the farmers. On the other hand, government controls of fingerlings ranked the least in importance among the respondents, which points directly to the situation on the ground since farmers can source their fingerlings from anywhere without the need to comply to any strict regulations. This study found that on average, almost all the farms were taking precautions to protect the farms from predators. Record keeping is key in any biosecurity program. The study found that in as much as the responses were that the farmers claimed to keep records, most of them relied on memory recall, since they could not provide the records for verification by the team on the ground. These findings are similar to those by Adah and collegues (2023) who investigated the status of biosecurity in catfish fish farms in Nigeria stating that mortality records are one of the most important records in a farm since one can easily notice if there is a problem developing and institute measures to avert it.

The role of laws and regulations to guide enforcement and compliance is an important factor in any enterprise. Despite having the EAC regulations, they are yet to be incorporated into the management of cage fish farming in Kenyan waters (Aura C. M., et al., 2021). Additionally, most fish farmers are not aware of the existence of the specific cage aquaculture regulations hence are not able to comply accordingly to what has not been captured in the Fisheries Management and Development Bill, the general policy document guiding fisheries and aquaculture in the country.

5.3 Impacts of cage aquaculture on water quality parameters.

Water quality monitoring is key in ensuring fewer impacts on the environment and ensuring higher productivity at a lower cost (Zhang, et al., 2020), which is beneficial to the fish farmer. There was no significant difference in the studied water quality parameters between the areas with cages and those without cages for the sites under investigation in this study. This could suggest that cages have not yet altered the water quality within the studied regions or, as in Musa, Aura, Tomasson, Sigurgeirsson, & Thorarensen (2022), the lake was able to absorb the perturbations caused by the cage aquaculture systems in the region. However, the authors found that the benthic fauna had undergone changes, and that even after the 4-month fallowing period, these organisms had not gone back to the initial state. The current study did not analyse the benthic fauna and thus could have missed a potential bio indicator of the impacts of cage fish farming in the region. Despite these findings and those of other authors, there is a need to exercise caution as the culture system intensifies, and considering the cyclic annual pattern of lake mixing (Orina, et al., 2018), which can result in re-suspension of accumulated debris from the bottom, leading to compromised water quality (Njiru, Aura, & Okechi, 2019), stressed fish and increased susceptibility to opportunistic infections and even massive mortalities, as have already been noted in the lake in the recent past (Orina, et al., 2018; Njiru, Aura, & Okechi, 2019).

Significant differences were noted between the gulf and open waters in most of the parameters investigated though most of the parameters were within the recommended values as stipulated in the East African community cage aquaculture guidelines (LVFO, 2016). However, Total

Dissolved Solids, Secchi depth, Total phosphorous, and chlorophyll values for some of the gulf sites were beyond the recommended values. Excess turbidity can be detrimental to fish in that it can lead to clogging of the gills or trigger stress which then makes the fish susceptible to diseases (Lawson, 1995). Elevated chlorophyll levels were also observed by (Musa S. A., 2022) who looked at the changes in various components in a dense aggregation of cages within Lake Victoria, Kenya. The authors attributed the high chlorophyll a level to the elevated N and P concentrations from fish feed and faecal matter resulting in dense algal blooms. Similar findings by Aura and collegues (2021) found elevated levels of chlorophyll a in cage sites and attributed it to the cumulative effect of eutrophication processes in the lake that were attributed to feeds and fish wastes.

A study on the relationship between water quality and bacterial populations in a tropical marine cage aquaculture farm found that elevated chlorophyll a levels had a positive relationship with elevated bacterial populations of *Vibrios* which arise from the high organic loading from fish feed and excretion (Arulampalam, Yussof, Shariff, Law, & Rao, 1998). Moreover, shifts in the bacterial community beneath cages was observed in a marine fish farm which then concluded that the fish farm waste resulted in a shift in the microbial metabolism pathways from aerobic to anaerobic, which could eventually have an impact on the ecosystem (Vezzuli, Chelossi, Riccardi, & Fabiano, 2002). The present study did not look at bacterial loading, but by using the elevated chlorophyll levels in the gulf as a proxy, there is need to check on nutrient loading in the system through fish feeds and excreta by having the cages located in the open waters where organic loading is easily flushed out and not much accumulated, hence protecting the fish from such negative effects. Moreover, elevated chlorophyll a level can result in algal blooms, which would then reduce the carbon dioxide in the water and increase the pH which could be detrimental to certain species of fish (Kann & Smith, 1999). Consequently, a collapse of the blooms would result to its decomposition, reduced dissolved oxygen and elevated ammonia which is also toxic to the fish (Svircev, et al., 2016).

Seasonal effects with respect to the 4 seasons investigated were noted which could point to the effects of allochthonous inputs from the catchment during the rainy and wet seasons. There were significant interactions between the stations (open water or gulf) and seasons in 50% of the parameters investigated.

5.4 Link between water quality and biosecurity and BMPs

A negative correlation between ammonia level and aquaculture performance index score (%) was observed, suggesting that ammonia accumulation can have negative impacts on aquaculture performance by altering a fish’s physiological state (Esam, et al., 2022). Additionally, it has been found that acute and chronic exposure to high levels of ammonia in the water could result in tissue damage due to oxidative stress (Hoseini, et al., 2022) and elevated stress levels, thus compromising fish immunity. Worth noting however is that the values recorded in this study were within the recommended values for fish culture according to the EAC cage aquaculture guidelines (LVFO, 2016). This could further go towards recommending location of cage investments in the open.

Positive correlations were shown between the biosecurity score and various practices of the study such as the % performance score and disinfection procedures, proper disposal of dead fish, monitoring of new fingerlings of brood stock, water quality monitoring, keeping records of the origin of fingerlings and keeping records of behavioural symptoms and mortalities of fish. In summary, the study established that biosecurity is key in ensuring a good environment for fish in aquaculture farms. Additionally, findings also indicate that locating cages out in the open has better prospects considering it is a cleaner environment, and with minimal seasonal effects, hence a more stable environmental condition is ensured. This would eventually result in minimal stressors to the fish, making them less susceptible to infections. This therefore points to the fact that adherence to good biosecurity practices could promote a better outcome in the cage aquaculture of Nile tilapia in the Lake Victoria.

5.5 Limitations and further research

The present study was limited by sample size. Considering that the number of investors has been fast rising in the last decade (Musa S. A., 2022) there is a need to conduct a wider survey that would give a better representation of the diversity of aquaculture practices. Additionally, it would be very useful to conduct the entire system evaluation of the APOIA-Aquaculture indicator system (Portinho, et al., 2021) which would provide a more comprehensive and wholesome biosecurity analysis and inform better on the gaps that need to be filled in the entire system. Further on, there is a need to conduct a cost benefit analysis of investing in biosecurity systems to enable the investors make evidence-based decisions on the importance of adopting biosecurity in their systems. Finally, this study proposes basic capacity building for cage investors and managers to start with on the various aspects of biosecurity and BMPs compliance.

6 CONCLUSION

As Kenya works towards boosting its fish production to respond to a deficit in fish supply through promotion and intensification of aquaculture, biosecurity, compliance with best management practices, and water quality management becomes key. This study set out to assess the integrated role played by biosecurity Knowledge, Attitude and Practices (KAP), adoption of Best Management Practices (BMPs) and water quality management in the promotion of fish health by using representative cage establishments in the open and gulf ecosystems within Lake Victoria, Kenya. The study established that knowledge of biosecurity varied widely, but that the farmers had a relatively positive attitude towards biosecurity. However, the practices on the ground were contrary to their knowledge and attitudes pointing to a need to develop an evidence-based approach to capacity building, focused on the importance of adopting biosecurity practices on cage aquaculture fish farms. The water quality analysis found that sites with cages and those without did not have significant differences in the various parameters examined. However, the study found that the gulf had significantly elevated levels in some water quality parameters as compared to the open waters and that there were seasonal effects with respect to the water quality. Nevertheless, most of the water quality parameters complied to the recommended ranges according to the EAC Cage aquaculture guidelines. Therefore, findings from this study propose that cage fish farming should be promoted in the open waters due to the enhanced water circulation and flushing, which results in better water quality, better fish health and improved sustainability of farming within the lake ecosystem. Future research should focus on a cost benefit analysis of investing in biosecurity systems to provide the farmers with empirical evidence for investing in biosecurity measures. Additionally, there should be regular water quality monitoring established that cover all the markers of ecosystem health.

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8 APPENDICES

8.1 Appendix 1. Pearson correlation analysis between the various parameters adopted from the APOIA performance indicators

	Distance from the shoreline	**Depth**	**Disinfection**	**Procedure for disposal of dead fish**	**Monitoring new fingerlings/ broodstock before stocking**	**Water quality monitoring**	**Predator control**	**Record of fingerling origin**	**Record of behavioral symptoms**	**Fish mortality records**	**% Score**
Distance from the shoreline	1	0.041667	-0.09234	0.113424	-0.27469	0.221163	0.034021	0.020515	0.221163	0.076267	0.282746
Depth	0.041667	1	-0.02916	-0.08006	-0.13363	0.147442	0.204124	0.184637	0.147442	0.032686	0.263061
Disinfection	-0.09234	-0.02916	1	0.154091	0.452023	0.705117	-0.02381	0.524055	0.705117	0.327881	0.600531
Procedure for disposal of dead fish	0.113424	-0.08006	0.154091	1	0.242511	0.283315	0.098058	0.108407	0.283315	0.403014	0.526973
Monitoring new fingerlings/ broodstock before stocking	-0.27469	-0.13363	0.452023	0.242511	1	0.472866	-0.10911	0.592157	0.472866	0.599852	0.580622
Water quality monitoring	0.221163	0.147442	0.705117	0.283315	0.472866	1	0.120386	0.798549	1	0.559038	0.873877
Predator control	0.034021	0.204124	-0.02381	0.098058	-0.10911	0.120386	1	0.150756	0.120386	-0.10675	0.214788
Records of fingerling origin	0.020515	0.184637	0.524055	0.108407	0.592157	0.798549	0.150756	1	0.798549	0.700067	0.796958
Record of behavioral symptoms	0.221163	0.147442	0.705117	0.283315	0.472866	1	0.120386	0.798549	1	0.559038	0.873877
Fish mortality records	0.076267	0.032686	0.327881	0.403014	0.599852	0.559038	-0.10675	0.700067	0.559038	1	0.734199
% Score	0.282746	0.263061	0.600531	0.526973	0.580622	0.873877	0.214788	0.796958	0.873877	0.734199	1

8.2 *Appendix 2. Pearson correlation analysis (p values) between the various parameters adopted from the APOIA performance indicators*

	Distance from the shoreline	**Depth**	**Disinfection**	**Procedure for disposal of dead fish**	**Monitoring new fingerlings/ brood stock before stocking**	**Water quality monitoring**	**Predator control**	**Records of fingerling origin**	**Record of behavioural symptoms**	**Fish mortality records**	Score
Distance from the shoreline	NA	0.843238	0.660653	0.589312	0.1839	0.288041	0.871746	0.922461	0.288041	0.717096	0.170847
Depth	0.843238	NA	0.88995	0.703621	0.524247	0.481853	0.327716	0.376937	0.481853	0.876739	0.203912
Disinfection	0.660653	0.88995	NA	0.462083	0.023298	8.28E-05	0.910056	0.007168	8.28E-05	0.109583	0.001503
Procedure for disposal of dead fish	0.589312	0.703621	0.462083	NA	0.242801	0.16995	0.640989	0.605987	0.16995	0.045766	0.006797
Monitoring new fingerlings/brood stock before stocking	0.1839	0.524247	0.023298	0.242801	NA	0.016978	0.603643	0.001818	0.016978	0.001527	0.002341
Water quality monitoring	0.288041	0.481853	8.28E-05	0.16995	0.016978	NA	0.566507	1.71E-06	0	0.003672	1.16E-08
Predator control	0.871746	0.327716	0.910056	0.640989	0.603643	0.566507	NA	0.471947	0.566507	0.611531	0.302514
Records of fingerling origin	0.922461	0.376937	0.007168	0.605987	0.001818	1.71E-06	0.471947	NA	1.71E-06	9.79E-05	1.86E-06
Record of behavioural symptoms	0.288041	0.481853	8.28E-05	0.16995	0.016978	0	0.566507	1.71E-06	NA	0.003672	1.16E-08
Fish mortality records	0.717096	0.876739	0.109583	0.045766	0.001527	0.003672	0.611531	9.79E-05	0.003672	NA	2.94E-05
Score	0.170847	0.203912	**0.001503**	**0.006797**	**0.002341**	**1.16E-08**	0.302514	**1.86E-06**	**1.16E-08**	**2.94E-05**	NA

8.3 Appendix 3. Linear model results of the impacts of sites, seasons and stations variations on the water quality variables in the study establishments.

Response variable	**Dependent variable**	**F statistic**	***p-value***	**Pr(>T)**
Nitrites				
	Station Open	63.98	< 2.2e-16	4.56e-15 ***
	Season Wet (slightly)			4.13e-06 ***
	Season Wet			0.0399 *
Nitrates		17.28	< 2.2e-16	
	Station Open			3.83e-11 ***
	Season Rainy			0.01080 *
	Season Wet			0.01532 *
	Station: Season Open: Rainy			0.01410 *
	Station: Season Open: Wet			0.00958 **
Temperature		11.42	9.546e-13	
	Station Open			0.0226 *
	Season Rainy			8.4e-06 ***
Turbidity		130.6	< 2.2e-16	
	Station Open			<2e-16 ***
	Season Rainy			0.0133 *
TDS		46.91	< 2.2e-16	
	Station Open			3.17e-08 ***
	Season Rainy			5.35e-11 ***
	Season Wet			7.27e-06 ***
	Season Slightly wet			5.10e-08 ***
	Site: Season Non cages: Slightly wet			0.032788 *
	Station: Season Open: Rainy			0.002747 **
	Open: Slightly wet			0.000337 ***
Conductivity		76.84	< 2.2e-16	
	Station Open			< 2e-16 ***
	Season Wet slightly			0.0004 ***
	Station: Season Open: Wet slightly			6.7e-05 ***
Dissolved Oxygen		2.673	0.0008192	

	Station Open			0.00657 **
	Season Rainy			0.01094 *
	Station: Season Open: Wet			0.00930 **
ORP		9.991	9.091e-14	
	Season Rainy			5.51e-06 ***
	Season Wet			0.000114 ***
	Season Wet Slightly			2.39e-06 ***
Secchi		66.46	9.091e-14	
	Station Open			< 2e-16 ***
	Season Rainy			6.43e-05 ***
	Station: Season Open: Rainy			0.00357 **
Hardness		12.02	< 2.2e-16	
	Station Open			0.000126 ***
	Season Wet			0.037679 *
	Season Wet slightly			0.012027 *
	Station: Season Open: Wet slightly			0.043018 *
Alkalinity		28.57	< 2.2e-16	
	Station Open			1.11e-08 ***
	Season Rainy			*0.000973 ***
	Season Wet			0.007065 **
SRP		7.528	5.676e-14	
	Station Open			0.003693 **
	Season Rainy			1.024e-05 ***
	Station: Season Open: Rainy			0.006502 **
NH_4		7.791	1.648e-14	
	Season Rainy			0.0343 *
	Station: Season Open: Rainy			0.0319 *
	Station: Season Open: Wet slightly			0.0130 *
TN		16.64	< 2.2e-16	
	Season Wet			0.0036 **
	Season Wet slightly			0.0321 *
TP		23.15	< 2.2e-16	
	Station Open	10.78		1.54e-05 ***
	Station: Season	4.0939		0.007266 **

Chlorophyll		51.86	< 2.2e-16	
	Season Rainy			< 2e-16 ***
	Season Wet			0.00206 **
	Season Wet Slightly			2.18e-05 ***
	Station: Season Open: Rainy			2.68e-11 ***
	Station: Season Open: Wet			1.05e-07 ***
	Station: Season Open: Wet Slightly			0.00115 **

Legend:
* - Lower significance level between the variables
** - Moderate significance level between the variables
*** - Highest significance between the variables

8.4 Appendix 4. Questionnaire for data collection

Questionnaire to assess biosecurity and farm management practices in the cage aquaculture of *O. niloticus*

Introduction

This survey is being conducted by Kenya Marine and Fisheries Research Institute (KMFRI) in collaboration with The Fisheries Training Program, in Iceland. The purpose of this survey is to better understand which biosecurity procedures need to be improved for *Oreochromis niloticus* cage aquaculture in Lake Victoria, Kenya. Findings from this study will be used to provide advice that fish farmers can use to improve their biosecurity. Improved biosecurity can lead to less mortality and higher profits as well as more sustainable use of the Lake ecosystem. Identified key respondents are asked to participate in this survey by providing personal views. The information collected will be held in strict confidentiality and will only be used for research purposes.

Socio demographics

Name: **County:**
Name of cage establishment:
Age: **Gender**: **Marital Status**:
Highest education attainment:

1. How long have you been a cage fish farmer (years)?
2. Do you have a formal traning for fish culture? (Yes/No) From which institution?
3. Are you in a cage farmer’s cooperative society? Y/N
    a. If Y, Name of the cooperative society:
4. Is cage fish farming your only source of income?
5. How long is your farming cycle? (from stocking fingerlings to the time of harvest)

Knowledge

6. Have you experienced the following kinds of diseases on your farm in the last 1 year? (if possible please name the specific disease or symptoms)
   Bacterial diseases ? (Yes or No)

   Parasitic diseases? (Yes or No)

   Fungal diseases ? (Yes or No)
7. Which of the following activities do you think could result in the introduction and spread of an infectious disease to your farm?

Sharing equipment with infected farms (equipment includes the use of boat)	☐Yes	☐No	☐Not Sure
Using the same source of fingerlings as infected farms	☐Yes	☐No	☐Not Sure
Sharing the same working area with infected farms	☐Yes	☐No	☐Not Sure
Using the same equipment over multiple growing cycles on infected farms without cleaning/ disinfecting?	☐Yes	☐No	☐Not Sure
Unknown health status of fingerlings/fry	☐Yes	☐No	☐Not Sure
Not having a controlled nursery area	☐Yes	☐No	☐Not Sure
Weather events water mixing/ disturbing/environmental changes	☐Yes	☐No	☐Not Sure
Has the water mixing/ environmental changes resulted to fish kills in your cages?	☐Yes	☐No	☐Not Sure

Practices

8. Biosecurity Practices

Do you have daily disinfection systems in your establishment?	☐Yes	☐No	
Do you disinfect your growing equipment after a growing cycle?	☐Yes	☐Sometimes	☐No
Do you disinfect equipment before restocking?	☐Yes	☐Sometimes	☐No
If yes, what do you use to disinfect them? (List)			
Do you share equipment with other farmers?	☐Yes	☐No	
Do you control movement of staff in your establishment?	☐Yes	☐No	
Do you control movement of visitors in your establishment?	☐Yes	☐No	
Do you quarantine and monitor new fingerlings/ broodstock before stocking?	☐Yes	☐No	
Do you monitor water quality?	☐Yes	☐No	

What water quality parameters do you monitor? (List)			
What equipment do you use to monitor water quality? (List)			
How often do you record/ monitor water quality?	☐Daily	☐Monthly	☐Others (state)
Do you keep records of fish mortalities?	☐Yes	☐No	
Have you visited/worked on other farms during the past 2 weeks?	☐Yes	☐No	
Do you inspect fish feed on delivery?	☐Yes	☐No	

9. If yes, what do you inspect the fish feed for?
   ☐ Expiry date

   ☐Quality according to manufacturer instructions

   ☐Spoilage

10. Did you experience mortalities from the recent fish kills in Lake Victoria? (Y/N)
    a. If yes, what was the approximate (%) loss of stocks out of your total quantities in the production unit from the mortalities?
11. Where do you source your fish fingerlings?

    ☐Government hatchery

    ☐Local private hatchery

    ☐Research centre

    ☐Non-Government Organisation ☐others

12. How do you dispose of dead fish when a disease outbreak occurs?
    ☐Take ashore to dispose of on land

    ☐Throw away in an area without farms close by

    ☐Throw away outside of your individual farm

    ☐Throw away within your farm area

13. If you have lost fish in the past year to diseases what did you do when you received new fingerlings on your farm?
    ☐Added new fingerlings without removing the entire old stock of fish

    ☐Removed all the old stock and restocked with only the new stock of fish

    ☐Removed the entire old stock and replaced the equipment before planting new stock

    ☐Left the farm empty/fallow for some time before restocking

14. How frequently do you assess fish health on your farm?

☐Daily

☐Weekly

☐When there appears to be a problem with fish growth

☐When the water conditions change

☐When other farmers have fish growth problems

☐Never

15. Which of the following routine practices do you use for disease management on your farm?

Do you share equipment with farms experiencing disease outbreaks?	☐Yes	☐Not always	☐No
Do you treat the fish with anything during the fish farming cycle?	☐Yes	☐Not always	☐No
If yes, what do you treat the fish with? (List)			
Do you decrease stocking density if you had unexplained mortalities/ loss in the previous production cycle?	☐Yes	☐Not always	☐No
Do you keep same year class (age) of fingerlings in one production unit?	☐Yes	☐Not always	☐No
Do you keep fingerlings from different sources in one production unit?	☐Yes	☐Not always	☐No
Do you remove the diseased/ impacted fish from the farm when they are affected?	☐Yes	☐Not always	☐No
Do you monitor your cages daily?	☐Yes	☐No	

16. If a neighbouring farm had a disease outbreak, which of the following practices would apply to you?

Visit other farms after knowing about their disease outbreaks?	☐Yes	☐No	
Forbid farmers from other farms that have disease outbreaks from visiting your farm?	☐Yes	☐No	

17. What is the approximate distance from the shore to your cages?
18. Which agency did you consult in selecting your site for cage farming?
19. What is the size of your cages?
20. What was the weight of your fish at stocking?
21. What is your stocking density?
22. Do you vaccinate your fish? (Y/N)
23. If yes, what do you vaccinate against?
24. At what age do you vaccinate the fish (months)?
25. Do you encounter predators (eg birds) near your cages? (Y/N)
26. What do you use to deal with predators in your establishment?

Attitude

This section provides 4 choices on your perception/attitude of the importance of various practices in cage aquaculture. Select based on how important each is to you as a cage aquaculture farmer/ manager based on your experience.

27. How useful are the following general management practice concepts?

Fish farming management (time and choice of stocking)	☐Very useful	☐Useful	☐Not useful	☐Not sure
Disinfection of farm materials/equipment (cages, nets etc.)	☐Very useful	☐Useful	☐Not useful	☐Not sure
Preventative disease control through biosecurity measures	☐Very useful	☐Useful	☐Not useful	☐Not sure
Early detection of diseases/parasites	☐Very useful	☐Useful	☐Not useful	☐Not sure

28. How useful are the following routine management practices?

Disinfecting equipment shared with another farm experiencing fish disease outbreaks	☐Very useful	☐Useful	☐Not useful	☐Not sure
Not sharing equipment with infected farms	☐Very useful	☐Useful	☐Not useful	☐Not sure
Decreasing stocking density if there were disease outbreaks in previous production cycle	☐Very useful	☐Useful	☐Not useful	☐Not sure
Isolation of new stock and monitoring them fod health status	☐Very useful	☐Useful	☐Not useful	☐Not sure
Keep same class of stock in one farm area	☐Very useful	☐Useful	☐Not useful	☐Not sure
Removing the affected fish from the farm when outbreaks occur	☐Very useful	☐Useful	☐Not useful	☐Not sure
Removing the algae and other macrophytes clogging the nets	☐Very useful	☐Useful	☐Not useful	☐Not sure
Learning to improve farm practices	☐Very useful	☐Useful	☐Not useful	☐Not sure
Monitoring fish health/growth regularly	☐Very useful	☐Useful	☐Not useful	☐Not sure
Changing/ Improving farm management through experience	☐Very useful	☐Useful	☐Not useful	☐Not sure
Regularly cleaning any farm maintenance equipment	☐Very useful	☐Useful	☐Not useful	☐Not sure

29. How useful are the following group of practices?

Keeping records of the water quality conditions daily to detect problems early	☐Very useful	☐Useful	☐Not useful	☐Not sure

Keeping records of fish infections and mortalities daily to detect diseases early	☐Very useful	☐Useful	☐Not useful	☐Not sure
Knowing the source of seeds/ fingerlings	☐Very useful	☐Useful	☐Not useful	☐Not sure
Quarantine of fingerlings from different areas before stocking on farm	☐Very useful	☐Useful	☐Not useful	☐Not sure
Government controls over the quality of fingerlings	☐Very useful	☐Useful	☐Not useful	☐Not sure
Disinfection of farm equipment after harvest	☐Very useful	☐Useful	☐Not useful	☐Not sure