AQUACULTURE FISH WELFARE TRAINING GUIDE

A practical guide for enhancing sustainable and welfare-compliant fish farming in Uganda

OHDI
ONE HEALTH & DEVELOPMENT INITIATIVE

AFIWEL
Africa Fish and Aquaculture Welfare Program

Uganda

CONTRIBUTIONS AND ACKNOWLEDGEMENT

Writing and development

Thaddeus Zaabwe (BSc, MSc, PhD-in-view) – Africa Fish Welfare (AFIWEL) Fellow, OHDI

Technical Review and Validation

- Dr Victoria Tebenda Namulawa, Aquaculture Research and Development Centre, National Fisheries Resources Research Institute (NaFIRRI), National Agricultural Research Organisation (NARO), Uganda
- Mr Byamukama Patrick Byaruhanga, Senior Fisheries Officer, Ministry of Agriculture, Animal Industry and Fisheries (MAAIF)
- Dr Joseph Webeleta Magona, Antimicrobial Resistance Expert, African Union InterAfrica Bureau for Animal Research (AU-IBAR), Kenindia, Westlands Road, Nairobi, Kenya
- Mr Opio Denis, Research Officer, Aquaculture Research and Development Centre, National Fisheries Resources Research Institute (NaFIRRI), National Agricultural Research Organisation (NARO), Uganda.
- Dr Kikiope Oluwarore, Executive Director, One Health and Development Initiative (OHDI)

Funding Support: Effective Altruism (EA) Funds

COPYRIGHT

Suggested Citation: *Zaabwe T. (2025). Fish Welfare Training Guide for Uganda; One Health and Development Initiative (OHDI), June 2025*.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

Fish welfare is increasingly recognised as a core component of sustainable and ethical aquaculture. Across Africa, where aquaculture plays a vital role in food security, livelihoods, and economic development, there is growing urgency to embed welfare principles into production systems, policy frameworks, and capacity-building efforts.

The Africa Fish and Aquaculture Welfare (AFIWEL) Program, implemented by One Health and Development Initiative (OHDI), was established to address this need. The AFIWEL program is a pan-African initiative that supports ethical, welfare-driven, safe, and sustainable aquatic life and production systems across Africa. One of its flagship initiatives is the AFIWEL Fellowship, which engages select fisheries and aquaculture professionals and experts in capacity-building, community-building, and field implementation programs to advance fish and aquaculture welfare practices and integrate them into existing sustainable aquaculture frameworks. Through this pan-African fellowship model, the program supports professionals across the continent to lead transformative action in fish and aquaculture welfare through education, stakeholder engagement, and policy advocacy.

This Fish Welfare Training Guide is one of several developed by AFIWEL Fellows. This particular guide has been tailored to the specific aquaculture realities of Uganda, providing practical, evidence-based knowledge and tools for fish farmers, aquaculture workers, extension officers, animal health professionals, and institutions involved in the fish production value chain.

The content draws from global best practices, scientific insights, and local expertise to ensure that welfare recommendations are both technically sound and contextually relevant. It covers key aspects such as water quality, stocking densities, feeding, handling, transportation, health management, and humane slaughter, all anchored in the principles of good welfare practices: freedom from pain, distress, discomfort, and suffering.

As you explore this guide, we invite you to reflect on the broader goal it serves, which is to promote responsible aquaculture systems that protect animal welfare, support livelihoods, and ensure long-term environmental sustainability. We hope it will be a valuable resource in your efforts to improve fish health, welfare, productivity and sustainability outcomes in Uganda and across Africa.

With best regards,
The AFIWEL Program Team
One Health and Development Initiative (OHDI)

ABBREVIATIONS AND ACRONYMS

AAH – Aquatic Animal Health
ALI – Aquatic Life Institute
AMR – Antimicrobial Resistance
AU-IBAR – African Union – Inter-African Bureau for Animal Resources
AWRA – Animal Welfare Research in Africa
CEA – Centre for Effective Altruism
DoF – Department of Fisheries
DVS – Department of Veterinary Services
EA – Effective Altruism
EU – European Union
FAO – Food and Agriculture Organisation
FW – Fish Welfare
FWI – Fish Welfare Initiative
GAWS – Global Animal Welfare Strategy
MDAs – Ministries, Departments, and Agencies
NFAP – National Fisheries and Aquaculture Policy
NGO – Non-Governmental Organisation
OHDI – One Health and Development Initiative
Q&A – Questions and Answers
SDGs – Sustainable Development Goals
TWGs – Technical Working Groups
WOAH – World Organisation for Animal Health
WTO – World Trade Organisation

MODULE 1: OVERVIEW OF AQUACULTURE IN UGANDA

Aquaculture, which dates back to 1941, is one of the fastest-growing food sectors and the primary source of protein and livelihood for approximately 30% of Uganda's population. Worldwide per capita fish consumption has increased significantly from 9.10kg in 1961 to 20.75kg in 2022 (FAO, 2024). Uganda's annual per capita fish consumption of 12.5kg is higher than the African average of 10.1kg (Adeleke et al., 2020). Comprising over 20,000 fish ponds averaging 500 m², Uganda is the third-largest aquaculture producer in Africa, behind Egypt and Nigeria, and the second-largest in sub-Saharan Africa, with 138,558 tonnes in 2021. Fish production from ponds ranges between 1,500 kg per hectare per year for subsistence farmers and 15,000 kg per hectare per year for commercial farmers.

Uganda projects to produce over 1,000,000 MT of fish by the year 2030 (MAAIF, 2017). The current investment has led to a significant increase in aquaculture production, from 800 MT in 2000 to 138,558 MT in 2021 (Flores Nava and Manjarrez-Aguilar, 2023). Most of the current production comes from fish cages and ponds. It is worth noting that cage fish farming was introduced in Uganda in 2006, and a significant amount of investment, especially from the private sector, has been realised on the major water bodies, namely Victoria, Albert, Kyoga, and the Nile River. Uganda's aquaculture is supported by fish hatcheries, though most of them are not certified to supply fish seed. Farmed fish in Uganda is marketed mainly in local, regional and international markets. Neighbouring countries, namely the Democratic Republic of the Congo, South Sudan, Kenya, Rwanda, and Tanzania, constitute the main regional market.

Aquaculture Production Systems in Uganda

Aquaculture production systems in Uganda are characterised according to several features based on various aspects, among which include: intensity of production, water quality attributes, species of fish cultured and scale of production (MAAIF, 2020). The most defining attribute, however, is the level or intensity of production. This defines the level of utilisation of production resources to maximise yield per unit volume or area of a production facility. In Uganda, there are mainly three production systems. These include extensive, semi-intensive and intensive production systems. Novel production systems, such as aquaponics and recirculating aquaculture systems, are, however, slowly gaining a foothold in the industry to enhance aquaculture production in Uganda.

Extensive fish production system

This system requires low investment to operate. There is very low resource input and limited monitoring. The stocking density in such units is very low, and commercial feeds are hardly used, which results in low fish production (overall yields). Since there is no supplementation of commercial feed, natural food production plays a critical role in fish production in this case. Natural feed production in extensive systems in Uganda is primarily generated through pond fertilisation using organic manure. This enhances the production of zooplankton and phytoplankton, which in turn feed fish under culture **(Figure 1)**. In this system, fish welfare is limited since the fish are not fed optimally. Usually, overstocking of extensive culture facilities leads to depletion of natural food, thus starving the fish. Feeding in this system is not well programmed and is thus referred to as "leisure feeding". Although it has some disadvantages, this system leads to minimal environmental impacts, is easy to operate, and promotes biodiversity in fish culture facilities. This system is practised by the majority of subsistence fish farmers and such fish is usually eaten at home, with a few pieces sold in the local market.

Figure 1 This pond is principally extensive but can also be characterised as semi-intensive (Photo by Rogers K)

Semi-intensive fish production system

This system aims at increasing fish production from ponds and other culture systems. There is a higher level of investment and input as compared to the extensive system (Altan, 2017). It operates beyond naturally occurring food, for it uses supplementary feed. Farmers usually make on-farm feeds to be used in fish culture. Ponds are usually fertilised once a week and have relatively higher stocking densities and yields than extensive production systems (**Figure 2)**. In Uganda, most semi-commercial farmers who own ponds averaging 1,000 m² practice this system. They usually have livestock on their farm and use the manure to fertilise the ponds, which stimulates primary food production for the fish. Feeding of fish in ponds is usually done twice or three times a week. Since there is a higher level of utilisation of production inputs, water quality parameters are generally compromised. Monitoring water quality is therefore of paramount importance.

Figure 2 Stocking of fish in a pond under a semi-intensive production system in Uganda. (Photo by Rogers K)

Intensive fish production system

There is a high level of resource input in the form of feeds, labour, fish seed, water quality maintenance, monitoring, and particularly stocking densities. Fish in this system are fed high-quality, nutritious commercial feeds formulated to meet the dietary nutrient requirements of the fish (Pomeroy *et al.,* 2014). The level of labour and technical expertise input is significantly higher. A planned schedule of fish feeding is implemented at various stages of growth, along with water maintenance, particularly aeration, and comprehensive data collection to monitor fish performance. The fish in this system are reared for a predetermined market. In Uganda, this culture system yields between 1,200 kg and 2,300 kg of fish per hectare. There has been a moderate to high investment in cage fish farming in Uganda, which involves the attributes referenced herein. This has also significantly enhanced aquaculture production in Uganda.

Figure 3 Cage fish farming on Lake Victoria characterised as intensive fish production

Integrated fish production systems

In Uganda, novel production systems aimed at increasing fish production have been adopted, with the majority involving integrated fish farming principles and practices. The main integrated system is the Aquaponic system. With the reduction of land for fish farming, the use of backyard farming, especially in urban centres, revolves around this system.

Aquaponic systems

This symbiotic type of farming involves a combination of aquaculture and hydroponics to grow fish and plants. Aquaponics offers a promising solution to food production challenges, especially in areas with limited arable land or water resources. The principle is that wastewater from the fish is utilised by plants for their growth. In aquaponic systems, plants grow rapidly using dissolved nutrients that are excreted directly by fish or generated from the microbial breakdown of fish excretions. The plants filter the water by extracting waste and nutrients, thereby creating a clean environment for the recycled water to be used in the fish production facility (**Figure 4).** This forms a closed-loop system and enhances efficient water use to maximise production. There are three types of this system, categorised by their operation. These include the **media-based system**, which utilises media such as gravel or rock for bacterial growth. This is the simplest form of aquaponics that is used in Uganda. The second type is the **nutrient film technique** (NFT), where the plant roots are exposed to a thin layer of nutrient-rich water that runs through horizontal pipes. The third system is **the raft system,** where plants are grown on floating rafts with roots submerged in nutrient-rich water. The last two methods are yet to be widely practised in Uganda.

Figure 4 An aquaponic system in the backyard of the farmer in Uganda (Photo by Uganda Aquaculture Association)

DISCUSSION QUESTIONS

- Which is the most practised fish production system in your area, and why?
- What are the significant challenges faced while practising this system?
- Are you aware of a symbiotic farming system that involves the rearing of fish and the growing of plants?
- What is your general overview of this system?

MODULE 2: INTRODUCTION TO ANIMAL WELFARE

Overview, History and Trends of Animal Welfare

The ability of an animal to experience physical and mental well-being is comprehensively referred to as animal welfare. Animal welfare represents our ethical responsibility to treat animals with compassion and respect. Holistically, animal welfare history encompasses the development of legal frameworks, public concern, and the generation of scientific knowledge (Vargo *et al.,* 1997). Hitherto, animal welfare science has involved studying how principally farm animals, but to a lesser extent also sport and pet animals and laboratory animals, are affected by various environmental factors (Algers, 2011). The chronological history of animal welfare has followed part or all of this trend.

- In India, animal welfare dates as early as the first millennium BCE (304-232 BCE), where kings built hospitals for animals. Orders were issued against animal hunting and slaughter, against well-stipulated doctrines of non-violence.
- Various legislative attributes and Acts were enacted in the 1600s on behalf of animals for their improved welfare, and in principle, these Acts were to facilitate animal welfare for dogs, especially in Japan. In the 1700s, books were written in support of animal welfare to draw public attention to these issues.
- It was not until the 20th century that substantial progress on animal welfare took place after a commission of inquiry into the welfare of intensively farmed animals (Sherwin *et al.,* 2010). Some of the guidelines recommended that animals be required to have the freedom to "stand up, lie down, turn around, train themselves and stretch their limbs". In principle, these guidelines have since been expounded as the **FIVE FREEDOMS (Figure 5)**.

Despite the tremendous work done in advocating for animal welfare, a vast knowledge gap exists among people and farmers who handle animals, which is also true for aquaculture. This is attributed to limited capacity building on animal welfare issues, poor policy implementation, and inadequate resources, among other factors. This limits the realisation of the one health goal of "*a sustainable balance and* *optimisation of animal, human and ecosystem health while controlling for economic benefits*".

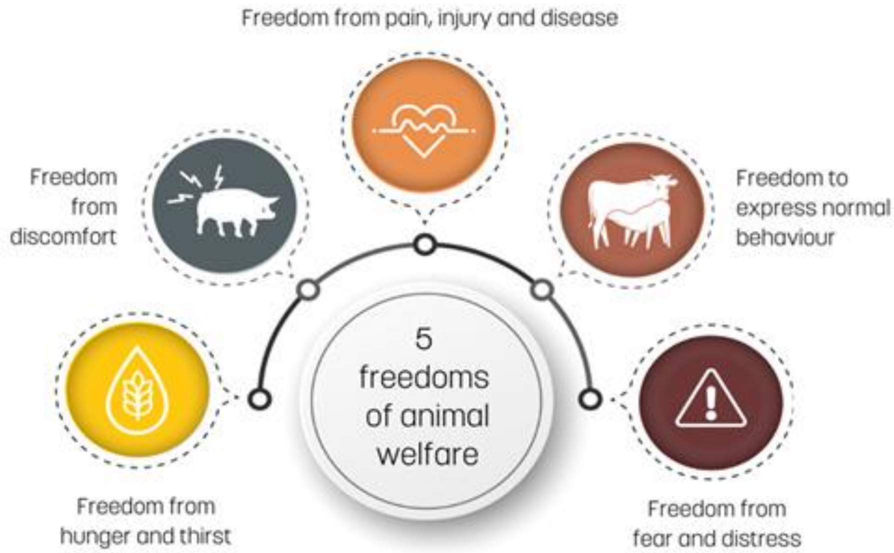

Figure 5 Five freedoms in animal welfare (Adopted from Euractiv, 2021)

The potential benefits of animal welfare include healthier animals, a minimised environmental impact, more productive animals, sustainability, consumer preference, and emotional support for animals. Well-treated animals seldom fall ill, thus reducing the need for medical attention from experts; they become more productive, generating higher income for farmers (WOAH, 2024). The reduced application of such treatments, especially antibiotics, minimises their bio-accumulation, bio-concentration and biomagnification in their tissues, thus reducing risks to humans at the consumption level. Well-treated animals require less feed and land to rear, and thus release fewer pollutants into the environment, thereby acting as objects that mitigate climate change. By providing animals with better infrastructure and improved living conditions, the risks associated with disease transmission from animals to humans are significantly reduced. This is in addition to proper handling before and during slaughter, a precursor to reduced food-borne illness and contamination. This safeguarding of public health reduces the transmission of zoonotic diseases, thereby benefiting both animals and humans. Balancing the benefits of animals, business, and society is key to ensuring animal welfare (Bozzo and Dimuccio, 2023).

The Five Freedoms of Animal Welfare

1. **Freedom from thermal and physical discomfort** – this is achieved through providing animals with a suitable environment comprising good shelter and a comfortable resting area where there is easy access to food and water.
2. **Freedom from hunger and thirst** – implies that animals should be able to access food and potable water. The food should be of the desired quantity, and highly nutritious to meet the dietary requirements of the animal, while the water must be free, fresh, clean and with no disease-causing pathogens. This is because animals require a balanced diet for tissue maintenance and physical health, while water facilitates the nourishment of the animal's body cells. The food supplied to the animal should be dependent on various animal factors, such as size, age, health status, and activity level.
3. **Freedom to express most normal behaviour** – entails providing the animal with the space, facilities and company to act in ways that promote their well-being. The space should be sufficient for the animal (fish) to move around, run, swim, and play; thus, space provision is paramount for their interaction. This freedom helps the animal express its normal behaviour and promotes the study of abnormal behaviours, such as aggression and cannibalism. Normal behaviour in an animal may include playing and grooming.
4. **Freedom from fear and distress** – ensures that conditions and treatment of an animal reduce mental and physical suffering. Fear is not only unpleasant but can have a great impact on an animal's health. An animal subjected to these conditions will experience poor mental and physical health. Mentally, the animal will be very alert and constantly feel overwhelmed and worried. As a result, the animal will experience physical issues, digestive complications, heart problems, and difficulties eating and sleeping.

5. **Freedom from pain, disease and injury** – requires quick diagnosis and treatment in case of injury, disease or pain. Since there is lack of a defined form of communication between man and animals, it is pertinent to pay special attention to ensure animals are not in pain.

The dimensionality of these freedoms is intricately linked to achieving good animal welfare, and a lack of any one means that animal welfare is compromised.

The Five Domains of Animal Welfare

Worth noting is the extensive knowledge and research that recognises the five freedoms for animals; however, for an animal to live a useful life, going beyond minimising negatives and providing them with positive experiences is necessary. This is achieved through an animal welfare assessment framework that facilitates evaluation of risks and opportunities. The five domains present opportunities for animals to engage in activities that provide positive experiences. The model consists of three survival-critical physical domains: health, nutrition, physical environment, behavioural interaction and mental domain (**Figure 6**). These domains interact with the animal's subjective experiences, of which the outcome is the animal's present state of welfare (Mellor *et al*., 2020).

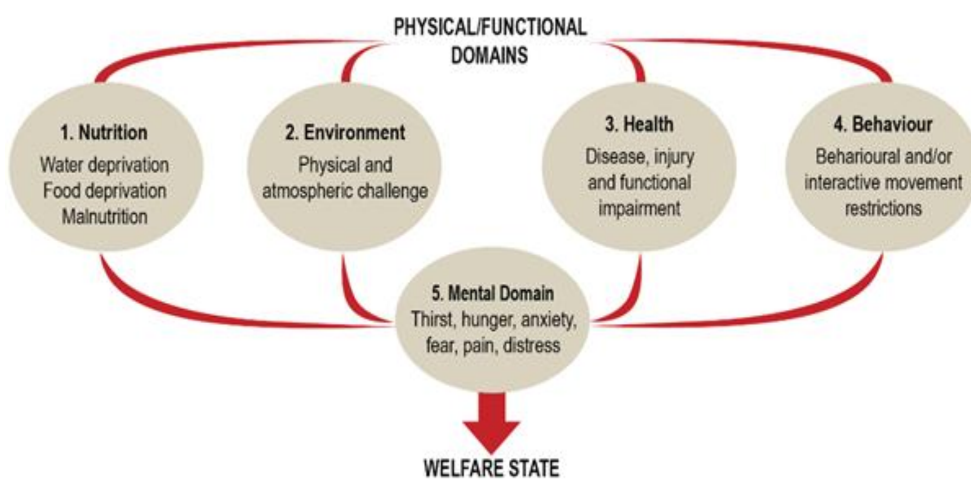

Figure 6 The five domains model (Adopted from Mellor et al., 2020)

The nucleus of the main four domains' interaction focuses on the mental domain of an animal. Although the mental domain is structurally separated from the four domains, its evaluation should not be done independently.

KEY FISH AND ANIMAL WELFARE VIOLATIONS

- Poor and inhuman handling during grazing, transportation, and slaughter leads to animal stress.
- Restrictions through the use of confinement to keep animals, especially cages in poultry and fish, with restrictions on their natural environment.
- Exposure of animals to harsh and unbearable rearing or resting conditions like overcrowding, which can lead to suffocation, disease spread and stress.
- Untimely treatment of animals in case of sickness or disease outbreak.
- Uncontrolled use of chemicals in treating fish and the aquatic environment where fish dwell.
- Exsanguination, where fish is slaughtered in highly vascular areas and left to bleed till death. Fish is not stunned prior to slaughter, but rather, natural, unethical slaughter is exercised.
- Feeding fish in culture facilities on poor-quality or low-nutritious feeds, ultimately leading to stunted growth and poor feed conversion ratios.
- Starvation of animals and fish before their transportation over long distances, before slaughter or stocking in culture facilities.

Legal Frameworks for Animal and Fish Welfare in Uganda

Prevention of animal cruelty in Uganda is mainly governed by the Animals (Prevention of Cruelty) Act, Cap. 39, which was later reviewed by the Uganda Law Commission (ULC). The purpose of the review was to broadly strengthen the prevention of animal cruelty and its enforcement of the law (Uganda Law Commission, 2022). The Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF) has guidelines and standard operating procedures on the handling and transportation of live animals (MAAIF, 2022). Animal welfare, trade, movement and health in Uganda are guided and regulated by the following legislations, standards and manuals:

1. The Animal Diseases Act, Cap. 38, which provides for the regulation of animal handling and transportation aimed at the prevention and control of diseases. The main regulations include obliging animal owners or handlers to report any

disease outbreak to the nearest veterinary officer, prohibiting the movement of animals through infected areas, and prohibiting the movement of animals at night. Additionally, they empower veterinary officers to issue health certificates and designate stock routes for the transportation of animals.

2. The Animals (Prevention of Cruelty) Act, Cap. 39 is the primary act which provides for the prevention of animal cruelty and welfare. The main provisions include empowering authorised officers, like fisheries officers, to conduct emergency slaughter of animals injured during transportation. It further prescribes penalties for persons who allow the free movement of diseased animals. It gives powers to courts of law to order the destruction of diseased animals or fish that have been found in possession of a handler.
3. The Fisheries and Aquaculture Act (2023) of Uganda addresses fish welfare through various provisions aimed at ensuring the safety, quality, and humane treatment of fish:
   - ***Safety and Quality Measures***: *Section 60* requires the construction of aquaculture establishments to ensure the safety and quality of live fish and fish products, including sanitary measures to protect fish health.
   - ***Prevention and Control of Contaminants***: *Section 61* stipulates that aquaculture practices must have measures in place to prevent and control contaminants and disease-causing agents, ensuring a healthy environment for fish.
   - ***Conditions of Aquaculture Activity Licence***: *Section 63* allows the Chief Fisheries Officer to impose conditions on aquaculture activity licenses to protect the environment and fish health, including the use of appropriate feed and disposal of waste.
   - ***Notice of Disease***: *Section 66* requires owners or persons in charge of aquaculture establishments to notify authorities if they suspect that fish are infected with a disease, ensuring prompt action to prevent the spread of the disease.

DISCUSSION QUESTIONS

- What is your opinion on animal welfare, especially fish welfare?
- What gaps do you think government and researchers need to address as regards animal and fish welfare?
- Can you expound on how you think animal or fish welfare is important on your farm in social and economic aspects?
- How best would you complement the Government of Uganda in its realisation of enhanced animal and fish welfare?
- Fish are being marginalised in developing acts that address their welfare. Why do you think it is necessary to have an independent act addressing fish welfare?

MODULE 3: INTRODUCTION TO FISH WELFARE

What Is Fish Welfare?

The definition of animal welfare is complex and often subject to dispute. There is no single framework that is commonly agreed upon. Instead, most definitions fall into one of two broad categories:

1. Feeling-based definitions, in which welfare links to the emotional (or emotion-like) states of the animal under review. Good welfare under these definitions typically requires a reduction in negative experiences (such as stress or fear) and an assurance of positive experiences (such as the presence of counterparts for members of social species).
2. Function-based definitions focus on an animal's ability to adapt to its current environment, in which good welfare requires the animal to be in good health.

The Five Pillars of Animal Welfare in Aquaculture

Drawing reference from the five freedoms of animal welfare, the Aquatic Life Institute provides five key welfare pillars for aquatic animals, especially fish in aquaculture. These comprise feed composition and feeding, space requirements and stocking density, stunning and slaughter, water quality and environmental enrichment (**Figure 7**).

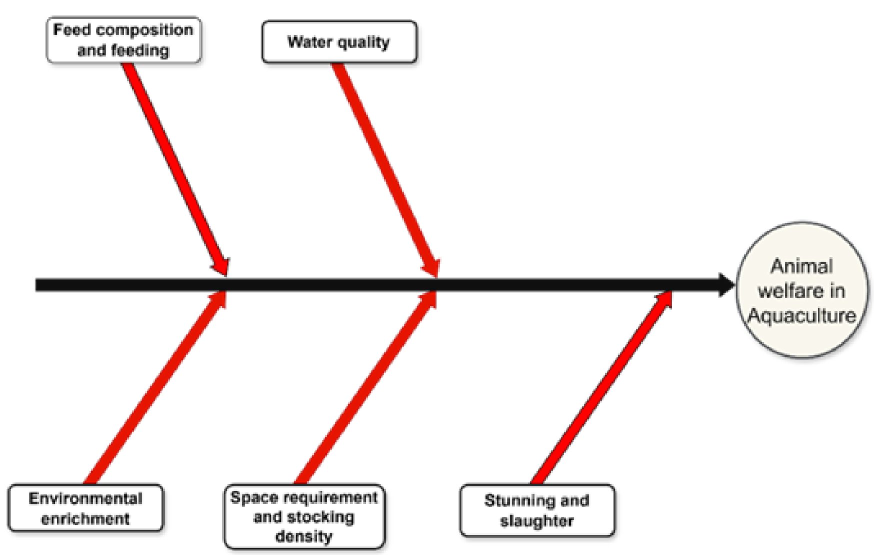

Figure 7 Five pillars of animal welfare in aquaculture (Generated by author)

Benefits of Improved Aquaculture Welfare

Enhanced fish growth: Minimising stress allows for the enhanced utilisation of food nutrients for tissue development rather than relying on coping mechanisms. This idea is predominantly critical in the aquaculture industry and widely embraced by culturists. This is because higher fish welfare significantly means improved growth rate, better conversion rates, disease resistance, reduced physical injuries and stress response, and consequently, higher economic benefits for stakeholders (Dara et al., 2023).

Better fish health: Stress weakens the fish's immune system, thus increasing the risks of disease outbreaks in aquaculture facilities. Minimising stress levels in fish culture systems improves faster healing from injuries. This would ultimately lead to lower fish mortalities, thereby improving income generation for farmers involved in aquaculture (Toni et al., 2019).

Environmental benefits: Reduced fish stress improves feed intake and efficiency, resulting in less waste generated from culture facilities. This leads to improved water quality as less waste is released in the aquaculture system and the environment.

Social and economic benefits: Great concerns about fish welfare among consumers are on the rise. This has led to a higher demand for fish raised under good welfare practices, boosting the aquaculture industry's status, as some markets may offer higher prices for fish raised under high welfare standards. This serves as a foundation for improved fish welfare management, particularly for those generating low income from fish due to poor fish welfare (Berlinghieri et al., 2021).

Introduction to Fish Welfare Practices

It is crucial that fish welfare practices are adhered to during fish rearing to mimic their natural environment. This should be done regardless of the rearing system. The main fish welfare practices of water quality, especially monitoring the most important parameters (pH, temperature, dissolved oxygen, total dissolved solids, and Ammonia concentration), stunning and killing using humane ways, feeding through availing fish with the right feed with the dietary nutrient requirement for tissue development, protection from predators, proper handling to minimise stress, training of fish in order to minimise stress when individuals appear during feeding.

Having an appropriate culture environment for fish species cultured in Uganda, among which include: Nile tilapia (*Oreochromis niloticus*), North African catfish (*Clarias gariepinus*), Mirror carp (*Cyprinus carpio*), Grass carp (*Ctenopharyngodon idella*), Redbelly tilapia (*Coptodon zilli*), Redbreasted tilapia (*Coptodon rendalli*) and Labeo (*Labeo victorianus*). Although these species have different demands in terms of water quality, it is essential to understand the species-specific environmental needs to enhance their welfare during culture.

DISCUSSION QUESTIONS

- Which key aquaculture fish welfare practices do you practice on your farm?
- How have you benefited from practising fish welfare on your farm?

MODULE 4: GROWING SYSTEMS AND FISH WELFARE

Prior to fish culture in rearing facilities, suitable culture facilities that enhance fish welfare are required for improved fish production while controlling for economic gains. It is paramount to set operational standards on various aspects of your farm prior to its establishment. Key factors include having a suitable site for farm establishment, a comprehensive business plan that will be followed during investment, fish stocking biomass standards, feeding protocols, and biosecurity and biosafety standards to minimise injuries and diseases to fish and personnel. These need to be adhered to for improved fish production in a suitable environment while improving fish welfare. Some of the key aspects that stand out in Uganda's Aquaculture Sector are the culture facilities where fish are reared, their location, and the fish stocking biomass. These are expounded as follows:

Rearing Systems

Muthusamy and Viswanathan (1999) described a rearing facility as a controlled environment used to care for and raise young animals, especially in agriculture. It entails key factors like proper housing and feeding, all done in accordance with the dietary nutrient requirements of the animal. In Uganda, the predominant fish rearing facilities used include fish cages, earthen ponds, concrete tanks, dam-lined tanks, and movable ponds. The use of recirculating aquaculture systems in Uganda has not been widely adopted.

Fish cages

A fish cage is an enclosure suspended in water for the purposes of rearing fish (**Figure 8**). Cages are culture units having an open-framed net at the top and floating on the water surface. Cages are kept slightly below the water by adjustable buoyancy. In Uganda, the usage of cage culture is extremely varied. Rivers, reservoirs, lakes, and valley dams are suitable for culture without altering the natural habitat function.

The massive use of fish cages is attributed to specific advantages:

- Given the production being in small units, quick and simple harvesting, this renders methods of flexible adaptation to defined fish markets and thus continued fish supply.
- Cages are a convenient means of wintering; thus, they save the vast investments for separate wintering ponds.
- Fish observation is very possible, although high stocking densities are used.
- Harvest is simple and quick, and the technological steps can be mechanised.
- It facilitates the growth of carnivorous fish.
- The cost of nursery pond construction is not necessary as a cage can be used.
- Since fish are reared in fish cages, the land area where ponds would have been constructed is saved for other agricultural purposes.
- Cage culture can be well associated with sport fishing and recreational facilities.
- Cages give higher fish production per unit area (productivity) compared to traditional fish farming methods.

Figure 8 Suspended fish cages on Lake Victoria, Uganda (Photo by SON Fish Farm)

Fish cage stocking densities in Uganda

The biomass of fish to be stocked per m^3 is derived from the production per m^3. Fish production in a cage is typically measured in kilograms per cubic metre (kg/m^3). It is estimated that, in one cubic metre, a cage would yield between 30 and 35 kilograms of fish. To achieve the stocking biomass or number of fish in a 5 m X 5 m X 5 m (125 m^3) cage, the following formula is used;

Cage volume = 125 m^3

Production per m^3 = 30 kg

Target of individual fish at harvest = 500 g / 0.5 kg

Size of fish at stocking = 5 g

Biomass stocked = ????

Solution

Biomass at harvest: 125 x 30 = 3750

Number of fish stocked: Biomass at harvest (kg) / Target weight of individual fish at harvest (kg). 3750 / 0.5 = 7500 fish.

Biomass stocked: 7500 x 5 = 37.5 kg

Earthen ponds

A fish pond is a shallow excavation on land used to hold water with the main purpose of rearing or farming fish. Earthen ponds are principally dug from soil, and the soil holds the water in which fish dwell (**Figure 9**). The pond should be constructed in a way that does not impact the fish's welfare.

Figure 9 Earthen fish ponds located in Buikwe, Uganda (Photo by Kasasa R.)

The key welfare issues to consider include

- The soils should be loamy-clay, containing at least 20% of clay, in order to minimise water seepage, which may expose fish to predators and heat from the sun. 80% of the soil should be loam, as this helps with the easy rehabilitation of ponds in case of leaks. The soil pH range should oscillate between 6.5 and 8.5. The environment should not favour the growth of disease-causing pathogens in fish.
- The pond dykes should be constructed at angles of 45 degrees to minimise silting of the pond. Ponds with dykes constructed at 90 degrees tend to silt up as soil particles accumulate in the pond due to the pond's water-wave action. This makes the pond shallow, exposing the fish to predation.
- Before its construction, site suitability tests should be carried out to assess the type of soil, water quality and quantity, relief, vegetation, and predation attributes. The site should have good soil, and the water should be enough to fill the pond in 48-72 hours.
- The pond should be positioned in a way that the water flow does not cause flooding. The water velocity should not be too high to cause stress to fish during swimming activities.

- The water source should be devoid of suspended solids, which contain minerals like iron, which cause stress to fish during gaseous exchange.

Concrete fish rearing tanks

In Uganda, concrete tanks have been used for rearing fish, particularly in research institutes, semi-intensive, and intensive fish farms (**Figure 10**). Tanks are constructed in a way that their edges and surface do not injure fish through abrasion. The tanks must have a smooth in-lining with dull colours to minimise fish stress, as fish react differently to different colours. Since tanks have a high water retention time, low dissolved oxygen levels are expected. These low levels lead to hypoxic and anoxic conditions, thus increasing stress levels in fish. Therefore, sufficient volumes of clean water from the water source are required for exchange to enhance and boost oxygen levels in the facility.

Figure 10 Fish concrete tanks (Photo by author)

SITE SELECTION

Selecting a suitable site for establishing a culture facility is crucial, as the site's characteristics can significantly impact fish welfare. Potential threats to fish welfare resulting from site selection need to be addressed prior to enterprise establishment. Priority to such aspects includes, but is not limited to:

Environmental and social impact assessment (ESIA)

Aquaculture, being an enterprise that is centred on natural resources, poses environmental and social impacts which in turn may affect fish welfare. Conducting a holistic and comprehensive ESIA is paramount to overcoming this. These should be well thought over and all situations considered, following well-developed and aligned protocols (**Figure 11**). For example, constructing fish ponds in an area may lead to a reduction in the water table in the environment, and, additionally, socially, arable land is used up in the process of pond construction. This may affect the livelihoods of people since limited land is available for crop farming, hence, poor livelihoods (food and income insecurity). Furthermore, rearing fish in ponds with a limited water supply increases stress levels in the fish, as the required exchange is insufficient for their growth and free movement. The over-retention of this now untreated water may lead to disease incidences, thus increasing morbidity and mortality in fish. The effects and impacts should be clearly outlined in the ESIA and should not have a significant impact on fish welfare.

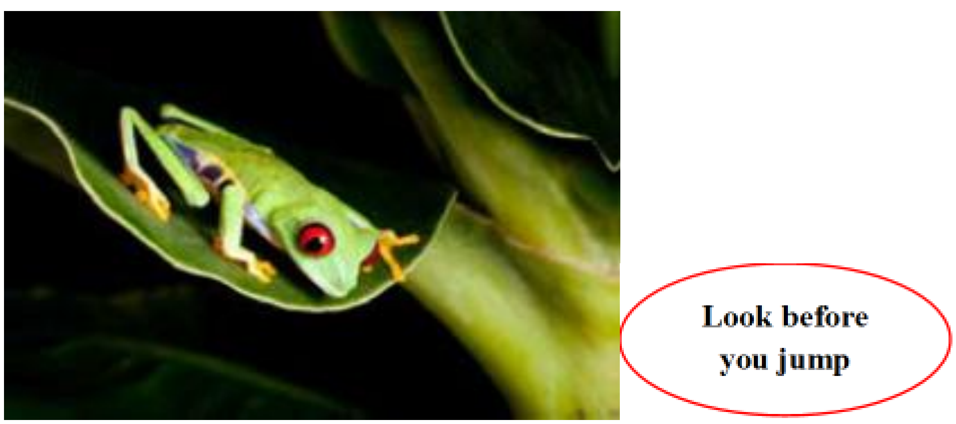

Figure 11 Precautionary measures have to be thought over before setting up an aquaculture farm (Developed by author)

Siting and culture facility design

Site selection in a suitable location with optimal conditions for good fish welfare prior to culture establishment is key. While selecting suitable sites, places where these sites will be located **MUST** be devoid of point and non-point source pollutants, especially chemical effluents from the pharmaceutical industry, wastewater from urban and sewage sources, agrochemicals resulting from farming and other anthropogenic activities, stable water table, clean source of water with enough water to culture fish, and industrial waste, among others. The release of these effluents into water channels, which serve as sources of water for fish rearing facilities such as ponds and cages, may lead to direct poisoning, hypoxic or anoxic conditions, thereby causing high stress levels in fish. Furthermore, the bioaccumulation and bioconcentration in fish myotomes may lead to biomagnification, hence undifferentiated tissue development in fish. Some of these poorly divided cell divisions may lead to body conditions such as atresia, hyperplasia, or hypoplasia in fish, resulting in poor fish welfare.

Culture facilities like fish ponds should additionally be sited in locations with a good relief to allow for gravitational flow of water, with minimal velocity which does not allow for expenditure of energy by fish during swimming. The soils should be of good quality (20% clay) to minimise water seepage, as low water levels expose fish to predators. Hence, the stress that comes with predation needs to be minimised for improved fish welfare. Good water quality and quantity are key, as pollutants in water stress fish by altering their environment. Polluted water may lead to the proliferation of dense phytoplankton mats, which, when not removed, suppress light penetration, resulting in reduced or limited photosynthetic activity. The lack of food in the aquatic environment leads to starvation, which causes stress in fish, especially in semi-intensive or extensive culture systems. The culture facility must be designed in a way that minimises stress to the fish when water is added. A pond that is too deep (more than 2.4 metres) and not constructed at a higher depth tends to stratify, while a shallow pond leads to oxygen depletion during hot seasons.

These stress fish by altering the environment, thus poor fish welfare is realised. A stratified pond will deter fish from swimming the entire pond, thus limiting them to the thermocline. Hence, in nest-brooding species like *Oreochromis niloticus*, breeding is restricted since they cannot construct nests at the pond bottom. Ponds should be designed to have harvesting basins in order to minimise handling stress during harvesting. Fish cages should be designed to have smooth meshes and twine ropes to minimise abrasion leading to injury of the fish. Wounds on fish serve as portals for disease-causing pathogens, leading to disease occurrence, which in turn results in fish morbidity and mortality. The cages should be installed in water with a minimum depth of >5 m and <8 m, not suspended in fast-flowing streams or rivers or against the direction of water. This leads to fish stress, as fish expend more energy swimming against the current than they do growing.

DISCUSSION QUESTIONS

- What fish culture facilities do you own at your farm?
- How do they improve fish welfare?
- What key steps do you undertake before establishing a fish culture facility?
- What precautionary measures do you undertake to improve fish welfare on your farm?

MODULE 5: WATER QUALITY AND FISH WELFARE

In aquaculture, a suitable environment with optimal growing conditions is crucial for fish welfare. Good water quality equals good fish welfare, as fish prefer stable water quality without changes in the physicochemical parameters. Alterations in water quality tremendously shape fish behaviour, a very critical index in determining fish welfare. The prominent water quality parameters of importance are dissolved oxygen, temperature, pH, total dissolved solids, total suspended solids, ammonia, nitrites, and electronic conductivity, among others (Segner *et al.,* 2019). Fluctuations in these parameters lead to stress in fish and negatively impact their welfare. Water provides oxygen to fish, which is required for survival (respiration), and also dilutes toxic substances, which would cause stress to fish and affect fish welfare.

Water quality monitoring enables farmers to take the necessary action to ensure optimal fish welfare. Besides water quality, the water quantity should be sufficient to fill the pond within 72 hours. A pond should be given a good water retention time, and this is highly correlated with the quantity of water. Low volumes of water lead to constant replenishment of the culture facility, especially ponds, which alters the pond environment, thereby stressing fish, as they are poikilothermic organisms. It is essential to always check or measure these water quality parameters in situ and ex situ to prevent spontaneous changes that may cause stress to fish and subsequently affect their welfare. Measurement of these parameters, especially in situ, is done using multi-parameter water quality equipment that displays digital readings of results to the data collector. Farmers should be well-trained on how to use this equipment, especially in terms of calibration, to achieve good results. In addition, farmers should be able to take records and follow the trends of their data, as this would facilitate determining the welfare of the fish in the culture facility. Good water quality monitoring and maintenance, especially in intensive systems, favour high stocking densities, resulting in higher yields per unit volume with minimal or no stress to fish.

Water quality considerations for optimal fish welfare

A farmer or production farm must maintain good water quality to ensure improved fish welfare, a prerequisite for optimal fish production. A suitable environment with optimal growth conditions enhances fish welfare. It is important to note that different fish species have different suitable physicochemical parameter ranges, which are highly correlated to their welfare attributes like growth, breeding, and feeding.

For parameters like pH, at 25°C, a value of 7 is assumed to be neutral, thus the best at which fish welfare is good, below which is acidic, and above which is alkaline (**Table 1**). However, since temperatures keep fluctuating, a shift in the pH is experienced. Therefore, maintaining an optimal range between 6.5 and 8.5 is important for most fish species. These ranges apply to most warm or freshwater species in Uganda, especially *Oreochromis niloticus*, *Clarias gariepinus*, *Ctenopharyngodon idella, Cyprinus carpio, Labeo victorianus, and Oncorhynchus mykiss,* among which are cultured in aquaculture facilities.

Table 1 pH tolerance levels in Uganda and their effects on warm water fish species

pH level	Effect on fish
<4.0	Acid death point
4.0 – 5.0	No production
6.5 – 8.5	Desirable range for fish production
8.5 – 11.0	Slow growth
>11.0	Alkaline death point

(*Improved from Tarazona and Muñoz, 2008*)

Dissolved oxygen is the most critical water quality variable in aquaculture. Oxygen is available in a dissolved state. It is found in microscopic bubbles mixed in between water molecules. It can enter the system through direct diffusion and as a by-product of photosynthesis. A thorough understanding of the factors that affect the concentration of dissolved oxygen in water is required. In addition, understanding the influence of dissolved oxygen on feeding (more to nutrition) to fish under culture is of great importance for good fish welfare (Boyd, 1998). This means that the level of dissolved oxygen in the water can be increased through mechanical aeration, such as paddle wheels, agitators, vertical sprayers, impellers, airlift pumps, air diffusers, and liquid oxygen injection, naturally through considerable wind and wave action, and the presence of aquatic plants and algae, among others. However, caution should be exercised with the latter, as it can also cause oxygen depletion when the phytoplankton population becomes too dense. On the other hand, oxygen is removed through respiration and decomposition. Oxygen concentration may be reported in terms of milligrams per litre (mg/L) or its equivalent, parts per million (ppm). The oxygen concentration measurement in both units is the same.

MODULE 6: FEEDING AND FISH WELFARE

Fish in culture facilities require feed for somatic growth, maintenance, reproduction and daily functions. Feed is available in natural and artificial (commercial) forms. Natural feed usually comes from pond water fertilisation using organic and inorganic fertilisers. Some of the organic fertilisers include animal wastes from poultry, piggery, cattle, rabbits, and goats, among others, while inorganic fertilisers include commercial types such as NPK, DAP and Urea. These are applied in various quantities to enhance natural feed production. Usually, poultry waste, which has the highest Nitrogen content, is applied at rates of 350g/$m^{2,}$ while inorganic fertilisers can be applied at rates of 20g/m^2. The common natural feed in culture facilities occurs as phytoplankton and zooplankton. The facility should not be over-fertilised, as this would lead to algal blooms, thereby reducing dissolved Oxygen in the facility, which in turn would cause fish stress and poor fish welfare. The natural feed in fish culture facilities is insufficient for fish to grow; thus, there is a need for supplementation with commercially formulated feeds. The formulated commercial feed should be formulated and applied according to the dietary nutrient requirements and age of the fish concerned.

Figure 12 Feeding fish on commercially formulated feeds (Monitor Publications, 2024)

Good-quality ingredients should be used in diet formulation. Usually, younger fish (fry and fingerlings) and breeding (broodstock) fish require high-protein content feeds for tissue and gonadal development, respectively. Although all fish exhibit carnivorous behaviour, the protein requirement of herbivore fish like Tilapia is different from that of North African catfish. Tilapia fish require crude protein (CP) levels oscillating between 25% and 40% CP, while for omnivores like catfish, it is between 40% and 45% CP, depending on the development stage, physiological condition, and production system. The protein content in the feed should be enough to effect growth and improve fish welfare. Fish in culture facilities, unless it is part of an experiment, are fed to satiation and to achieve average body weight (ABW). Fish fry and broodstock fish are fed between 11% to 1% of their ABW. Fish fry should be fed at 11% ABW, and this is reduced as the fish grows. Additionally, the protein content in the feed should be reduced, as fish do not require more protein for tissue development when they reach grow-out or broodstock size. The amount of crude fat in the diet should also not exceed 8% and should not affect the protein-sparing effect.

Best Fish Feeding Practices

To improve fish welfare while feeding, the following steps must be followed:

- Feed fish by response. A good fish response indicates that the fish are in good condition, the feed is suitable, and thus, there is good welfare. Fish which offer a poor response should not be fed.
- Avoid feeding fish of varied sizes in the same facility. Stress resulting from competition for food between small and large fish impacts fish growth, as larger fish outcompete smaller fish.
- Do not feed fish on very cold days. Because they are cold-blooded, fish metabolic rate slows down during cold weather. They are unable to digest food under such conditions and are not physically active enough to respond when offered feed. Undigested and uneaten feed deplete the culture facility of Oxygen and release toxic chemicals that stress and harm fish. Fish, being

poikilotherms, tend to use the generated heat for warmth rather than expend energy on feeding.

- Feed the right amounts. Overfeeding of fish leads to large amounts of uneaten feed. This feed negatively impacts water quality, leading to hypoxic or anoxic conditions, which in turn result in mortality. Disease-causing pathogens can also emerge from the uneaten feed and affect fish.
- Fish should not be fed when the water quality in the culture facility is poor. This would lead to fish gasping for Oxygen, leading to stress and thus poor fish welfare.
- Spot feeding should be avoided for fish to have equal access to feed, especially the small fish. During feeding, different spots should be identified in a culture facility to cater for all sizes of the fish.
- Fish should be fed on feed pellets that can be swallowed and ingested by the fish. The gape of the mouth should be commensurate with the size of the pellets. Bigger fish require pellets larger than 2mm, while fry start with powder or crumbles, because their digestive system is not yet well-developed enough to break down pellets.
- The fish feed should have a better feed conversion ratio and offer high digestible results.

Fish Feed Storage

Formulated fish feeds should be stored in dry areas, not in moist areas, on plastic pallets to prevent moulding. Moulds may lead to mycotoxin contamination, which greatly affects fish welfare. The formulated feed used in aquaculture should follow the "*First in First out*" (FIFO) principle. Nutrient deterioration in feeds starts with storage. Feeding fish on old, low-quality feed results in poor growth, leading to low fish yields. Fish welfare will be affected as the ability for the fish to extract nutrients for their development is minimised.

DISCUSSION QUESTIONS

- How do you ensure that feed fed to fish meets the dietary nutrient requirements of fish and their specific ages?
- What challenges have you faced in using poor-quality feed, and how have you overcome them on the farm?
- What are some of the best feeding practices that you carry out on your farm to ensure good fish welfare?
- How do you store your feed to avoid quality deterioration?
- Why is it important to use commercially formulated feeds on your farm?

MODULE 7: FISH WELFARE DURING HANDLING AND TRANSPORTATION

Fish Handling

Most fish demonstrate an emergency response when threatened. This may follow a sudden disturbance from a net, noise or other unexpected activity, or when they are removed from water. The response usually involves an increase in stress levels, which will have a negative effect on the welfare of the fish and also the quality of the flesh quality (Humane Slaughter Association, 2016). Fish handling should be done in a way that significantly minimises stress. Since fish movement from one facility to another, farm to farm, from farm to markets and exhibitions, tagging, vaccination, and slaughter are seldom avoided, fish should be exposed to minimal stress during these processes.

Figure 13 Crowding of fish harvested from a concrete-lined fish pond in Uganda (Photo by Samuel P. Wamala)

Figure 14 Crowding of fish harvested from a fish pond in Uganda (Monitor publications - updated January 2021)

Live fish should not be kept out of water for more than 15 seconds unless anaesthetised, as this is deemed to cause significant amounts of stress, hence affecting the fish's physiology. Fish removal from water causes the highest emergency physiological response and should only be carried out when absolutely necessary (Ashley, 2007). Care must be taken at all stages to avoid abrasions and removal of scales in addition to the fish's protective mucous coat, which serves as a physical and chemical barrier to infection, as well as being important in osmoregulation and locomotion.

Fish crowding during periods of transfer, stripping, and grading must be minimised by the use of large containers holding a few fish. Crowding is stressful and leads to damage of scales, skin ulceration, eye and snout bruising and damage (EFSA, 2009). Where applicable, fish should be handled with wet hands and species-appropriate nets, keeping the fish moist during handling. Unless crowding is carefully controlled, fish will be exposed to a decrease in Oxygen levels and a rapid rise in stocking density. In Uganda, fish handling from culture facilities through various processes is minimal, as experts in this field (welfare) are minimal or completely lacking.

Live Fish Transportation

Live fish experience some form of transportation across distances, which may be short or long, for short or long hours or days. Live fish transport is used to transfer aquaculture products, mainly high-value fish, from either wild capture fisheries or aquaculture rearing facilities, for purposes such as restocking, slaughter in restaurants and hotels, breeding, live experiments, and others. Live fish transport enables fish and fish products to be transported long distances in a controlled environment, which helps to maintain product quality, freshness, and prevent death and spoilage that would occur in non-live products. Stress in live fish during transportation occurs at various stages, including pre-transportation treatment (pond draining, starvation to rig gut for food and waste), packing, and exhaustion from the journey during transportation. Transport can occur at different stages between harvesting and consumption. Starvation of fish for prolonged periods is unacceptable from a welfare point of view.

Starvation periods should be kept as short as possible and should not exceed 72 hours. Inappropriate starvation periods can deplete immune function and body condition (European Union, 2021). For certain species, transportation of farmed fish between facilities is a regular and routine part of their production cycle. Young rainbow trout, for example, are often transported to on-growing farms to be fattened to slaughter weight, and salmon smolts are moved from freshwater sites to seawater cages as they develop; fully grown salmon then often require further transportation to a separate processing plant for their eventual harvest. Although this transport is common and frequent, the process is extremely stressful for fish and may negatively impact the survival rates of the population as a whole. In salmon smolt, for example, it takes more than 48 hours for cortisol levels to return to pre-transport levels.

In Uganda, a wide range of transportation means are used, as fish and fish products are transported on foot, by bicycle, canoe, motorcycle, rail, pickup truck, boat, lorry, refrigerated trucks, and in baskets. The transportation of live fish revolves precisely around using polythene bags filled with Oxygen, perforated jerrycans, and live fish transportation tanks (Figure 15) mounted on pickups and supplied with Oxygen from cylinders (**Figure 16**). Usually, the transportation of catfish fingerlings involves the use of jerrycans without or with minimal aeration for very long distances owing to the scarcity of nearby hatcheries and inadequate transport logistics. This leads to fish stress, thereby impacting the overall welfare of the fish.

Figure 15 Live fish transporting tank

The live fish transporting tanks have a perforated aeration system that is connected to Oxygen supply cylinders. It contains a perforated outlet, meshed to release wastewater during transportation.

Figure 16 Live fish transporting tank with Oxygen cylinders mounted on a pick-up (NaFIRRI, Uganda)

Precautionary aspects during live fish transportation process

All personnel handling fish throughout the transportation process should ensure that potential negative impacts are minimised.

1) The responsibilities of the competent authority for the exporting and importing jurisdiction include:

i. Establishing minimum standards for fish welfare during transport, including examination before, during and after their transport, appropriate certification, record keeping, awareness and training of personnel involved in transport.

ii. Ensuring implementation of the standards, including possible accreditation of transport companies.

2) Owners and managers of fish at the start and at the end of the journey are responsible for:

i. The general health of the fish and their fitness for transport at the start of the journey, and to ensure the overall welfare of the fish during transport, regardless of whether these duties are subcontracted to other parties.

ii. Ensuring trained and competent personnel supervise operations at their facilities for fish to be loaded and unloaded in a manner that avoids injury and causes minimum stress.
iii. Having a contingency plan available to enable humane killing of the fish at the start and at the end of the journey, as well as during the journey, if required.
iv. Ensuring fish have a suitable environment to enter at their destination that ensures their welfare is maintained.

3) Transporters, in cooperation with the farm owner/manager, are responsible for planning the transport in a way that ensures that fish transportation can be carried out in accordance with fish health and welfare standards, including:

a) Using a well-maintained vehicle that is appropriate to the species to be transported.
b) Ensuring trained and competent staff are available for loading and unloading, and to ensure swift humane killing of the fish, if required.
c) Having contingency plans to address emergencies and minimise stress during transport.
d) Selecting suitable equipment for the loading and offloading of the vehicle.

4) The person in charge of supervising the transport is responsible for all documentation relevant to the transport, and the practical implementation of recommendations for the welfare of the fish during transport (Southgate, 2008).

It is worth noting that:

a) Transportation of live fish should be well planned and prepared to minimise fish stress and mortality.

b) Transport procedures should take account of variations in the behaviour and specific needs of the transported fish species. Handling procedures that are successful with one species may be ineffective or dangerous for another species.

c) Some species or life stages may need to be physiologically prepared before entering a new environment, such as by feed deprivation or osmotic acclimatisation.

DISCUSSION QUESTIONS

- Can you identify fish welfare challenges associated with fish harvest and transportation?
- How do you ensure good fish welfare during harvesting and transportation on your farm?
- What precise areas do you think need to be improved on your farm to enhance fish welfare?

MODULE 8: SLAUGHTERING AND FISH WELFARE

Fish slaughter

Slaughter is the process of killing fish after they have been harvested. Several methods are used to slaughter fish, but most have been found to be inadequate and inhumane. Methods such as asphyxiation in air, carbon dioxide stunning, gill-cutting (exsanguination), salting, which leads to desiccation, and live chilling are now recognised to be inhumane and, as such, should not be used. Acceptable slaughter methods should render the animal insensible without causing avoidable pain or suffering. According to the World Organisation for Animal Health (OIE) (WOAH, 2024), persuasive stunning and electrical stunning systems are best able to provide humane slaughter.

Fish stress factors at pre-slaughter

When fish are subjected to stress, vigorous swimming increases anaerobic glycolysis, leading to the production of lactic acid and a consequent decline in muscle pH, which is accompanied by a faster onset of rigor mortis. The combination of stress and intense physical activity at pre-slaughter can increase the degree of protein denaturation. This leads to increased access of proteolytic enzymes to protein substrates, leading to faster muscle softening, which is detrimental to fish muscle. Prior to slaughter, harvested fish are subjected to various stressors or pre-slaughter factors, such as starvation, crowding, low dissolved Oxygen, repeated handling, and transportation, among others. These factors or procedures have a significantly negative impact on fish welfare. These processes tend to cause far more pain to the fish than the slaughter process itself. Increased overcrowding and high stocking densities pre-slaughter increase cortisol levels, and reduce the expression of catalase and glutathione peroxidase enzymes, which are important indicators for activation of the cellular antioxidant defence system and protection against oxidative stress (Goes et al., 2019).

In addition to denaturation and proteolysis, muscle proteins also undergo oxidative damage after slaughter and subsequent meat ageing. Protein oxidation is responsible for various biological changes, including protein fragmentation or aggregation, and decreased protein solubility, which can impact meat quality. Oxidation may also play a role in regulating the proteolytic activity of enzymes and is linked to meat tenderness.

Humane fish slaughter

The overwhelming majority of farmed fish produced throughout the world are killed with little or no consideration for their welfare. Fasting periods can be excessive, transport stressful and killing inhumane. With increasing public awareness of fish sentience and aquaculture, there is a growing demand for more ethical fish products, not only sustainably produced but also with good animal welfare. A humane slaughter is essential when farming to higher animal welfare standards; however, fish welfare at slaughter varies substantially across the world and in different sectors (Compassion and Food Business, 2017). The key ethics of humane fish slaughter are that death should either be instantaneous or, if insensibility is induced progressively, it should be without anxiety or pain (FAWC, 1996). The effective evaluation of insensibility and stunning is vital to prevent any suffering or distress that might occur when invasive killing methods, such as bleeding or evisceration, are used. Insensibility may be measured using evident indicators such as fish behaviour, or through measuring brain activity using electroencephalography. There is concern that visible indicators, such as opercular movement, righting responses, and spontaneous movement, may not be reliable signs of insensibility (Wahltinez et al., 2024). In this regard, humane fish slaughter is paramount and has some potential benefits:

i. High-quality fish fillets due to minimal pre-slaughter stress. Little or minimal volumes of blood are clogged up in the fish tissues, hence providing a bright and clear fish fillet.

Figure 17 High-quality fish fillet (Adopted from Goes et al., 2019)

ii. Minimal over bleeding of the fish during slaughter if better slaughter methods like electrical stunning are used.
iii. Minimises unnecessary pain and cruelty to fish since the process is fast.
iv. Improves eating quality, as has been found for farmed fish. In some long-line and trolling fisheries, the relatively humane slaughter method of spiking is used soon after landing to improve flesh quality by reducing pre-slaughter activity.

Overview of fish slaughter in Uganda

Usually, there is no clearly defined protocol available to farmers or fishermen on the best way to slaughter fish. In aquaculture, harvested fish are either stitched onto grass strands through their gills or simply dropped into ice before slaughter. For more resilient species like North Africa Catfish (*Clarias gariepinus*), stunning, using a metallic hammer or stones is common. In some instances, hitting the fish on the ground until it is dead is another cruel way of pre-slaughter. Harvested fish are placed on the ground and left to die in the open due to air asphyxiation. The fish is usually slaughtered inhumanely and left to bleed till death. Other fish species, such as the Lungfish (*Protopterus aethiopicus*), are stunned with large stones and sometimes large sticks until they die. In order to minimise this, there is a need to embrace the more sophisticated humane methods of fish pre-slaughter processes and slaughter methods. These may include a persuasive stunning with a club, spiking the brain, and persuasive and electrical stunning machines.

DISCUSSION QUESTIONS

- How do you slaughter your fish on the farm?
- Given this training, what shortcomings do you face during fish slaughter?
- How would you improve fish slaughter on your farm?
- How would you want to be helped in improving fish slaughter for improved fish welfare on your farm?

MODULE 9: ENVIRONMENTAL ENRICHMENT AND FISH WELFARE

Environmental enrichment (EE) involves stimulating the brain through physical and social surroundings. It includes complex inanimate and social stimulation, such as housing conditions that promote enhanced sensory, cognitive, motor, and social engagement. EE can improve fish welfare in aquaculture systems. It aims to offer new sensory and motor experiences to help meet the behavioural, physiological, morphological, and emotional needs of fish, while reducing stress and the occurrence of irregular behaviours (Arechavala-Lopez et al., 2022). In fish farms, rearing environments are often designed from a human perspective and based on economic factors, mainly for practical reasons for the farmer, with little regard for animal welfare. Throughout aquaculture production cycles, many farming activities can be stressful for fish, and EE may not only help them cope with these stresses but also enhance their overall welfare. Nonetheless, numerous other enrichment strategies, especially targeting physiological aspects, also provide valuable welfare benefits (Ojelade et al., 2022). These include sensory, occupational, social, and dietary/nutritional enrichments (Gerber, 2015).

Types of Environmental Enrichments

Physical enrichment – involves adding structures like plants, tree branches, logs and gravel to the rearing facility. Alternating the pond, tank or cage bottom with a unique creation of crevices through which fish can swim and hide. Changing lighting in the facility enhances fish behaviour and improves fish welfare.

Social enrichment – introduction of new, different fish species in the culture enhances fish communication and thus improves fish welfare. Fish appreciate species' behaviour, including mating, courtship, and feeding, among others. This is more plausible when fish do not exhibit cannibalism behaviour, enhancing behaviours like shoaling and foraging, hence encouraging interspecific good welfare (Aude et al., 2023).

Dietary enrichment – introduction of various flavoured feed, swim-like feed pellets and substrates, different pellet sizes, and addition of attractant oils in water to improve fish feeding in the culture facility. Variations in the time fish are fed, the area where fish are fed, and the use of varying feeders enhance fish welfare. Introducing feeding bowls and trays in a culture facility minimises energy expenditure by the fish, thus improving their welfare.

Sensory enrichment – involves the introduction of various sounds, like music, to fish. This is most pronounced in Koi farming in Thailand. This includes: changing the background of the rearing facility, like a fish tank, changing the cover of the facility and providing air bubble curtains, especially in Rainbow trout culture (Amichaud et al., 2024). The change in various stimuli like sight, sound, and touch enhances fish welfare. The introduction of moving objects and varied visual patterns in water relaxes the fish's brain, thus causing minimal stress and ultimately increasing fish welfare.

Benefits of Environmental Enrichment in Fish

Overall, EE aims to improve fish welfare by enhancing fish survival and overall fish performance. Precisely, EE has significant benefits, among which include;

- Reduced fish aggression due to the shelters provided by the physical structures. This is very important for fish which are territorial and also for less aggressive species.
- Due to the provision of hiding places, fish feel safer, causing reduced stress, which leads to low-level production of stress hormones like cortisol.
- The adventure of added structures, such as pipes and logs, increases fish activity, thus leading to more exercise and body activity.
- Increased body growth since the rate of movement facilitates food breakdown for tissue development.
- Predictable feeding can reduce aggression and bursts of acceleration before mealtime. It can also reduce oxidative stress and enhance immune responses.
- Improved social learning, which in turn causes improved adaptive social behaviour.

DISCUSSION QUESTIONS

- What type of environmental enrichment is carried out on your farm and why?
- How would you improve environmental enrichment on your farm?

MODULE 10: FISH HEALTH AND WELFARE

Animal health and welfare are highly interconnected concepts. Good fish health is understood as the lack of disease or injury, and the ability of the animal to perform its physiological functions at normal levels. Good health and welfare can be supported if responsible farming practices are consistently followed. These include husbandry methods that encourage the monitoring of health and welfare, the application of site-specific biosecurity plans, the implementation of disease prevention schemes, adherence to good welfare practices, and the responsible use of therapeutics when needed, among other requirements. Fish health and welfare are very crucial as concerns regarding sustainability and ethically responsible aquaculture production, and need to be taken seriously (Johansen et al., 2006). Significant concerns are usually linked to biosecurity, production intensity and changing environmental conditions, thus leading to new fish diseases and welfare challenges (Muniesa et al., 2022). Prioritising measures with positive effects on fish health and welfare is essential for both ethical reasons and aquaculture sustainability, leading to healthier fish, higher yields, better meat quality, and more efficient feed utilisation, which in turn results in a reduced environmental footprint.

Environmental changes and society's concerns about sustainability and ethically responsible production are making fish health and welfare issues increasingly more important. Biosecurity challenges, increasing production intensity, and shifting environmental conditions are of special concern as they may create new illnesses and welfare issues, and may have an increasing impact on the feasibility of ethically responsible treatment and maintaining good fish health and welfare. Yet issues like vaccination are key in sustainable disease management in aquaculture (Assefa and Abunna, 2018). Priority to actions that improve fish health and welfare is crucial for aquaculture sustainability and for ethical reasons. Choosing the right measures yields healthier fish, higher yields, better quality, and more effective feed utilisation, all of which reduce the environmental impact of aquaculture.

Increased fish mortality on Uganda's fish farms is a challenge to the aquaculture sector. The existing gap between the actual survival in fish production and the ability of fish to survive is worth investigating. One of the main causes of low fish production on farms in Uganda is infectious diseases resulting from high stocking densities, deterioration in environmental factors, poor hygiene in fish farms and equipment, among other factors. In order to achieve better fish health and welfare, it is vital to address these areas.

Biosecurity and Fish Welfare

Biosecurity in aquaculture consists of practices that minimise the risk of pathogen transfer (e.g. bacteria, viruses, fungi, and parasites), establishment, and their spread. These include practices for reducing the stress on fish, thus making them less susceptible to pathogens/disease. Biosecurity and health management are recognised by the Food and Agriculture Organisation (FAO) as recent priorities for appropriate aquaculture governance (Muniesa et al., 2022). The challenges and problems of managing good biosecurity are extensive and multifactorial, predisposing farmed stocks to an increased risk of infection with consequential stock losses (Subasinghe et al., 2023). Fish diseases continue to be one of the most significant causes of economic loss for the aquaculture industry. While some fish pathogens are well-known problems, other diseases are emerging or spreading to previously unaffected areas. Outbreaks can occur rapidly and spread quickly, often resulting in high mortality rates. It is difficult to predict when disease might occur; however, the routine use of biosecurity measures can reduce the risk of introduction and economic impact of these diseases.

Table 2 Differentiating between sick and healthy fish

	Healthy fish	Sick fish
Activity	Swim actively, sharp and responsive	Swim slowly and lethargic responses
Body Surface	Intact	White layered patches appearing as lesions
Body colour	Bright and glossy	Dull, dark and discoloured
Feed intake	Very good appetite	Poor appetite
Organs	Internal organs are healthy and normal	Internal organs are damaged, and this is in relation to specific diseases

Importance of Biosecurity to Fish Welfare

The main reasons for biosecurity application in aquaculture are to minimise the risk of disease introduction and spread, improve fish health, protect against new diseases like Viral haemorrhagic Septicaemia - VHS, improve human health and safeguard against economic loss, among other uses. High stocking densities intensify stress, making fish more susceptible to disease. Since treatment options are limited for most aquaculture diseases, prevention remains the best line of defence for the aquaculture producer.

Figure 18 Testing of fish for disease pathogens (Adopted from AFD, 2000)

Biosecurity measures can also help promote fish health and protect your economic investment. There are several regulations and trade requirements for fish, as well as a growing demand for specific pathogen-free (SPF) fish (Moss et al., 2012). Oftentimes, these requirements involve the implementation and documentation of biosecurity procedures on the farm. Maintaining healthy fish and acquiring pathogen-free status can improve or ensure a producer's reputation for providing high-quality fish and fish products. While most zoonotic diseases of fish primarily pose food safety issues, several fish pathogens can cause illness in humans when they come into contact with infected fish. Examples include *Edwardsiella Ictaluri*, *Mycobacterium marinum*, and *Aeromonas spp*. pathogens.

Fish Diseases in Aquaculture

Fish diseases can significantly impact the growth and survival of fish in rearing facilities. Fish diseases lead to low fish harvests, and high costs are incurred during the treatment of infected fish with drugs. In Uganda, heavy economic losses are experienced by fish farmers. In addition to the impact on rural communities from large-scale fish losses due to disease, diseases also have a considerable impact on investors' confidence. There are many factors contributing to the disease challenge, including:

- Increased globalisation of trade and markets;
- Intensification of fish-farming practices;
- Introduction of new species for aquaculture;
- Expansion of the ornamental fish trade;
- Unanticipated interactions between cultured and wild populations of aquatic animals;
- Poor or lack of effective biosecurity measures;
- Slow awareness of emerging diseases;
- Irresponsible use of veterinary drugs; and
- Climate change.

Regular monitoring of fish health is an effective way to identify diseases and apply appropriate treatments or management interventions. Some of the common fish diseases that affect fish farms in Uganda include:

Table 3 Common freshwater fish diseases in Uganda

Disease type	Cause	Clinical signs	Treatment	References
Viral Diseases				
Viral hemorrhagic septicemia – VHS	*Viral hemorrhagic septicemia virus*	Lethargic, abnormal swimming behaviour, fish colour is darker than normal, spiralling, dark red liver.	Quarantines of wild-harvested fish before stocking on fish farms.	(Smail and Snow, 2011)
Epizootic hematopoietic necrosis – EHN	*Epizootic hematopoietic necrosis virus*	Sudden death, especially in Rainbow trout, haemorrhage in the gills, lethargy and darkening of the fish's body.	Culling, disinfection, quarantines, and farm good management practices, e.g. low stocking densities and good biosecurity measures.	(Becker et al., 2019)
Bacterial Diseases				

Bacterial gill disease	*Flavobacterium branchiophila*	Lethargy, dyspnea, coughing and flared opercula, mucus strands from gills.	Use of antiseptic and surfactant baths, like chloramine T and benzalkonium chloride. Provide adequate oxygen to fish.	(Zamparo et al., 2024)
Mycobacteriosis (Fish tuberculosis)	*Mycobacterium*	Presence of acid-fat mycobacteria in the granuloma of the fish.	Cull and disinfect culture facilities (10,000ppm or 60-855 alcohol).	(Francis-Floyd, 2017)
Fungal Diseases				
Saprolegniosis	*Saprolegnia sp.*	White-mat-like structures on the fish, epidermal damage, lethargy, and restricted movement due to overgrown	Proper fish handling to minimise physical injury, a hygienic environment, stock disease-free seed, and maintain water flow.	(Lindholm-Lehto and Pylkkö, 2024)

		mycelium, listless.		
Parasitic Diseases				
White spot disease	*Ichthyophthirus multifilis*	Round-hairy, grown brown coloured parasite, irritation and itching, flashing.	Dip treatment in a 2-3% salt solution for 1-2 minutes, apply lime at 30-50 mg/L, Dip treatment of Potassium permanganate at 1 ppm.	(Sánchez-Paz, 2010)
Whirling disease	*Myxobolous cerebralis*	Circular or whirling movement, erratic swimming, darkening of the tail region, deformity of the skeleton and mortality.		(Sarker et al., 2015)

Biosecurity Measures for Fish Health and Disease Control in Aquaculture

Biosecurity in aquaculture involves management actions to prevent the introduction of disease-causing agents to aquaculture facilities. Key measures include:

Quarantine and movement restriction: Confine new aquatic animals with unknown health status before introducing them to the stock. Quarantine duration ranges from 15 days to 3 months, with strict observation and diagnostic tests (Asiva, 2015).

Disinfectants and pesticides: Use physical or chemical agents to remove microorganisms on inanimate objects and fish eggs. Common disinfectants include quaternary ammonium compounds, formaldehyde, hydrogen peroxide, chlorine, and iodine (El-Dakour *et al.,* 2015). Some dosages include the use of quick lime (Calcium oxide) at a rate of 500g per square metre. For culture gear and pipes, use 100ml of formaldehyde for every 0.4 tonnes of water. Immerse the equipment in water for 1 hour and then rinse thoroughly. To prevent the spread of infections from outside the farm, these disinfectants can be applied in footbaths at the entrances, both to the farm and key points within the farm, such as hatcheries that are frequented by staff and visitors. The disinfectant solution should be carefully prepared and maintained, checked regularly and replaced when needed. For more effective use of a footbath, it is advised to consider a two-stage process (scrubbing of solid particles followed by disinfection).

Surveillance for diseases: Regular surveillance helps identify potential disease routes and detect new diseases in their early stages. It includes passive surveillance (using existing data) and active surveillance by conducting specific surveys (Assefa and Abunna, 2018).

Sanitation and water treatment: Clean and dry ponds properly, ensure high-quality, well-aerated water, and implement sanitation protocols for equipment.

Stocking density reduction: Lower stocking densities to control ectoparasite infections and increase water flow for better parasite flushing.

Implementing these biosecurity measures can significantly reduce the risk of disease outbreaks and ensure the welfare and health of fish in aquaculture.

Antimicrobial Resistance and Fish Welfare

Antimicrobial resistance (AMR) is a natural process in which microorganisms, such as viruses, bacteria, fungi and parasites, evolve and develop mechanisms to resist the effect of antimicrobial drugs. AMR is one of the top global public health and development threats. The misuse and overuse of antimicrobials in humans, animals and plants are the main drivers in the development of drug-resistant pathogens (Murray et al., 2022). Infections become increasingly difficult to treat, even with standard medications. In traditional aquaculture, unfavourable conditions and exposure to pathogens often lead to disease outbreaks, prompting the use of antibiotics to maintain fish health. Diseases are a primary constraint to the culture of many aquatic species, and as a result, there is widespread use of anti-microbial veterinary medicines in aquaculture across the globe. The imprudent use of veterinary medicines in aquaculture is a contributing factor to the spread of antimicrobial resistance. This practice not only fosters the development of resistant bacteria but also poses risks to ecosystems and public health. For example, the use of antibiotics in aquaculture when they are not necessary to promote fish growth or fecundity, but rather to treat infections, contributes to the development of AMR. Some studies conducted in Ethiopia among community members indicated that a small proportion (39.8%) of the population was aware of AMR (Simegn and Moges, 2022). Knowledge enhancement in AMR among communities is paramount. In aquaculture, intensive culture systems provide a platform for AMR.

Why AMR is a challenge in aquaculture

High stocking densities and reliance on antimicrobials create an environment conducive to pathogen growth (bacteria, viruses, and parasites) and survival (Okon et al., 2022). Acute infections can lead to poor fish welfare and loss of fish stock. The release of antimicrobial residues into the environment, combined with the spread of resistant bacteria through fish farm water discharge, can facilitate the transfer of resistant bacteria to other fish farms that use the same drainage system as a source of water. The residues can also contaminate other water resources, posing a health risk to both aquatic and human life.

The consumption of fish contaminated with antibiotic-resistant bacteria or parasites poses a challenge to treat (zoonoses). These bacteria and parasites can cause discomfort to human beings, morbidity and subsequently death. The unethical use of antibiotics can lead to contamination of marine and freshwater life. The bioaccumulation and bioconcentration of these antibiotics can lead to biomagnification in the tissues of freshwater and marine fish, thereby impacting fish welfare. When such marine fish is consumed, human health is also compromised.

DISCUSSION QUESTIONS

- Do you have any biosecurity measures on your farm? If yes, describe them in detail.
- Do you experience fish disease outbreaks on your farm? If yes, how do you control disease outbreaks?
- How would you want to be helped in managing disease outbreaks on your farm?
- How do you handle fish for stocking on your farm?

REFERENCES

Adeleke, B., Robertson-Andersson, D., Moodley, G., and Taylor, S. (2020). Aquaculture in Africa: A Comparative Review of Egypt, Nigeria, and Uganda Vis-À-Vis South Africa. *Reviews in Fisheries Science and Aquaculture*, *29*(2), 167–197. https://doi.org/10.1080/23308249.2020.1795615

Algers, B. (2011). Animal welfare - Recent developments in the field. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, 6(10),1-13. https://doi.org/10.1079/PAVSNNR20116010

Altan, O. (2017). *Diversification of Aquaculture Activities and Production Methods Extensive Aquaculture *Hundreds of ponds ; Hectares of pond surface* . 1–14).

Amichaud, O., Lafond, T., Fazekas, G. L., Kleiber, A., Kerneis, T., Batard, A., Goardon, L., Labbé, L., Lambert, S., Milla, S., and Colson, V. (2024). Air bubble curtain improves the welfare of captive rainbow trout fry and fingerlings. *Aquaculture*, *586*, 1-17. https://doi.org/10.1016/j.aquaculture.2024.740828

Arechavala-Lopez, P., Cabrera-Álvarez, M. J., Maia, C. M., and Saraiva, J. L. (2022). Environmental enrichment in fish aquaculture: A review of fundamental and practical aspects. *Reviews in Aquaculture*, *14*(2), 704–728. https://doi.org/10.1111/raq.12620

Ashley, P. J. (2007). Fish welfare : Current issues in aquaculture Fish welfare. *Applied Animal Behaviour Science,* 107, 199 - 235. https://doi.org/10.1016/j.applanim.2006.09.001

Asiva Noor Rachmayani. (2015). *Procedures for the quarantine of live aquatic animals*.

Assefa, A., and Abunna, F. (2018). Maintenance of Fish Health in Aquaculture: Review of Epidemiological Approaches for Prevention and Control of Infectious Disease of Fish. *Veterinary Medicine International*, *2018, 1-10*. https://doi.org/10.1155/2018/5432497

Aude, K., Mathilde, S., Mélanie, R., Vitor, F., and Bessa, H. (2023). *Archimer Cognitive enrichment to increase fish welfare in aquaculture : A review*. *575*, 1-40.

https://doi.org/10.1016/j.aquaculture.2023.739654

Becker, J. A., Gilligan, D., Asmus, M., Tweedie, A., and Whittington, R. J. (2019). Geographic distribution of epizootic haematopoietic necrosis virus (Ehnv) in freshwater fish in south eastern Australia: Lost opportunity for a notifiable pathogen to expand its geographic range. *Viruses*, *11*(4), 1-15. https://doi.org/10.3390/v11040315

Berlinghieri, F., Panizzon, P., Penry-Williams, I. L., and Brown, C. (2021). Laterality and fish welfare - A review. *Applied Animal Behaviour Science*, *236*,1-11. https://doi.org/10.1016/j.applanim.2021.105239

Boyd, C. E. (1998). Water quality in ponds for aquaculture. *Research and Development Series*, *43*, 482.

Bozzo, G., and Dimuccio, M. M. (2023). Implementation of Animal Welfare: Pros and Cons. *Agriculture (Switzerland)*, *13*(4), 10–12. https://doi.org/10.3390/agriculture13040748

Business, C. in F. (2017). *Driving Innovation in Humane Fish Slaughter:* 1–8.

Dara, M., Carbonara, P., La Corte, C., Parrinello, D., Cammarata, M., and Parisi, M. G. (2023). Fish Welfare in Aquaculture: Physiological and Immunological Activities for Diets, Social and Spatial Stress on Mediterranean Aqua Cultured Species. *Fishes*, *8*(8),1-15. https://doi.org/10.3390/fishes8080414

EFSA. (2009). The Welfare of Farmed Fish. *Applied Animal Behaviour Science*, *83*, 153–162.

El-Dakour, S., Saheb, A. I., and Al-Abdul-Elah, K. (2015). Effects of commonly used disinfectants on bacterial load, hatchability and survival of Bluefin Sea bream (Sparidentex hasta) eggs. *Aquaculture Research*, *46*(6), 1281–1291. https://doi.org/10.1111/are.12302

European Union. (2021). Particular welfare needs in animal transport : aquatic animals. *Workshop on Animal Welfare during Transport on 25 May 2021*.

FAO. (2024). *WORLD FISHERIES AND AQUACULTURE*.

FAWC. (1996). Report on the welfare of farmed fish. *Farm Animal Welfare Council*, 43.

Flores Nava, A., and Manjarrez-Aguilar, J. (2023). Latin American and the Caribbean call to increase the contribution of fisheries and aquaculture to food and nutrition security. *FAO Aquaculture News*, *67*, 22–23. www.fao.org/publications

Francis-Floyd, R. (2017). Mycobacterial infections of fowl. *Journal of the Hellenic Veterinary Medical Society*, *57*(2), 127. https://doi.org/10.12681/jhvms.15017

Gerber, B. (2015). *Environmental Enrichment and its effects*. *41*(0).

Goes, E. S. dos R., Goes, M. D., and Castro, P. L. de (2019). *Effect of Pre-Slaughter Stress on the Quality of Tilapia Fillets*. Global Aquaculture Advocate, 1-11.

Humane Slaughter Association. (2016). Humane Harvesting Of Farmed Fish. *Online Guides*, *44*, 19. https://www.hsa.org.uk/removal-from-water/removal-from-water

Johansen, R., Needham, J. R., Colquhoun, D. J., Poppe, T. T., and Smith, A. J. (2006). Guidelines for health and welfare monitoring of fish used in research. *Laboratory Animals*, *40*(4), 323–340. https://doi.org/10.1258/002367706778476451

Lindholm-Lehto, P. C., and Pylkkö, P. (2024). Saprolegniosis in Aquaculture and How to Control It *Aquaculture, Fish and Fisheries*, *4*(4), 1–22. https://doi.org/10.1002/aff2.200

MAAIF. (2017). *REPUBLIC OF UGANDA MINISTRY OF AGRICULTURE, ANIMAL INDUSTRY AND FISHERIES*. *July*.

MAAIF. (2022). *MINISTRY OF AGRICULTURE, ANIMAL INDUSTRY AND FISHERIES Guidelines and Standard Operating Procedures for handling and transporting live animals in Uganda. THE REPUBLIC OF UGANDA*.

Mellor, D. J., Beausoleil, N. J., Littlewood, K. E., McLean, A. N., McGreevy, P. D., Jones, B., and Wilkins, C. (2020). The 2020 five domains model: Including human–animal interactions in assessments of animal welfare. *Animals*, *10*(10), 1–24. https://doi.org/10.3390/ani10101870

Moss, S. M., Moss, D. R., Arce, S. M., Lightner, D. V., and Lotz, J. M. (2012). The role of selective breeding and biosecurity in the prevention of disease in penaeid shrimp aquaculture. *Journal of Invertebrate Pathology*, *110*(2), 247–250. https://doi.org/10.1016/j.jip.2012.01.013

Muniesa, A., Furones, D., Rodgers, C., and Basurco, B. (2022). An assessment of health management and biosecurity procedures in marine fish farming in Spain. *Aquaculture Reports*, *25*, 1-23. https://doi.org/10.1016/j.aqrep.2022.101199

Murray, C. J., Ikuta, K. S., Sharara, F., Swetschinski, L., Robles Aguilar, G., Gray, A., Han, C., Bisignano, C., Rao, P., Wool, E., Johnson, S. C., Browne, A. J., Chipeta, M. G., Fell, F., Hackett, S., Haines-Woodhouse, G., Kashef Hamadani, B. H., Kumaran, E. A. P., McManigal, B., and Naghavi, M. (2022). Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. *The Lancet*, *399*(10325), 629–655. https://doi.org/10.1016/S0140-6736(21)02724-0

Muthusamy, P., and Viswanathan, K. (1999). Influence of Rearing System on Egg Quality Traits of Commercial Layers. *Indian Veterinary Journal*, *76*(6), 533–536.

Ojelade, O. C., Durosaro, S. O., Akinde, A. O., Abdulraheem, I., Oladepo, M. B., Sopein, C. A., Bhadmus, A. S., and Olateju, M. (2022). Environmental enrichment improves the growth rate, behavioural and physiological response of juveniles of Clarias gariepinus under laboratory conditions. *Frontiers in Veterinary Science*, *9, 1-19*. https://doi.org/10.3389/fvets.2022.980364

Okon, E. M., Okocha, R. C., Adesina, B. T., Ehigie, J. O., Alabi, O. O., Bolanle, A. M., Matekwe, N., Falana, B. M., Tiamiyu, A. M., Olatoye, I. O., and Adedeji, O. B. (2022). Antimicrobial resistance in fish and poultry: Public health implications for animal source food production in Nigeria, Egypt, and South Africa. *Frontiers in Antibiotics*, *1*, 1–19. https://doi.org/10.3389/frabi.2022.1043302

Pomeroy, R., Dey, M. M., and Plesha, N. (2014). The Social and Economic Impacts of Semi-Intensive Aquaculture on Biodiversity. *Aquaculture Economics and Management*, *18*(3), 303–324. https://doi.org/10.1080/13657305.2014.926467

Sánchez-Paz, A. (2010). White spot syndrome virus: An overview of an emergent concern. *Veterinary Research*, *41*(6), 1-34. https://doi.org/10.1051/vetres/2010015

Sarker, S., Kallert, D. M., Hedrick, R. P., and El-Matbouli, M. (2015). Whirling disease revisited: Pathogenesis, parasite biology and disease intervention. *Diseases of Aquatic Organisms*, *114*(2), 155–175. https://doi.org/10.3354/dao02856

Segner, H., Reiser, S., Ruane, N., Rosch, R., Steinhagen, D. and V. (2019). *Welfare of fishes in aquaculture, FAO*. *1189*.

Sherwin, C. M., Richards, G. J., and Nicol, C. J. (2010). Comparison of the welfare of layer hens in 4 housing systems in the UK. *British Poultry Science*, *51*(4), 488–499. https://doi.org/10.1080/00071668.2010.502518

Simegn, W., and Moges, G. (2022). Awareness and knowledge of antimicrobial resistance and factors associated with knowledge among adults in Dessie City, Northeast Ethiopia: Community-based cross-sectional study. *PLoS ONE*, *17*(12), 1–16. https://doi.org/10.1371/journal.pone.0279342

Smail, D. A., and Snow, M. (2011). Viral haemorrhagic septicaemia. *Fish Diseases and Disorders*, *3*, 110–142. https://doi.org/10.1079/9781845935542.0110

Southgate, P. J. (2008). Welfare of Fish During Transport. *Fish Welfare*, 185–194. https://doi.org/10.1002/9780470697610.ch11

Subasinghe, R., Alday-Sanz, V., Bondad-Reantaso, M. G., Jie, H., Shinn, A. P., and Sorgeloos, P. (2023). Biosecurity: Reducing the burden of disease. *Journal of the World Aquaculture Society*, *54*(2), 397–426. https://doi.org/10.1111/jwas.12966

Tarazona, J. V, and Muñoz, M. J. (2008). *Reviews in Fisheries Science Water quality in Salmonid culture Water Quality in Salmonid Culture* (Issue May 2013).

Toni, M., Manciocco, A., Angiulli, E., Alleva, E., Cioni, C., and Malavasi, S. (2019). Review: Assessing fish welfare in research and aquaculture, with a focus on European directives. *Animal*, *13*(1), 161–170. https://doi.org/10.1017/S1751731118000940

Vargo, C., Taylor, S., and Haines, D. (1997). Book Review / Compte rendu de livre. *Contemporary Accounting Research*, *14*(2), 203–213. https://doi.org/10.1111/j.1911-3846.1997.tb00533.x

Wahltinez, S. J., Cohen, S., Hardy-Smith, P., Huynh, C., and Kells, N. J. (2024). Evaluation of insensibility in humane slaughter of teleost fish including the use of electroencephalogram with a case study on farmed barramundi (Lates calcarifer). *Aquaculture*, *590*, 1 -17.

https://doi.org/10.1016/j.aquaculture.2024.740993

WOAH. (2024). Animal welfare: a vital asset for a more sustainable world. *Animal Welfare - Vision*, 1–8. https://www.woah.org/app/uploads/2024/01/en-woah-visionpaper-animalwelfare.pdf

Zamparo, S., Orioles, M., Brocca, G., Marroni, F., Castellano, C., Radovic, S., Mandrioli, L., Galeotti, M., and Verin, R. (2024). Novel insights on microbiome dynamics during a gill disease outbreak in farmed rainbow trout (Oncorhynchus mykiss). *Scientific Reports*, *14*(1), 1–15. https://doi.org/10.1038/s41598-024-68287-w

ONE HEALTH & DEVELOPMENT INITIATIVE

Africa Fish and Aquaculture Welfare Program

AFIWELProgram

@afiwelprogram

Africa Fish & Aquaculture Welfare

afiwelprogram@onehealthdev.org