Faculty of Humanities, Social Sciences and Education

Fish Health Management in Uganda

From Soft Laws to Practical Implementation

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If you wan' go wash, na water you go use
If you want cook soup, na water you go use
If your head dey hot, na water go cool am
If your child dey grow, na water he go use
If water kill your child, na water you go use
Nothing without water
Water, him not get enemy!

Fela Kuti (1938-1997), "*Water Get No Enemy*"

This thesis marks the ending of my time as a student at the University of Tromsø. The work has been conducted over a period of one year; the research questions were developed during the autumn of 2017, while the interviews, literature searches and analysis were performed during the spring of 2018.

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Executive Summary

Fish farming is becoming an increasingly important part of the food supply for the growing world population. Uganda is one of the countries in Africa where fish farming is on the rise, largely dominated by Nile tilapia and North Africa Catfish. With abundant water resources, an ideal climate and a market demand for fish, the conditions for development of the fish farming sector are in place.

This study has assessed biosecurity and fish health management in Uganda. The case is interesting since Uganda currently is a medium sized producer of farmed fish with the ambition to expand in the years to come. Adequate fish health management is likely to be critical for the country to achieve this. In this study, a literature and media review has been combined with three expert interviews, aiming to answer the following:

1. *What is the current status of fish health management in Uganda?*
2. *What biosecurity related factor(s) can be regarded most important to support a continued growth in the sector?*

From the literature and media review, it was concluded that very few published studies have focused on pathogen and disease prevalence, geographical distribution and impact on aquaculture production. Lack of predictable funding and human capacity seems to be main constraints in that work. The results also suggest that fish diseases still are not a pressing issue for fish farming in Uganda. This may however be masked by other more prominent issues, such as the need for quality feed and seed, as well as the low level of disease knowledge and awareness among farmers. Para-veterinarians seems to be the most important providers of disease information since very few trained veterinarians are working with fish or have specialized within aquaculture. Some basic biosecurity measures are carried out in hatchers, but very few or no basic biosecurity measures are implemented routinely in grow-out farms. There is still very little use of antibiotics even though farmers do not use vaccination as a prophylactic strategy. The most important existing policies were written almost a decade ago and are currently enforced only to a small degree. However, a new policy with more emphasis on aquaculture will soon take effect. Adequate implementation and enforcement of this policy will be important for Uganda to reach its goals of maintaining a sustainable fish farming sector while the production increases. A key factor for success may be to collect more hard field data on the subject to ensure a knowledge-based way forward.

The study indicates that securing the upstream part of production may be a cost-efficient approach to improve biosecurity at the time being. Maintaining disease free brood stocks and health certification of seed producers may contribute to decrease the general risk of diseases throughout the sector.

Overall, the findings from the study suggests that fish health management and biosecurity still is in its infancy in Uganda.

List of Abbreviations

ADEPT	Analysis of determinants of policy impact
AU	African Union
AU-IBAR	African Union – Interafrican Bureau for Animal Resources
CCP	Critical control point
DiFR	Directorate of Fisheries Resources
EAC	East African Union
EpiUnit	Epidemiological unit
FAO	Food and Agriculture Organization
GDP	Gross domestic product
IAVBC	International Aquatic Veterinary Biosecurity Consortium
KARDC	Kajjansi Aquaculture Research and Development Centre
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MT	Metric ton
muZARDI	Mukono ZARDI
MVM	Merck Veterinary Manual
NaFIRRI	National Fisheries Resources Research Institute
NARI	National Agricultural Research Institutes
NARO	National Agricultural Research Organization
NDP	National Development Plan
NEPAD	New Partnership for Africa's Development
NPA	National Planning Authority
NSD	Norwegian Centre for Research Data
OECD	Organization for Economic Co-operation and Development
OIE	World Organization for Animal Health
PARIHS	Promoting Action of Research Implementation in Health Services
SOP	Standard operating procedures

SPS	Sanitary and Phytosanitary Measures Agreement
TI	Transparency International
TILV	Tilapia lake virus
UBOS	Uganda Bureau of Statistics
UGGDS	Uganda Green Growth Development Strategy
UN	United Nations
USD	United States dollar
WAHIS	World Animal Health Information System
WTO	World Trade Organization
ZARDI	Zonal Agricultural Research and Development Institutes

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1 Context and Research Questions

Aquaculture is a term that covers farming of fish, crustaceans, molluscs, aquatic plants, algae and other aquatic organisms in fresh and sea water. Aquaculture dates back to 1100 BC and has since been an important provider of dietary supplement for humans (Hishamunda and Subasinghe 2003). The last century aquaculture, and especially fish farming, has become industrialized, moving from family-owned small scale businesses with local or regional sales consolidating in to larger units with multinational owners, investors seeking profit and global distribution networks. The aquaculture industry is currently the fastest growing food sector in the world producing about 106 million metric tons (MT), of which fish farming alone constitutes about 52 million MT (Figure 1). At the time being the production is outpacing the population growth (Hersoug and Revold 2012; FAOstatistics 2015). The growth accelerated in the late 80's and early 90's and has been steady ever since resulting in an accumulated increase of about 600% in the period from 1990 to 2015. As a comparison, the global traditional capture production has stagnated around 90 million MT annually the last 2-3 decades. For this reason, aquaculture is prospected to become key to supply important proteins and micronutrients for the human population, which is projected to increase from its current 7.3 billion to 8.5 billion in 2030 and 9.7 billion by 2050 (UN 2017; FAO 2014).

The current work will be limited to development of *fish farming* and focus on its progression in *Uganda* in *East Africa*. Although Africa has had the largest relative growth in percentage the last 15 years, the fish farming production volume still only accounts for about 3% of the annual global production. Egypt and Nigeria are the lead producing countries with

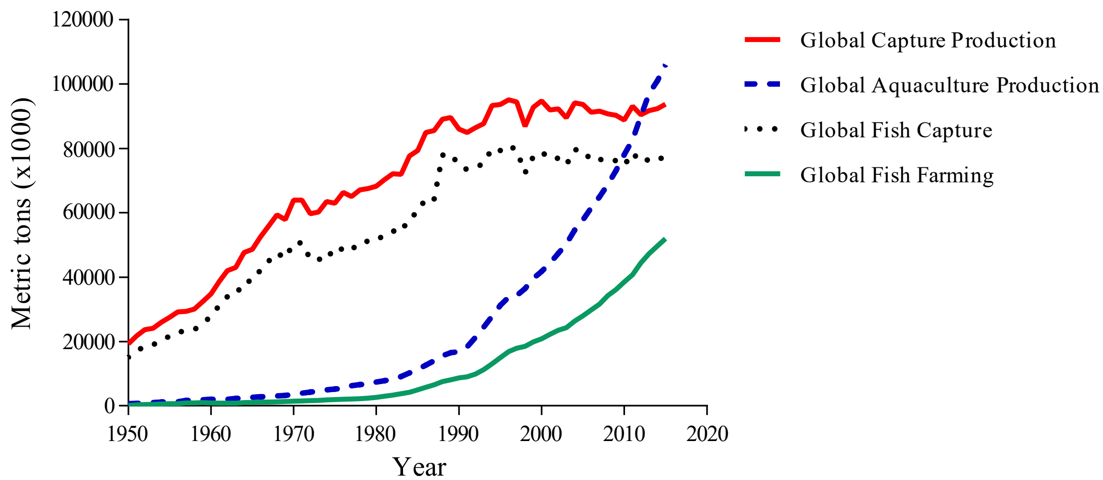

Figure 1. *Development of aquaculture and capture from 1950 until 2015. Production refers to all species (of fish, crustaceans, mollusks, aquatic plants, algae and other aquatic organisms), while fish is limited to diadromous, freshwater and marine species of fish. Graph based on data from FAO (FAOstatistics 2015).*

67% and 18% of the production volume, respectively, followed by Uganda at 7 % (FAOstatistics 2015). This intraregional skewness in production is not uncommon. From the bi-annual reports on global aquaculture production published by the Food and Agriculture Organization (FAO) of the United Nations (UN), it is evident that not only production volumes, but also the level of industrialization and professionalization to a high degree is unevenly distributed between countries, regions and continents. In many cases this is explained by an obvious lack of natural preconditions such as water resources. In other cases, it is complex involving a mix of cultural, political, technological and economic aspects.

The initial objective of this work was to assess the African fish farming sector for its potential for growth and profitability, in a more general term. However, as the search for knowledge on the subject started it was soon realized that many African and non-African stakeholders had already explored and reported on the topic; major bottle-necks related to the fish farming activity were to a large extent already identified. Key issues are summarized in a recent newsletter by FAO:

"*…the aquaculture sector, primarily in Asia and sub-Saharan Africa, is constrained by various other factors, including inadequate access to finance, a lack of technical innovation, an absence of feed formulation and processing knowledge and the use of inappropriate feed management practices…[ ] … . Other issues that need to be addressed are training and the dissemination of information to farmers, particularly small scale farmers with limited access to the latest technological and management developments."*

Hasan M.R. (FAO newsletter April 2017, no. 56)

Although *fish health management* generally is a significant input factor in modern fish farming, this topic seems to have undergone little scrutiny in the context of successful industry development in Sub-Saharan Africa. As a term, fish health management includes biosecurity activities, from implementation of regulatory policies to veterinary medicine methodology, that aim to limit disease outbreaks and spread of pathogens. Since financial losses due to diseases can be substantial, disease control is cardinal to maintain a sustainable and predictable production (Subasinghe 2005). Akoll and Mwanja have addressed this issue in a recent review of the fish health status in East Africa (Burundi, Kenya, Rwanda, Tanzania and Uganda) and identified gaps in research as well as argued for a strengthened aquatic biosecurity. According to these authors the past and current research has been focused on parasites in *wild hosts*, rather than bacterial, viral or fungal disease agents in *fish culture systems*. Furthermore, even though policies related to fisheries and aquaculture existed in most of the studied countries, the policies did not provide strategies for fish health management (Akoll and Mwanja 2012).

Statistics on African fish farming provided by FAO points to a continued increase in production volumes in the years to come (FAO 2014). Interestingly, is that the prospects for the sector seems to some degree to be detached from the political and social environment it will take place in. The business of farming apparently come with promise of profitability and growth, and somewhat exaggerated, that the only input factors missing, are technological and economic investments to the farming itself (e.g. fish, feed, water, hardware etc., that is, *operative factors*). This could be the case in developed countries where there is presence of and a high degree of public trust in enabling institutions such as the banking sector, in health care, law enforcement, educational system etc. Many states in Africa, Uganda included, are regarded as so-called fragile (OECD 2016). This is a condition the World Bank defines as *countries facing particularly severe development challenges: weak institutional capacity, poor governance and political instability* (Olowu and Chanie 2018). The last 5-6 decades of development assistance to the African continent has also shown that there is not necessarily a linear conjunction between investments and business establishment (Eidhammer 2012). The argument being, it may not be sufficient to have all operative factors relevant for fish farming in place to succeed in building a business. It also demands for key enabling functions, fish health management included. In an excellent review, Palic and co-workers have addressed biosecurity in aquaculture and suggested a standardized "best-practice" step-by-step approach for preventing, controlling and eradicating infectious diseases (Palic, Scarfe, and Walster 2015). This work discusses biosecurity bottom-up, from the level of a single epidemiological unit (called *EpiUnit*), e.g. a farm or zone, to national and international regulatory requirements, aiming to standardize the steps in developing, implementing, auditing and certifying an effective biosecurity program that would be feasible irrespective of species or farm site.

As a clinician in a pharmaceutical company and a fish health biologist involved in development of vaccines for the Asian fish farming industry, it is unfortunately well known that some markets under development generally are not structured or proactive when it comes to management of animal health. In many cases even the most simple, low-tech, but cost effective measures are not utilized at farms level. From my perspective, there are two prominent reasons for this; the financial situation and lack of general knowledge about fish health as a science. Farming of low cost species such as tilapias or catfishes often leaves the farmers with low margins for long term investments, and often health personnel with competence on aquatic diseases and fish farming are not available.

As a producer of about 118 000 MT of farmed fish, Uganda can be considered a medium-sized fish farming nation even in a global context, and the production volume is of a size that should entail biosecurity strategies (FAOstatistics 2018). The production largely takes place in bodies of water that are shared with other nations which makes fish health management more complex and the country an interesting case to study. In this context, the current work will try to answer two research questions:

1. **What is the current status of fish health management in Uganda?**
2. **What biosecurity related factor(s) can be regarded most important to support a continued growth in the sector?**

The next chapter aim to give more background to global and African fish farming in general, and Ugandan fish farming in particular, and will to some degree introduce the inherent natural and political preconditions the country has to develop the sector. The background will be followed by a presentation of theory (chapter 3) relevant for biosecurity and fish health management. As there are no standardized theoretical frameworks to *evaluate* biosecurity in fish farming, the topic will be covered by frameworks designed to *establish* biosecurity measures, such as the one by Palic and co-workers. Justification of Uganda as study case, as well as methods for data collection will be presented in chapter 4. In the analysis (chapter 5), the research questions will be addressed in three distinct but overlapping parts based on a literature and media review and expert interviews. Since diseases are a major risk factor in all animal husbandry, the first part in exploring the Ugandan fish health management and biosecurity will be to inquire what diseases are causing the highest losses to the most important farmed species. Having identified disease presence and impact based on the literature review, the second part of the study will investigate more in detail, using expert respondents, what biosecurity measures are employed in Ugandan fish farming. This will be done by considering biosecurity divided in five subtopics or components:

- The farm level (EpiUnit)
- Health professionals
- Diagnostics, surveillance and monitoring
- Documentation
- Regulations, policies and legislations

Findings will be presented descriptively and discussed in relation to relevant theory, trying to identify inadequacies and strengths in the level of biosecurity in Uganda. The final chapter will summarize and conclude based on a holistic approach.

2 Background

2.1 Global Fish Farming – a Production Review

Today, about 362 of the 580 aquatic species farmed globally are finfishes, most of the production destined for human consumption. Fish farming is practiced both by some of the poorest farmers in developing countries and as well as multinational companies, providing jobs for 19 million people in the primary sector (FAO 2016). According to Smith and co-workers, 92 % of the animal aquaculture production occurs in developing countries and products from the aquaculture and fisheries/harvest are the most highly traded food commodity internationally. In many developing countries the value of seafood products exceeds the value of coffee, rubber, cocoa, tea, tobacco, meat, and rice combined (Smith et al. 2018).

Asia is by far the largest producer globally with 88.1% of the farmed fish, mainly carps and catfish, but also cichlids like the well-known tilapias (*Oreochromis* spp.), with an estimated value of 75 billion USD. Of this, China alone stands for a staggering 55% of the global production, followed by India and Indonesia. In comparison, the production volumes in Europe, the Americas and Africa are between 1.7-2.3 million tons annually in each of the continents, thus only about 4-5% of the production in Asia (more details are provided in Appendix 1).

A common feature between Asian and African production is that both regions are dominated by pan-size (500-1000 g fish) production of low-value species such as catfish and tilapias. This is reflected in the low average value/ton ratio for the region (Appendix 1, second column). Production in Europe, Oceania and the Americas is on the other hand dominated by high-value species such as salmonids farmed either to pan-size (e.g. inland trout farming) in freshwater or several kilos (e.g. salmon farming at sea) in larger cages, resulting in a high average value-to-ton ratio.

Another interesting feature with the development is that every region is dominated by one country being the major producer, e.g. Norway in Europe, China in Asia and Egypt in Africa (Appendix 1). Except for in the Americas where the production is distributed more evenly between a few lead countries, the second largest producing country generally has volumes considerably lower than the lead country in most regions (e.g. China with 63% of the production volume followed by India at 10%). This could of course be explained by a lack of natural resources, traditions for culturing of fish or desire or ability to invest in the sector, but also suggest that most regions or countries have a potential to develop fish farming in one form or another, either inland or at sea. Examples of this are the massive production increase of sea bass (*Sparus aurata*) and sea bream (*Dicentrarchus labrax*) in the Mediterranean and the pangasius (*Pangasianodon hypophthalmus*) industry in Vietnam just the last decade (FAO 2016).

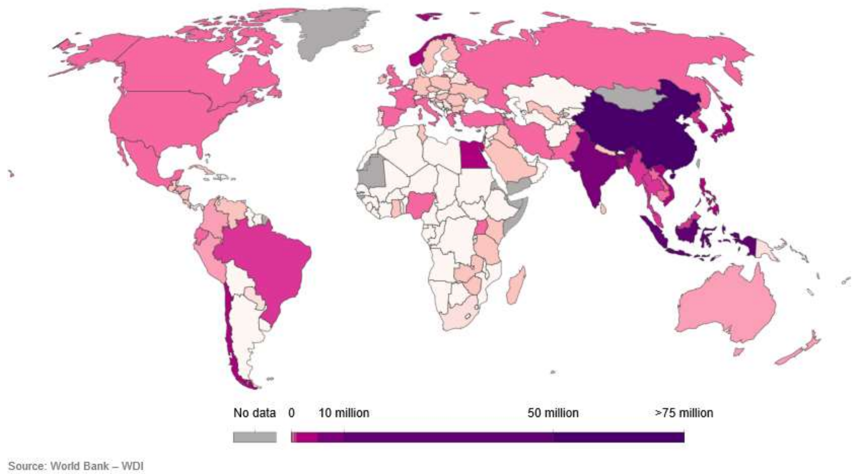

Figure 2. *Production of aquaculture (farmed fish and seafood) species per year (2015), by region. Production is measured in metric tons with color intensity indicating production volumes (dark=high, light=low). Source: (OurWorldinData 2018).*

A final point to be made is that most of the global fish farming production (88 %) takes place in fresh or brackish water (FAOstatistics 2018). In many parts of the world, clean water is a limiting resource as it is used by households, in agriculture and for miscellaneous industrial activities. Not only does this make pollution an increasingly relevant issue, as recently reported in Vietnam (Paddock 2016), but it may also restrict fresh water reserves to direct human use, and limit the use in water demanding sectors such as fish farming (Karklis, Tierney, and Soffen 2018). While the impact of human activities and climate change may contribute to limit development of fish farming in certain inland areas, it may also contribute to push for new technologies for water recirculation in farming systems to be developed and motivate for more fish farming in sea water in the time to come.

2.2 Fish Farming on the African Continent

Egypt, Kenya and Malawi has the earliest recorded history of modern fish farming in the Northern/Eastern Africa dating back to the beginning of the last century (Dadzie 1992). In the period between 1940-60 aquaculture was initiated also in Rwanda, Uganda, Zambia, Zimbabwe and Tanzania and during the 1950's there was an expansive fish culture development of tilapias, catfish and carp due to ambitious governmental programmes resulting in almost 300 000 ponds being in production in Africa (Meshkat 1967). Already in the 1960's the interest had declined however, explained by a of lack of trained personnel and efficient culture techniques, poor water quality, inadequate locations and political unrest, consequently many of the ponds where abandoned (Aguilar-Manjarrez and Nath 1998; Dadzie 1992). Although there was some development the following three decades, it did not fully gain momentum until the mid-1990's (Figure 3).

At present, more than 99% of the fish farming in Africa takes place in fresh water with Nile tilapia and North African catfish being the major species produced (FAOstatistics 2018). Farming of Nile tilapia and North African catfish is conducted in earthed ponds, concrete tanks or cages, and both species reach harvest size of 500-1000 grams in 7-9 months. Egypt has established farming practices able to produce about 1.4 million ton and provide their internal market with 2/3 of the fish consumed (Beveridge et al. 2013). In spite of strong markets and available natural resources for fish farming elsewhere in Africa, it has yet to develop to industrial levels in many other countries. The second largest producer is Nigeria, followed by Uganda, Ghana and Zambia (Appendix 1 and 2), where production in the three latter is relatively modest. Generally, sub-Saharan production remains dominated by smallholder, subsistence-type operations located in rural areas, but intensive commercial production is on the rise (AU-IBAR 2013).

In more recent times, the main constraints for fish farming development in Sub-Saharan Africa has been described to include:

- **Poor aquaculture development policies** that can support a sustainable growth in the sector.
- **Few farming traditions**. Agriculture has traditionally dominated many economies in the region and therefore little knowledge about farming exist among farmers.
- **Social and economic instability** has retarded foreign and local investments, while trained personnel have left for other countries, thus reducing technical expertise and institutional memory.
- **Lack of fish seeds** makes is difficult to predict and plan production.
- **Unavailability of feed**. While many small-scale producers can rely on fertilization or feed made on site, intensive farming will demand for higher and more consistent quality and quantity.
- **Transport costs and poor infrastructure**. This is a key factor in fish farming since fish seeds, feed and harvested fish has to be transported to and from isolated or rural producers.
- **Lack of research institutions** that can support the industry with knowledge-based recommendations and systematic studies on how to improve farming.

Summarized from (Machena and Moehl 2001)

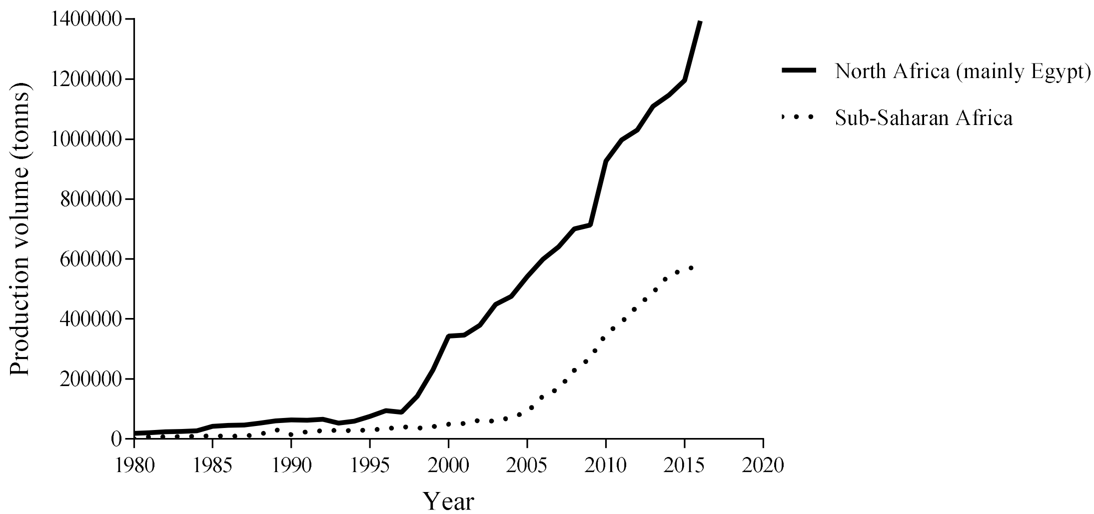

Figure 3. *Production development in fish farming in North Africa (Egypt, Marocco, Algerie, Tunisia, Libya and Sudan) and Sub-Saharan Africa (all other countries). The graph represents a sum of diadromous, freshwater and marine species. Based on data from FAO (FAOstatistics 2018).*

2.3 Uganda – a Country in the African Great Lakes Region

2.3.1 Key Facts and Figures; The Republic of Uganda

Uganda, officially the Republic of Uganda (Figure 4) has an estimated population of 42.9 million people (UN 2018). The capital and largest city is Kampala (population: above 2 mill.). The official languages are English and Swahili.

Uganda became independent from Britain on the 9th of October 1962, after being ruled as a protectorate by the British since 1894. In 1967, the Republican Constitution came into force and maintained a multi-party system of Government (UgandanParliament 2015). Due to the military coup launched by Idi Amin in 1971, parliament was in abeyance until 1979. The current president in the 10th Ugandan parliament is Yoweri Kaguta Museveni who came to power in 1986 after a six-year guerrilla war. According to the World Bank, Uganda had a sustained period of high growth (7% in average) and poverty reduction between 1987 and 2010. This has slowed down (3-5%) in recent years driven by adverse weather, unrest in South Sudan, private sector credit constraints, and the poor execution of public sector projects (TheWorldBank 2018). Transparency International (TI) has listed Uganda as number 151 of 180 countries (2018) in their corruption index and the country was reported to be the most corrupt in the East African community (EAC) in 2012 (TransparencyInternational 2012). Corruption affects a wide range of sectors and governmental institutions, and challenges the system by weak separation between public and private spheres, leading to clientelistic practices and patronage (see e.g. (Chabal 2009; Ayittey 2005)). Uganda's weak institutional capacity, poor governance and political instability is also acknowledged in a recent OECD report (OECD 2016). The unemployment rate varies between 8-13% for people in the age of 25-59, and overall about 18% of the households received remittance (money or goods) from abroad. Currently only 3% of the population has professional or technical education (UBOS 2016).

According to the National Planning Authority (NPA) the 2040 vision for Uganda priority areas include agriculture (which also covers aquaculture), tourism, minerals, oil and gas, infrastructure and human capital since these are seen as growth drivers with the greatest multiplier effect (NDPII 2015). With more than 5.2 million agriculture households in Uganda (over 97% of whom are subsistence farming) the sector is already central to the country's economic growth and poverty reduction strategy. It currently employs 72% of the total labor followed by tourism, which employs about 7% (UGGDS 2017). The mineral, oil and gas sector is however projected to be the major driver in employment creation and GDP growth through mineral exports and use of oil and gas for local consumption/generation of electricity. Infrastructure development is regarded critical to enable a timely and efficient movement of merchandise and labor resources from production zones to the market (NDPII 2015). In the context of the current work, it is worth to point out that although fisheries have declined in recent years due to overfishing, the green growth development strategy for Uganda 2017/18-2030/31 does not include aquaculture as an alternative (UGGDS 2017).

2.3.2 Geography and Water Resources

Uganda is a landlocked country in Eastern Africa bordering to Kenya in the east, the United Republic of Tanzania to the south, Rwanda to the southwest, the Democratic Republic of the Congo in the west and South Sudan in the north (Figure 4). Situated south of equator, Uganda covers an area of 241 038 km^2 (similar to UK) and has about significant 165 lakes. About 18% of the land is open waters while 3% is swamps. The major lakes include Lake Victoria, Lake Albert, Lake Kyoga, Lake Edward and Lake George and together with the Nile River, these waters contribute to more than 80% of the capture fisheries production. Main rivers include the Victoria Nile, Albert Nile, Achwa River and Kazinga Channel (Hyuha et al. 2017). Uganda has a tropical climate with average temperatures in the range of 21-25^{o}C. The territory is plateau land enclosed by snow covered mountains on its western and eastern flanks. The southern half of Uganda has two periods of heavy rainfall (March-June and September-November) and because of this the southern part has more vegetation with savannah, equatorial forest and richer soil. As a consequence, the south has traditionally been able to support extensive farming and sizeable human population densities. Rainfall is much lower in the north (one season March-April) and this area thus has thinner vegetation and is dominated by pastoralism (Reid 2017, ch.1).

Figure 4. Map of Uganda (NationsOnline 2018).

Bacterial contamination of both ground water and surface water from inadequate sanitation facilities remains the most important water quality problem. Contamination of hazardous chemicals from industries and agriculture is still at low levels, but eutrophication resulting from excessive quantities of nutrients reaching water bodies can cause algal blooms that may lead to oxygen deficits and fish kills, or promote excessive growth of weeds such as the water hyacinth (UGGDS 2017).

2.3.3 Fish Farming in Uganda, From Past to Present

Aquaculture in Uganda was started in 1941 after import of carp was proposed by the colonial authorities. In 1947, the Kajjansi Fish Experimental Station was established and a vital fish farming extension program resulted in the construction of 1500 ponds concentrated in the central (Buganda) and the southwest (Kigezi) regions by 1956, and by 1968 up to 11 000 ponds were producing fish for subsistence. Changing policies under successive governments led to uneven support and many ponds were abandoned due to lack of stocking material, limited technical guidance and excessive government regulatory regimes. By 1999 only 4500 were still functioning with only a fraction being in use. However, strategic intervention by the government and development partners in the years to follow again provided impetus to resume development of the sector (FAO 2005) and today North African catfish and Nile tilapia are the main farm species (Figure 5).

While fisheries in Uganda have declined about 6% since 2005 (from 416 000 MT), fish farming has increased by 900% in the same period, from 11 000 MT in 2005, to the current production of 118 000 MT (FAOstatistics 2018). According to the National Development Plan for Uganda the target is to reach 300 000 MT by 2020 (NDPII 2015). The recent increase has mainly come as a result of expansion in the tilapia farming, while catfish production has been more or less stable (Figure 5). Earthen ponds are still dominating, with an estimated number of 20-25 000 ponds with an average surface area of 500 m^2 (MAAIF 2012). A typical pond is either an excavated ditch or a contour type built in a shallow valley forming a damn. Farming in cage systems made of closed net structures in lakes, water reservoirs and dams is expanding since they are cheaper to build and operate than ponds. Currently, more than 3000 cages are found in Lake Victoria and other water bodies, mainly owned by private commercial companies. Farming in tanks is less common due to lack of know-how and access to electricity (Hyuha et al. 2017). Most of the farmed tilapia and catfish are sold fresh directly to national consumers at the farmgate, or via intermediates such as supermarkets, restaurants, farmers associations, processors or other retailers. Some large companies sell tilapia and catfish to neighboring countries, but data is limited due to lack of detailed or accurate records about their business activities (Hyuha et al. 2017; Isyagi et al. 2009).

Four regional hatcheries (in Mbale, Gulu, Kajjansi and Bushenyi) have been established by the government, but only the one in Kajjansi remains functional. In addition, more than 50 private hatchery operators, concentrated in the central and east of Uganda, have been active with capacity to produce quality seeds for distribution (MAAIF 2012). In later years, hatcheries in the peri-urban areas have become specialized focusing on either tilapia or catfish, while the more rural hatcheries have dual-purpose working both as hatcheries and grow-out farms (Isyagi et al. 2009). Production of tilapia seed are done in ponds using brood stock with up to 1-to-5 male to female at 200 g and above. From breeding stocks, fingerlings are continuously harvested followed by sex reversal, which is typically performed in net hapas systems. For catfish, there are two kinds of hatcheries: small ones where all stages are pond based (typical for rural areas) and larger ones where fish are kept in tanks in the early stages (incubation, hatching and larvae rearing) followed by on-growing in ponds. Seeds are made by stripping the females (at 400 g and above), fertilizing the eggs and incubation in basin with water flow, and once the yolk sac is absorbed the larvae can be transferred to ponds fertilized with cow dung and poultry droppings (Isyagi et al. 2009), which has been found to significantly increase the fish yield (Hyuha et al. 2017).

Commercial diets have been available in Uganda since 2005/6, but the local commercial feed industry is still in its infancy (Hyuha et al. 2017). Availability of floating feed and hatchery diets has long been a critical requirement for the catfish farming. In 2011, the National Fisheries Resources Research Institute (NaFIRRI) started to produce sinking feed for tilapia, but its supply is also insufficient for the domestic marked due to limited availability of a main ingredient, *Rastrineobola argentea*, also known as the Lake Victoria sardine or *mukene*. It has been estimated that 80% of the farmers still use farm made by-products or formulate their own feed through mixing of different ingredients such as maize bran and oil cake of sunflower or cotton seeds, but is should be emphasized that the source dates a few years back (Isyagi et al. 2009).

In addition to insufficient supply of quality feed and seed, the sector development is constrained by lack of management skills. The Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) has estimated that about 150 service providers are employed by local governments to serve the about 12 000 farmers that are involved in aquaculture (MAAIF 2012). Tertiary institutions such as the Makerere University in Kampala have however started to offer diploma, undergraduate and postgraduate degrees in Fisheries and Aquaculture. Some of the criticism against the education is that much is class based and not practical nor research based, leaving the teachers short on hands-on experience. Graduates are therefore often unable to perform up to public expectations (Isyagi et al. 2009).

On a governmental level, aquaculture in Uganda is currently organized under MAAIF. Under MAAIF, the Directorate of Fisheries Resources (DiFR) operates through three departments for 1) Fisheries Management and Development, 2) Fisheries Regulations and Control and 3) Aquaculture (MAAIF 2017). Also under MAAIF is the National Agricultural Research Organization (NARO), established as an act of Parliament in 2005 and a council with mandate to coordinate, oversee and guide all agricultural research activities in the national agricultural research system. NARO also advise MAAIF on matters and is responsible to collect, collate and analyze data and information on research and ensure their publication and dissemination. The NARO is a collection of fifteen semi-autonomous public agricultural research institutes and are of two categories: the National Agricultural Research Institutes

(NARI) and the Zonal Agricultural Research and Development Institutes (ZARDI), where NARI deals with research of strategic nature and of national importance, while ZARDI manage and carry out applied or adaptive research for a specific agro-ecological zone. One of the seven NARIs is dedicated to fisheries and aquaculture, namely NaFIRRI. Its mandate is *to conduct basic and applied research of national and strategic importance in Aquaculture, Capture fisheries, Water environment, Socio-economics and Marketing, and Information Communication Management, and emerging issues in the fisheries sector* (NaFIRRI 2018), which is addressed under four broad programs, namely: Aquaculture and Fish Biosciences, Capture Fisheries and Biodiversity Conservation, Fish Habitat Management, and Innovations and Post-Harvest Fisheries. The main research related to fish farming is performed at Kajjansi Aquaculture Research and Development Centre (KARDC) where NaFIRRI has 25 ponds, 62 concrete tanks and 6 laboratories. Within NARO, NaFIRRI also collaborates with Mukono ZARDI (muZARDI) by sharing aquaculture research information (according to their web page they conduct research on tilapia monosexing (muZARDI 2018)).

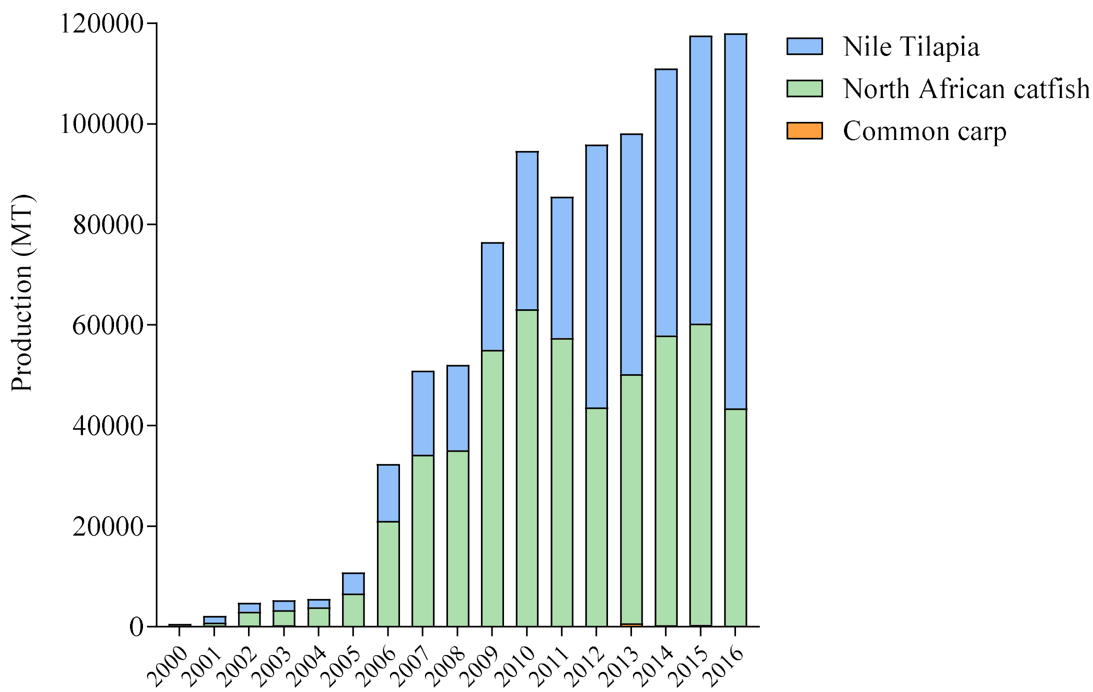

Figure 5. *Fish farming production in Uganda in the period 2000-2016. Graph based on data from FAO (FAOstatistics 2018).*

The Fish Act (Cap.197) of April 1951 is currently the main legislation managing fisheries in Uganda. It was put in place to make provision for the control of fishing, and does not give aquaculture any special attention (Isyagi et al. 2009). However, The Aquaculture Rules of May 2003 are a total of 32 subsidiary rules made under the Act and set forth the different permits required to engage in aquaculture and their modalities of issuance, as well as inspector powers, responsible aquaculture activities, conditions for fish seed production, fish transfer and live fish exports and imports (FAO 2011; MAAIF 2003). Other legislations relevant to fish health and biosecurity include the Animal Disease Act (Cap.38) of January 1918 (MAAIF 1918), but this law requires modification to accommodate aquatic animals (Akoll and Mwanja 2012). Fisheries and aquaculture is further regulated by The National Fisheries Policy from 2004. This policy provides the basic framework for the operations and marketing of fish and does only in general terms mention specific areas of development of aquaculture (e.g. seed production, semi-intensive farming). The National Agricultural Research System Act of November 2005 is also worth to mention in this context as it disrupts the monopoly of public agriculture research by public institutions and opens research opportunities to others (Hyuha et al. 2017).

On an international level, Uganda has membership in FAO and thus subscribe to the FAO Code of Conduct for Responsible Fisheries (1995). Uganda is also a member of the World Organization for Animal Health (Office International des Epizooties, OIE) and the World Trade Organization (WTO) (FAO 2011).

3 Theory

With the global increase in aquaculture production, focus on biosecurity and fish health management is becoming increasingly important to meet the risks and impacts of aquatic diseases (Bondad-Reantaso et al. 2005). Although biosecurity is a topic well covered in text books and review articles, it mainly exists as a conceptual framework and not within an acknowledged, holistic and defined theoretical framework. Two theoretical frameworks have however been found from review of relevant literature; one with a practical approach to the issue and the other more theoretical in its approach. These and relevant terminology will be presented with the objective to delimit the scope of biosecurity to the research issue herein. The final section will briefly introduce the concept of implementation theory and give an overview of the soft law hierarchy relevant for biosecurity in aquaculture. We start with delineating relevant terminology.

3.1 Terminology

According to OIE, the term biosecurity can be defined as "*a set of management and physical measures designed to reduce the risk of introduction, establishment and spread of pathogenic agents to, from and within an aquatic animal population*", where a pathogenic agent means "*an organism that causes or contributes to the development of a disease*" (OIE 2017b). This broad definition recognizes that disease is a complex interaction between the host, the disease-causing agent and the environment, and thus demand for compartmentalization for trade purposes (Collett 2018a). Although the term does have multiple meanings and may be defined differently according to various disciplines e.g. in bioterrorism (Koblentz 2010), biosecurity will herein be limited to the OiE definition as it focuses on *management* of pathogenic agents in populations. *Fish health* as a term comprises biosecurity, but it also covers other factors that can influence the health status of the fish, e.g. water conditions, feed quality/composition and genetics. It is therefore not limited to diseases and pathogenic agents. However, in the context of this work, fish health and the management of it, will be referring to issues related to diseases and will unless otherwise stated be used interchangeably with biosecurity. Epidemiology is also a term related to fish health and biosecurity. This is the study of disease in populations and of factors that determine its occurrence, the key word being *populations* (Thrusfield 1995). Finally it should be pointed out that the above mentioned terms must not be confused with the term *biosafety*, that describes the bio*containment* principles, technologies and practices that are implemented *in laboratories* to prevent the unintentional exposure to isolated pathogens and toxins, or accidental release of infectious material to the environment (WHO 2006). Biosafety will not be addressed further here.

3.2 Biosecurity Levels and Measures

As mentioned initially, two theoretical frameworks for biosecurity has been identified through literature searches. The first is a recent work by the International Aquatic Veterinary Biosecurity Consortium (IAVBC) published by Palic and co-workers (2015). Their aim was to introduce a best-practice biosecurity procedure for aquaculture that can be applied irrespective of inter- and intracontinental differences in water sources, farm systems and species. To standardize the procedure, a farm site, an economic entity (production facility or company), a geographical zone, nation or region is to be considered an epidemiological unit (called *EpiUnit*) and all assessments are performed with the EpiUnit in mind. According to the OIE glossary, an epidemiological unit "*means a group of animals that share approximately the same risk of exposure to a pathogenic agent with a defined location. This may be because they share a common aquatic environment…[…]… or because management practices make it likely that a pathogenic agent in one group of animals would quickly spread to other animals (e.g. all the ponds on a farm… […])*. While the definition and use of the concept EpiUnit seems to be common between different definitions or perceptions on what a biosecurity program or protocol should contain, this is not the case for how biosecurity is subdivided. For example, IAVBC have suggested *five* biosecurity levels comprising a total of nine steps (Figure 6, left). Their proposal can be viewed as a universal template or road-map, that is equally applicable to any EpiUnit as well as any disease, where the aim is to fulfill both the need for increased profitability for the farmers as well as satisfy national and international regulatory requirement (Palic, Scarfe, and Walster 2015). In the second theoretical framework, found in the Merck Veterinary Manual (MVM), biosecurity embrace *three* levels, where it is suggested that a comprehensive biosecurity program should be represented by a hierarchy of conceptual, structural and procedural components (Collett 2018b) (Figure 6, right). Others have also included a fourth component to this framework, namely cultural biosecurity, which focuses on the education of the employees to ensure that they understand the importance of biosecurity (ThePoultrySite 2014). The three following sections will give more detail on the subdivision presented by IAVBC and MVM, and summarize some of the terminology relevant for biosecurity. We start with the latter.

3.2.1 Common Biosecurity Measures in Aquaculture

As disciplines, biosecurity and fish health management comprises a range of terms and procedures that are somewhat overlapping and coherent. When put together they would constitute a holistic approach towards achieving a high level of biosecurity, but in most cases not all components are included in biosecurity programs (e.g. vaccination is still mainly implemented in developed markets). The following lists some of the most basic practical biosecurity measures that may be taken into use in fish health management:

- ***"All-in, all-out"*** production. So-called multi-age farms increase the risk of both introducing and attracting diseases to the EpiUnit.
- **Cleaning and disinfection**. Systematic and consistent routines for cleaning followed by disinfection will reduce the general disease risk on a site.
- **Quarantine period**. Animals with unknown health status should be kept separate awaiting a health declaration.
- **Zoning**. Avoid or reduce sharing input factors (fish, equipment, personnel and water resources) between EpiUnits to minimize disease transmission.

- **Removal and destruction of sick and dead fish**. Fish that are sick or have died of disease will shed pathogens to the surroundings. Continuous removal and adequate destruction (e.g. ensilage) of these fish contributes to reduce the overall infections pressure.
- **Fallowing**. An operation where an aquatic establishment is emptied of aquatic animals susceptible to a disease of concern or known to be able to transfer the pathogenic agent.
- **Disease monitoring**. Perform routine observations (e.g. weekly, monthly, annually) on health, productivity and environmental factors and the recording of these observations.
- **Disease surveillance**. Systematic series of investigations of a given population to detect and trace the occurrence of a disease for control purposes.
- **Immune stimulants**. Feed additives that stimulate the immune system is widely used in fish farming due to its low cost and easy administration.
- **Vaccination**. Vaccines are commercially available for many fish species against a range of diseases. Being a pharmaceutical product, vaccine efficacy and safety must be documented and vaccines licensed before marketing, which makes vaccination a practice most common in countries where fish farming has been industrialized.

Based on (OIE 2017b; Poppe 1999; Thrusfield 1995)

3.2.2 Conceptual, Structural and Procedural Biosecurity

In the MVM, biosecurity is divided in three levels, as illustrated in Figure 6 (Collett 2018b).

The *conceptual* or primary level of biosecurity revolves around the location and design of animal facilities and limiting risk by *physical isolation* (Collett 2018b). This includes restriction on access by personnel and vehicles not directly involved in the farming operations, and controlling the spread of disease by vermin, wild animals and wind. In a larger context, the conceptual level encompasses defining geographical zones (e.g. national or regional boarders or watershed, as is relevant for fish farming in open, connected systems) for transfer of live or dead material of animal origin. This can include defining disease free zones and protection zones. The latter refers, in short, to a zone that is established to protect the health status of animals in a free zone from those in a country or zone of a different aquatic animal health status (e.g. different set of pathogens).

The second level, *structural* biosecurity, discloses on-site factors, such as farm layout, perimeter fencing, signage, drainage, equipment, changing rooms etc., to ensure as low risk as possible for whatever pathogen is present in the facility to be transported to or from the premises.

The tertiary and last biosecurity level referred to by the MVM is *procedural* biosecurity, where the aim is to work out and constantly review and optimize operating procedures (thus often referred to as operational biosecurity) to prevent introduction (bioexclusion) and spread (biocontainment) of infection within a facility (Collett 2018b). This will include the day-to-day operations and standard operating procedures (SOPs) implemented at a farm or in a company, as summarized in section 3.2.1.

3.2.3 The IAVBC Approach – Biosecurity in Five Levels

According to IAVBC approach (illustrated in Figure 6), an optimal biosecurity program or plan demands for efforts and close cooperation between key stakeholders in fish farming; producers (operation manager), para-veterinary health personnel, experienced veterinarians and government officials providing regulatory input (Palic, Scarfe, and Walster 2015).

Once the EpiUnit (e.g. a fish farm) is defined, the first step or biosecurity level aims to identify what diseases may be introduced or is already present, and what risk (probability) or impact (consequences: decreased production, high mortality, depopulation etc.) the disease(s) represent for the farm. Qualitative and quantitative risk assessment is a complex exercise outside the scope of this work, but it is pointed out that a semi-quantitative combined with qualitative approaches in most cases are adequate for developing biosecurity plans in fish farming (OIE 2017c). Examples of how risk assessments can be performed is found in publications by Sumner and Arthur (Sumner 2004; Arthur 2009).

Biosecurity level II deals with measures to prevent the introduction and spread of the diseases into, within and from a facility. In all cases, disease will be transmitted through so-called vectors (animate carriers such as people or animals) or fomites (inanimate objects such as water, feed, vehicles etc.), and production processes should be outlined to determine critical control points (CCP) for intake or escape of a disease (Karreman 2015). The next step will be to mitigate or manage risks by strengthening the CCPs by e.g. quarantine periods, disinfection routines and recording of related activities.

Biosecurity level III and IV are somewhat overlapping and the key question is; what should be done if unexpected mortality or morbidity is found in the EpiUnit? This can first of all be answered through a contingency plan that trigger a chain of predefined actions related to the affected animals (containment, treatment or disposal) and a communication strategy to stakeholders. Imperative for an effective contingency plan is that farm personnel is trained in recognizing disease as early as possible and that all measures against disease are documented, verified and filed, which will allow for post-assessment and improvement of the contingency plan. Furthermore, it is advocated that all EpiUnits should have periodic clinical evaluation and disease testing during production, regardless of current disease risk (Oidtmann et al. 2013). This will include a site visit, clinical exam and necropsy and review of the anamnesis (disease history) and other records related to production (water quality, feeding etc.). This is usually performed by degree holding veterinarians, but to manage maintaining veterinary services especially in rural or developing areas, veterinary para-professionals[1] are common (Ilukor 2017). Depending on formal or informal requirements in the biosecurity plan, the veterinarian must decide what test services to rely on for adequate testing; official services, in house suppliers, third-party (external) or governmental accredited laboratories.

The final biosecurity level (V) involve certifying the operation or EpiUnit as free of a specific pathogen, which of course will demand for an endorsement from an external veterinary authority based on the actions mentioned above. Such endorsements may have great economic advantages for commercial aquaculture, as will be returned to in a later section. More details to all levels are presented in Palic et al 2015.

To summarize, the above presentations of the two biosecurity hierarchies (IAVBC and MVM) shows that they are similar in structure, but while the MVM can be considered a general framework, almost theoretical in nature, IAVBC is a far more detailed guideline on how biosecurity can be improved. Both will form the basic theory for the analysis in the current work.

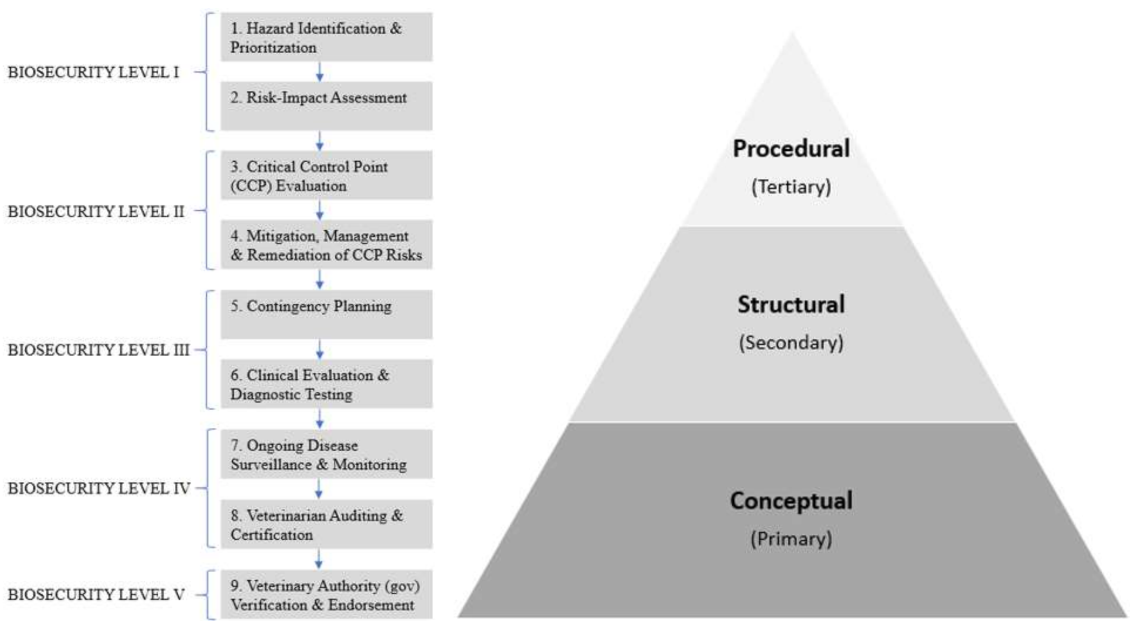

Figure 6. *Left: The five levels in a biosecurity program defined by IAVBC, modified from Palic et al 2015. Right: The hierarchy of biosecurity as defined in the Merck Veterinary Manual* (Collett 2018b).

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[1] OIE defines this as a person authorized by the Veterinary Statutory Body to carry out certain tasks in a given territory, delegated to them under the responsibility and direction of a veterinarian.

3.3 Policy Implementation and Economic Impact of Diseases

Policies are central to facilitate biosecurity measures. This section will introduce implementation theory relevant to policies and give an overview of the economic impact of diseases.

3.3.1 Policies and Implementation

Policies can be defined as a set of ideas or plans that are used as basis for making decisions. In a broad sense, public policies are a government's attempt to strategically satisfy the needs, demands and desires of the public. This is done by developing and institutionalizing political processes to realize societal goals. They are generally designed to influence and determine stakeholders in all major decisions and actions, and all activities take place within the boundaries set by them. (Hanekom 1987). Implementation can be defined as carrying out or giving practical effect to and ensuring actual fulfillment of goals by concrete measures (Palumbo and Wright 1984).

3.3.2 Implementation Theory

There is a rich taxonomy within the field of implementation science and the scope and focus in this work does not allow for a comprehensive summary. Instead the work by Nilsen (2015) is recommended for an excellent review (Nilsen 2015). However, the following will present three relevant theories and frameworks for policy implementation to illuminate the research question.

First, implementation theory has been defined as *"a study of the relationship between the structure of the institution which individuals interact and the outcome of that interaction"* (Jackson 2011). The objectives of implementation theory is to provide an analytical framework for situations where 1) resources have to be allocated among individuals/agents and, 2) the information needed to make these allocation decisions is dispersed and privately held, and 3) the individuals/agents possessing the information behave strategically and are self-utility maximizers (Kakhbod 2013, ch.2). In this context, implementation theory may help manage the process of transforming research in to practice, assist the understanding of what influences implementation outcomes and finally evaluate implementation (Nilsen 2015).

The *contextual interaction theory* was developed for environment protection policies due to a need for key actors to be involved in the implementation process (Bressers and Klok 1988). As a theory, it emphasizes policy implementation as a multi-actor process with interdependent action between implementers and targets. It involves three components (Figure 7). The first component is the input, which includes resources and activities needed for implementation of a policy. The second component implies a conversion process produced by the interaction between different actors and activities within an arena. The third component is the output, seen as change or in this case varying degrees of compliance to a policy (Bakari and Frumence 2013). The theory can be viewed as deductive, based on the argument that not all variables can be held constant or incorporated simultaneously. Interaction between actors are therefore assessed by adding policy instruments one by one element followed by an evaluation of how it shapes the output. By focusing on "core circumstances", that is, basic sets of actor characteristics (their objectives, information and power) it will allow for a route to a manageable heuristic[2] (O'Toole 2004).

The PARIHS (*Promoting Action of Research Implementation in Health Services*) framework was developed in an attempt to represent the complexity of the change process involved in implementing research-based practice (Kitson, Harvey, and McCormack 1998). The three elements in the framework, *evidence*, *context* and *facilitation* are positioned in a high-low continuum. The framework argues that successful research implementation is most likely to occur when 1) scientific evidence matches professional consensus and patient preferences (high evidence), 2) healthcare context is receptive to implementation, including supportive leadership, culture and evaluation systems (high context), and 3) mechanisms are in place to facilitate implementation (high facilitation) (Rycroft-Malone 2004; Ullrich, Sahay, and Stetler 2014).

The ADEPT (*analysis of determinants of policy impact*) model (Figure 8) aims to explain and influence policy development and policy implementation with four determinants: *goals*, *obligations*, *resources* and *opportunities* (Rütten, Gelius, and Abu-Omar 2010). It is an adaptation of the conception by the Finnish philosopher Georg Henrik von Wright where he identified determinants that influence an individual's *intention to act* (Wright 1976). The ADEPT model uses operationalization of the four categories to defined organization capacities needed to achieve a bridging between theory, research and practice in health promotion. (Rütten and Gelius 2013). This is done using a questionnaire consisting of 35 items with or without a 5-point answer scale (quantitative or qualitative approach, respectively). The different phases of the policy process (development, implementation and impact) are viewed as dependent variables, where impact consists of output (i.e. the actions taken at a policy level) and outcome (i.e. the effect, in this context improved fish health) (Rütten, Gelius, and Abu-Omar 2010).

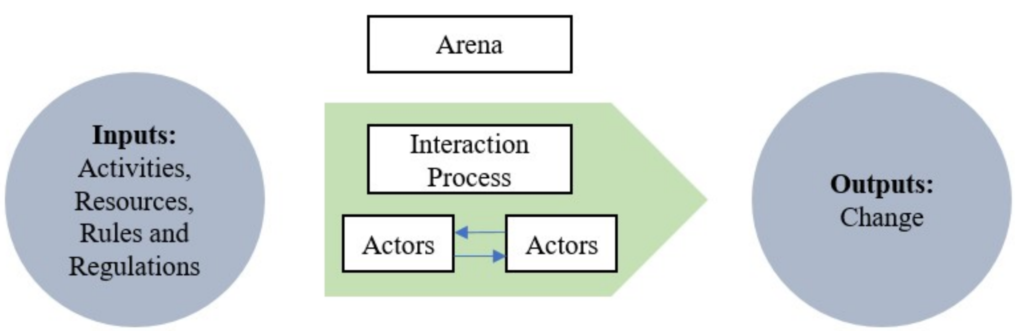

Figure 7. *Model of conceptual interaction theory illustrating conversion of inputs into outputs through an interactive process. Modified from (Bressers 2007).*

[2] Heuristic, meaning enabling a person to discover or learn something for themselves.

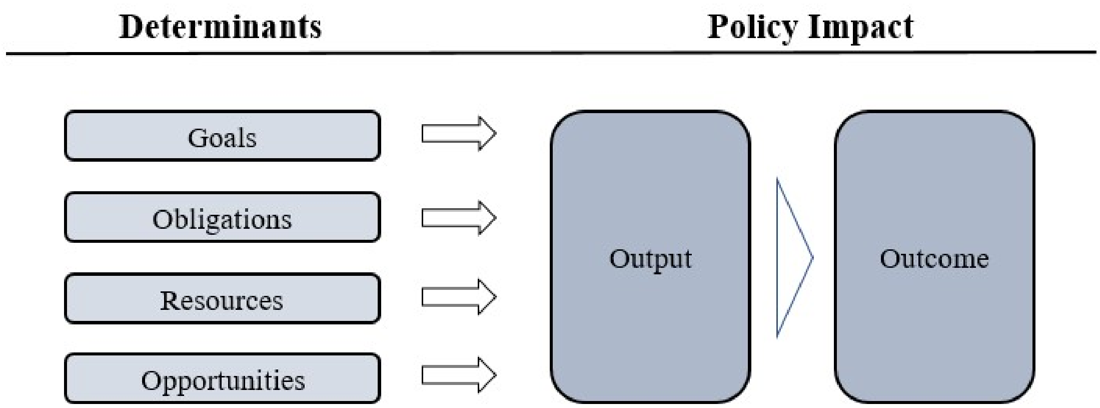

Figure 8. *The ADEPT model (Rütten, Gelius, and Abu-Omar 2010).*

3.3.3 Economics of Disease

Economic assessments are an integral part of many epidemiological investigations, providing a complimentary perspective to that of biological studies. The increased veterinary interest in economics come as a result of requirements to justify budgets especially in intensive production, optimize use of limited resources (land and feed) and the need to facilitate international trade (Collett 2018a). Disease increase costs mainly in two ways. First, because resources are being used inefficiently, the product yield are for an unnecessarily high resource cost. Oppositely, in the absence of disease, output could be obtained for a smaller expenditure of resources. Second, there is a cost to people who may be deprived of products (less quantity), have only products of low quality available or as a result of increased marked prices (Reed 2014). The relationship between the input and output is called *production function*. Through empirical studies the relationship has been demonstrated to be non-linear since certain inputs to production are fixed (Thrusfield 1995, p.313). Consequently, beyond a certain point an increase in variable input is associated with a less than proportionate increase in input, according to the "*law of diminishing returns"* (Heady and Dillion 1961). Disease shifts the input-output relationship and acts as a "negative input", reflected by lower output for given inputs in diseased animals compared to disease-free animals. The economic objective will thus be to identify the least-cost method to restore health and productivity (Thrusfield 1995, ch.20).

3.4 Regulatory Frameworks and Policies for Biosecurity

Much of the international soft laws that applies to fisheries and aquaculture have been reviewed elsewhere (Oidtmann et al. 2011; Hastein et al. 2008) and will thus only be summarized here. As illustrated in Figure 9, the lowest level in the regulatory hierarchy comprise industry codes of practice or operating procedures that applies locally within a farm or between farms in a region. This would for example include implementing some, or all of the management practices summarized in section 3.2.1 combined with coordinated contingency plans in collaboration with relevant local stakeholders. On a national level, the primary requirement to a biosecurity framework is to prevent the introduction and spread of exotic pathogens. Early detection via monitoring combined with statutory stamping-out[3] may be appropriate responses should an introduction occur. Secondly, the control of non-exotic and endemic disease is focused on minimizing the spread or elimination from the country or parts thereof (Oidtmann et al. 2011), and some countries have implemented mandatory vaccination as a measure to achieve this, cf. the Norwegian regulation for aquaculture operations (*Akvakulturdriftsforskriften*, § 63).

The Sanitary and Phytosanitary (SPS) Measures Agreement is the highest international agreement and describes basic rules on food safety and animal and plant health standards within the World Trade Organization (WTO 1995). According to Article 1.1 the SPS agreement *"…applies to all sanitary and phytosanitary measures which may, directly or indirectly, affect international trade"*. Furthermore, the SPS agreement recognizes the OIE[4] as the international body that provides guidelines or standards in the field of animal diseases (Oidtmann et al. 2011). Its key missions are to ensure transparency in the global animal disease situation, collect, analyze and disseminate veterinary scientific information, provide expertize and encourage international solidarity in the control of animal diseases and improve the legal framework for veterinary services (OIE 2018). Two established international standards by OIE are widely recognized for aquatic animal health: the Aquatic Animal Health Code (in short: Aquatic code) and the Manual of Diagnostic Tests for Aquatic Animals (in short: Aquatic Manual). The Aquatic Code aim to "*...set our standards for the improvement of aquatic animal health and welfare of farmed fish…*" and is intended to be a measure for "*…competent authorities and exporting countries for early detection, reporting and control of agents pathogenic to aquatic animals*" (OIE 2017a). The Aquatic Manual (OIE 2017c) is thus a supplement to the Aquatic Code, as its intention is to provide a standardized approach to the diagnosis of the listed diseases in the Aquatic Code. A recent report also adds to this; the Guide for Aquatic Animal Health Surveillance published by Corsin and co-workers (Corsin 2009). It provides information and guidance on the design and evaluation of surveillance systems for aquatic animal diseases (Oidtmann et al. 2011). In sum, these OIE standards are in support of the intentions behind the SPS agreement of facilitating safe trade.

The two last of the most relevant animal health standards to be mentioned here are the international Code of Conduct for responsible fisheries by FAO (article 2, section g: *"...promote protection of living aquatic resources and their environments...*") which, as the title implies, is mainly focused on fisheries and resources related to its activity. The European

[3] According to the OIE glossary stamping out refers to "*…killing the aquatic animals that are affected, those suspected of being affected and the population and those in the populations that have been exposed to infection by direct or indirect contact"*. Although similar to fallowing, which is considered a disease management issue and normally based on a risk management where the decision to act is made by the farmers or owners, stamping-out is a requirement from authorities that applies depending on how a disease is co-called *listed*, that is, its classification as an exotic, non-exotic or a national disease.

[4] The OIE is an intergovernmental organization created in 1924 and is currently counting 178 member countries or territories

Union Council Directive 2006/88/EC is also worth to mention as it is a result of supranational economic and political unions, and thus common policies and legal frameworks for animal health have developed. According to article 1, section b the Directive 2006/88/EC lays down *"…minimum preventive measures aimed at increasing the awareness and preparedness of the competent authorities, aquaculture production business operators and others related to this industry, for diseases in aquaculture animals*" (EU 2006) and includes *inter alia* chapters related to disease surveillance, disease prevention related to transport and animal health certifications. Similar policies can be expected to emerge within the African Union (AU) with the establishment e.g. the New Partnership for Africa's Development (NEPAD), as indicated by the recent Policy Framework and Reform Strategy for Fisheries and Aquaculture(AUC-NEPAD 2014). Policies and legislations relevant for Uganda were presented in section 2.3.3 and will be discussed further in the analysis.

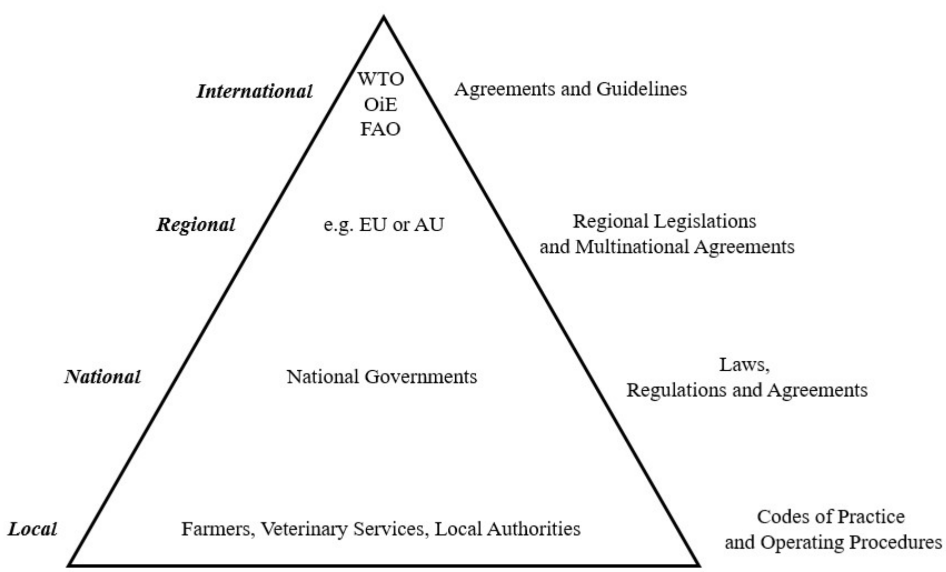

Figure 9. *The regulatory pyramid of biosecurity (modified from Oidtmann et al 2011).*

4 Methodology of Research

The research questions presented in chapter one will be explored in two steps:

1. **Literature and media review -** Describe the type and scope of information related to fish diseases in Uganda. This part aim to serve as a baseline for the coming analysis, and will mainly answer research question #1.
2. **Stakeholder interviews** – Three expert respondents will be interviewed to fill in gaps identified in step 1 and mainly explore and answer research question #2.

4.1 Choice of Case and Justification of Method

Case studies are intensive studies of one or a few units. This can be individuals, organizations (or parts of them), decisions, negotiations, chain of events, procedures etc., existing in a defined space and time (Andersen 2013, p.23). The current work is an atheoretical, single case study aiming to describe and explain the phenomenon and its context in light of a holistic understanding (Andersen 2013, p.61). There are four main reasons for choosing fish health management and biosecurity in Uganda as a case:

1. **The need for fish health management**: The aquaculture sector is still under development in the region, but is prospected to support food production in the coming years. Adequate fish health management can be a critical factor for Uganda to reach its ambitions.
2. **Production volumes**: As the third largest producer of farmed fish in Africa, one can assume that enabling and supportive infrastructure related to fish health management have been or are beginning to develop (e.g. diagnostic laboratories, educational institutions, public administration), and it is the level of development and professionalization that is interesting to study.
3. **Water resources**: Uganda has a stabile climate and numerous freshwater resources that are suitable for fish farming, many of which are shared with neighboring countries. The first point facilitates sector development, while the second point makes the question of disease management more complex.
4. **Language**. Since English is the official language relevant information is easily accessible to study the case. This will apply both for scientific publications as well as official documents (e.g. national statistics, legislations), news reports and verbal or written communication.

The current work is qualitative in nature. Method triangulation[5] combining literature searches with interviews will be used to increase the validity and credibility of the results from the study. A qualitative approach to a research issue is often used when the issue is difficult to concretize and there is a need to explore. It demands for openness and flexibility in the search

[5] Triangulation refers to the application and combination of several research methods in the study of the same phenomenon (Jacobsen 2013, p.229).

for and gathering of information about the case. As pointed out in the first chapter (*Context and Research Questions*), very few scientific works have so far addressed the issues raised herein, which underpins the need for an explorative approach to know more about the subject. It also stresses the need to focus the investigation on a limited number of subjects or units, to enable a higher level of scrutiny. An intensive study design will however give little opportunity to make generalized assumptions or statistically valid conclusions based on the results from the study (Jacobsen 2013, ch.7).

4.2 Data Collection

4.2.1 Secondary Data - Literature and Media Searches

Source data was obtained from two main sources; internet searches and through networking/personal request for suggested literature from people contacted during the study. Regional and national aquaculture policies, grey literature (non-governmental and governmental reports) and peer-reviewed articles were central to the literature review, and was supported by a media review. Policies were reviewed for content related to aquaculture in general, and fish health, diseases/epidemiology and biosecurity in particular. The grey literature was used to get an overall impression of the stakeholders, sector development as well as to obtain information on fish health/biosecurity, while peer-reviewed articles accounted for the disease status description. This part of the data collection may be limited by the fact that 1) the literature generally is written to serve other agendas or purposes than the study objective herein and that 2) not all data will be available (e.g. un-published, raw data) (Jacobsen 2013, ch.8). Internet resources, databases and some of the most important search words are listed in table 1. The search words were used either individually or in combination when deemed appropriate.

4.2.2 Primary Data - Interviews

Three experts in the field of fish health management in Uganda were interviewed either over the phone and recorded by hand writing (respondent #1), using a Dictaphone (Olympus® Digital Voice Recorder, VN-541PC) (respondent #2) or by returning written answers based on a questionnaire sent via e-mail (respondent #3). The two interviews were conducted according to an active, semi-structured approach. Prior to the interviews, the interview guide was sent via electronic mail to respondents #1 and #2 to give them time to prepare. Respondent #3 received and returned a modified version of the interview guide via e-mail. The interview with respondent #1 was conducted using telecommunication since internet access in Uganda to a large extent is limited to internet cafes and has connection of poor quality. Respondent #2 was interviewed face-to-face. Between the first and second, and the second and third interview, the questionnaire was revised and optimized to better target the research questions. Revision was mainly done by removing some of the questions in part #0 and adding questions related to the biosecurity at the farm (#1) (see section 4.2.4). The two oral interviews lasted between 1h 15min and 1h 30 min. The respondents gave long and extensive answers, resulting in the interviews taking twice as much time as indicated in the guide. It is not known to what extent the use of a recorder limited or influenced the answers given by the respondents.

4.2.3 Respondents

Since the subject for the study is narrow it required that the respondents possess specific training, education or experience about the research area. Their role was therefore as experts within a field (elite interviews) and ethnographic affiliation to Uganda, and their contribution expected to be more descriptive (facts) than emotional (Kvale 2015, p.123-124). Respondents were recruited via educational programs between Uganda and Norway, networking at relevant conferences/seminars and indirect inquiries through personal network. The scope of this work is limited, and respondents were therefor selected to cover different perspectives of the research question, including enforcement officers, researchers and academia, all of whom have wide experience from fish farming throughout the country. Some of the questions in the interview requested answers with personal opinions on the matters in question. Since fish health and biosecurity is a narrow scientific discipline it demands for extra caution

Table 1. Overview of key internet resources and search words used to collect secondary source data.

Internet Resources and Databases	**Key Search Words**
PubMed (https://www.ncbi.nlm.nih.gov/pubmed/)	Biosecurity
The African Journal of Aquatic Science	Fish health
(https://www.tandfonline.com/loi/taas20)	Fish health management
Makerere Journal of Higher Education	Bacteria (different species)
(https://www.ajol.info/index.php/majohe)	Virus (in general)
Uganda Journal of Agricultural Sciences	Parasites (in general)
(https://www.ajol.info/index.php/ujas)	Disease/fish diseases
Norart (https://www.nb.no/baser/norart/)	Epidemiology
EBSCO-HOST (search.ebscohost.com/)	Disease control and eradication
United Nations (http://www.fao.org/home/en/)	Disease monitoring and surveillance
World Organization for Animal health (OIE) (http://www.oie.int/)	Pathology
SARNISSA (www.sarnissa.org/HomePage)	Uganda
AU-IBAR (http://www.au-ibar.org/)	Lake Victoria
NaFIRRI (http://www.firi.go.ug/)	Lake Edward
MAAIF (http://www.agriculture.go.ug/). Note: the web-page was	Lake Albert
down for maintenance during the study period (Jan-May 2018).	Tilapia
Google (www.google.com)	African catfish
Youtube (for televised news reports) (https://www.youtube.com/)	
Sector Media:	
IntraFish (www.intrafish.com)	
FISHupdate (www.fishupdate.com)	
SeafoodSource (https://www.seafoodsource.com/)	
World Fishing & Aquaculture (http://www.worldfishing.net/)	
Ugandan Media:	
Daily Monitor (http://www.monitor.co.ug/)	
East African Business Week (http://www.busiweek.com/)	
The Independent magazine Uganda (https://www.independent.co.ug/)	
NTV (http://www.ntvuganda.co.ug/)	
Bukedde (https://www.bukedde.co.ug/)	

on which information about the respondents are being disclosed, to ensure confidentiality in the final document. Confidentiality was also considered important to ensure that the respondents would give answers that to the least extent as possible were influenced by the circumstances.

General information about the respondents:
Respondent #1. BSc./MSc./PhD., 10+ years of experience within fish farming/health. Current position: Research officer at governmental institution.
Respondent #2. BSc./MSc./PhD candidate, Lecturer in fish health. Current position: University.
Respondent #3. BSc./MSc. 10 years of experience within fish farming from Uganda and exchange programs abroad. Current position: Fisheries officer (aquaculture).

It cannot be excluded that the respondents may have a personal agenda when answering the questions, e.g. by giving a positive impression to reflect one's own efforts to the subject or give a negative impression to amplify the need for more funding to fish health. However, this was compensated for by comparing answers from three independent respondents and combining their information with a literature review. This approach increases the validity of the respondent's description of the subject (Jacobsen 2013, ch.11).

4.2.4 The Interview Guide and Questionnaire

The respondents were provided general information about the aim of the study, expected time use, ethical standard and confidentiality in the «*Request to Participate in Study*». The interview guide was partly based on the framework presented in Figure 10 and partly on the knowledge gaps identified during the preliminary literature searches. The different sections in the interview guide were:

#0: *General information*.
#1: *The farm site*
#2: *Education, diagnostics and dissemination of information related to disease and fish health*
#3: *Political, legislative and social aspects*
#4: *Your opinion*

4.3 Project Evaluation and Approval

The study objective and methods have been notified and approved by the Data Protection Official for Research at the Norwegian Centre for Research Data (NSD) and is listed as project no. 57729. In accordance with the NSD requirements, all electronic audio recordings from the interviews will solely be used to answer the study objectives herein and not shared with any third parties. All data will be deleted once the study is completed (June 2018).

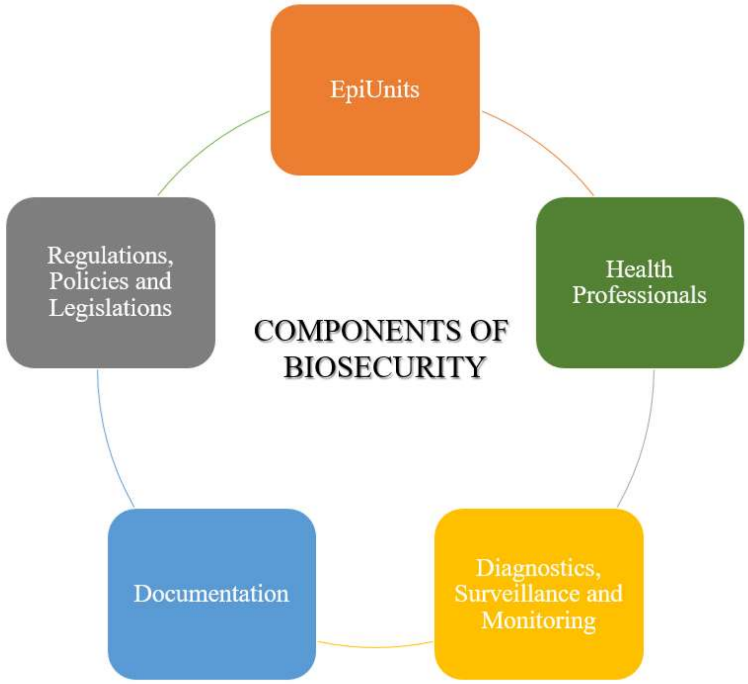

Figure 10. Components of biosecurity as defined in the study methods.

5 Analysis

The analysis will be presented in three parts. The first section (5.1), literature and media review, aim to shed light on what type of information related to fish diseases exists and at what academic level/impact they are published. This part will be highly descriptive, but findings will be discussed when relevant. The next section (5.2, expert interviews), comprise the components of biosecurity, namely 1) the farm level, 2) health professionals, 3) diagnostic laboratories, surveillance and monitoring, 4) documentation and 5) regulations, legislations and policies. The literature and media review will here be seen in relation to and combined with key information gathered from the respondents to draw a more detailed picture of fish health management and biosecurity. These two sections will thus try to answer the first study objective;

1. *What is the current status of fish health management in Uganda?*

The final section (5.3, general discussion) will, by taking a more overall perspective on *all* the aspects of biosecurity in Uganda, aim to identify issues of priority for the improvement of biosecurity in Uganda and thus answer the second study objective:

2. *What biosecurity related factor(s) can be regarded most important to support a continued growth in the sector?*

5.1 Literature and Media Review

The secondary data was descriptively analyzed and categorized in three distinct parts; the public narrative, the sector media and grey literature, and academic publications. Analysis was done on content in each part, but also by comparing the content between the categories (Jacobsen 2013, ch.10). The main emphasis was on grey literature and academic publications.

5.1.1 Introduction – the Public Narrative

To get a general impression about the fish farming sector in Uganda and add perspectives to the statistical data provided by FAO and others, the current work was begun by reviewing the narrative by the national public media. Online articles from 2015 to 2018 (April) by the three largest English language papers (Daily Monitor, East African Business Week and The Independent magazine Uganda) and TV broadcasters (NTV, Bukedde) indeed depict an industry under development. Two topics were recurrent, while two was worth a notice due to the context. First, the numerous success stories; a single farmer who has profited from using part of his or her land for fish farming (in addition to other animals, banana trees, coffee etc.). Surprisingly, the online articles and TV news reports included quite detailed instructions on how to perform fish farming and even recipes for how fish feed can be made by using simple tools and ingredients. The second reoccurring story was the increasing use of cage farming in different lakes in Uganda and its potential to increase profit compared to the more established pond farming. The two final topics where more discouraging, the first describing governmental failure to finalize the establishment of aquaculture research centres intended to support farmers. Finally, the finding of a new viral disease (Tilapia Lake virus, TiLV) in tilapia farming and its threat to the sector elsewhere (China, Indonesia and Egypt), but not in Uganda where it also has been found recently (Mugimba et al. 2018). In the context of this work the public narrative is worth a rendering since it portrays a low degree of commercialization and describes an optimistic view of easy profit for small scale production. However, it also indicate potential bottle-necks for further growth in the sector; lack of enabling functions such as governmental research institutions for basic research, feed availability and biosecurity risks that may limit profitability (selected articles are listed in chapter 8), not far from the summary made in the FAO report by Machena and Moehl almost two decades ago (Machena and Moehl 2001).

5.1.2 Sector Media and Grey Literature

Since disease outbreaks to a large extent is connected to profitability in fish farming, it is given much coverage by the sector media in established markets. For the case of tilapia and North African catfish in Uganda, a review of some of the key online publishers in the sector (Intrafish, Seafoodsource, ThefishSite, Worldfishing) mainly resulted in findings related to the need for quality feeds and the establishment of feed factories in the region (Fischer 2017). Again, only the recently discovered TiLV was found mentioned, but not related specifically to Ugandan fish farming (Intrafish 2017). Even wide-ranging searches for the most common diseases in tilapia globally resulted in few results, and was mainly related to vaccine development by the established pharmaceutical companies. Although diseases are given little attention, the commercial interest for developing vaccines indirectly underlines the economic impact of diseases.

After review of relevant grey literature, four publications were particularly interesting from both a national and regional perspective:

- The institute profile for the **National Fisheries Resources Research Institute** (NaFIRRI), published in 2013.
- The annual achievement reports 2015/2016 and 2016/2017 by **NARO/NaFIRRI**, published in 2016 and 2017, respectively.
- The **African Union – Interafrican Bureau for Animal Resources** (AU-IBAR) report entitled "*Mapping study of aquatic animal diseases – Eastern Africa*", published in 2016.
- The **FAO** report (Hyuha et al. 2017) entitled *"Social and economic performance of tilapia farming in Uganda"*, published in 2017.

In the NaFIRRI report from 2013, none of the research areas in the period 2013-2016 or long-term training topics addressed animal health (other than growth) or diseases. According to their institute profile, the challenge for the next five years (note that the report dates to 2013) will be to generate and disseminate technologies and knowledge that should result in production increase to 300 000 MT. It is obvious from the report that for this increase in production to take place, other issues than fish diseases are more pressing to resolve, including improving feed availability, genetic progress of Nile tilapia and North African catfish and development of appropriate cage culture technologies (NaFIRRI 2013). These topics are also continued in the more recent reports by NARO/NaFIRRI, but interestingly, in these annual achievement reports fish health and surveillance had been included in the aquaculture research program (NaFIRRI 2017, 2016). Three of the achievements listed in the reports are relevant for biosecurity. These are the writing of a "*Guideline for establishment and zoning of cage fish farming*", the identification of major pathogens in tilapia and catfish and preliminary testing of what is referred to as bio-control agents against infections. An electronic copy of the guideline was kindly provided by Dr. Richard Ogutu-Ohwayo at NaFIRRI upon request. To achieve a license for cage farming there are, according to the guideline, requirements to have a *Disease Risk Management Plan* (section 4.0) and cage farming is limited to the species Nile tilapia or North African catfish. Several of the basic biosecurity measures listed in section 3.2.1 herein were also found included in the guideline: disease monitoring, quarantine periods and proper disposal of dead fish onshore. Although this is a guideline, not a legislation, the fact that the guideline require a risk management plan to achieve a farming license may force the applicant to make a pre-assessment on how to avoid disease, which to some extent is in line with biosecurity level III and IV in the IAVBC approach (Palic, Scarfe, and Walster 2015). To summarize, the NARO/NaFIRRI achievement reports indicate that more attention has been given to fish health management in recent years.

The purpose of the work presented in the AU-IBAR report from 2016 was to determine the current disease status in the East Africa Community (EAC), including risks and prevalence (AU-IBAR 2016). Compared to the NARO/NaFIRRI reports from 2016 and 2017, the AU-IBAR is far more comprehensive in its disease description, but they have in common that both reports mainly describe parasitic diseases, something that the latter report suggest being a result of inadequate personnel experienced only in parasitology. Of the countries in EAC, Uganda has most of the studied pathogens (45%, but this will of course be biased by reporting systems and access to data compared to other countries), but none of the related diseases are listed[6] by OIE. Surprisingly, Ugandan respondents in the AU-IBAR study did not report of any aquatic animal diseases, although the literature review revealed numerous reports of aquatic pathogens, including virus (not specified) and bacteria (*Aeromonas hydrophila* and *Edwardsiella tarda*). Of more general findings, most of the countries in the EAC reported that they did not have the ability to issue health certificate for movement of fish, that brood stock were collected from wild waters and that they imported or exported genetic material between countries (AU-IBAR 2016, p.9). Furthermore, it was found to be common that farmers exchange fingerlings and equipment, and most of the countries stated that they had an aquatic animal health policy and reporting system in place, but only the minority (17%) had diagnostic facilities. These findings indicate a discrepancy between policy making and

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[6] According to the Aquatic Animal Health Code (Article 1.1.2) the detection of the pathogenic agent of a listed disease in an aquatic animal should be reported to OIE.

practical implementation, and that few efforts are made to meet the requirements in the biosecurity hierarchy as described in the MVM (Collett 2018a). A key question is if this is due to lack in basic knowledge about fish health and biosecurity or a lack of resources, or a combination of both? This will be returned to.

The fourth and final work to be addressed here is the FAO report (Hyuha et al. 2017) covering a vast range of aspects related to tilapia farming in Uganda. Although not a single word on animal health/diseases are found in the report, a few of the sector challenges listed in the report are interesting. These are:

- Lack of reliable data from the industry since farmers do not keep, or keep inadequate farm records.
- Lack of human capacity to support development.
- Lack of production standards regarding information flow and support functions.

As these shortcomings are made to fish farming in general, the challenges will also indirectly apply to the subject of fish diseases and biosecurity. For example, all three are key to meet the requirement for disease monitoring and surveillance according to the Aquatic Code (OIE 2017a), and inadequate records would also indirectly suggest that biosecurity levels I and II in the IAVBC approach would be difficult to implement since the farmer or competent authority[7] would be unable to review previous production activities.

5.1.3 Academic Publications

This part of the review was targeted against the most commonly known bacterial and viral diseases from Nile tilapia and North African catfish. These include bacterial diseases caused by *Streptococcus* spp., *Aeromonas* spp., *Edwardsiella* ssp. and *Flavobacterium* ssp., and as previously mentioned, the emerging viral disease caused by tilapia lake virus (TiLV) (Munang'andu, Paul, and Evensen 2016; Pridgeon and Klesius 2011; Eyngor et al. 2014; Aznan et al. 2018). As already reported by Akoll and Mwanja in 2012 and AU-IBAR in 2016, the majority of academic studies have so far focused on reporting the occurrence and taxonomy of parasites in wild populations (Akoll and Mwanja 2012; AU-IBAR 2016), and thus very little research output and knowledge exist on bacterial, viral and fungal diseases. Interestingly, no relevant publications could be found on the NaFIRRI homepage listing academic publications. However, four scientific publications highly relevant for the current study were found. Two of them addressed bacterial screening from wild and farmed North African catfish and Nile tilapia (Walakira et al. 2014; Wamala et al. 2018). All bacterial pathogens listed above, as well as many others were identified in both of these studies. Prevalence was found to be significantly higher in ponds compared to cages. Acquired

[7] According to the OIE Glossary, Competent Authority means the veterinary authority or other governmental authority of a (OIE) member country having the responsibility and competence for ensuring or supervising the implementation of aquatic animal health and welfare measures, international health certification and other standards and recommendations in the Aquatic Code in the whole territory.

antibiotic resistance was also assessed and found not to be significant, suggesting minimal use of antibiotics in aquaculture in Uganda (Wamala et al. 2018). Walakira and co-workers also investigated farmer's perception on diseases through interviews and found that as many as 69% of the fish farmers (N=44) had never seen sick fish in their farm and 12% did not know how to identify sick fish. Mortalities up to 70% had been registered in catfish hatcheries and antibiotic treatments were done without advice from veterinary personnel or fish experts. Some farm managers used internet as a source of disease information (Walakira et al. 2014), which corroborates the findings by Matuha who investigated the use of mobile phones among fish farmers in Uganda (Matuha 2015). The two other relevant publications were the aforementioned TiLV affecting tilapia (Mugimba et al. 2018) and a new bacterial agent, proposed the name *Candidatus Actinochlamydia clariae* causing epitheliocystis in North African catfish (Steigen et al. 2013). Both diseases are considered important for the fish farming industry due to significant welfare problems and mortalities as high as 20-90%, as reported for TiLV (Surachetpong et al. 2017). However, from a brief review of these publications, there are no indications on how the diseases may impact on fish farming and biosecurity in Uganda, although levels of *Cand. A. clariae* were found to be extremely high in catfish thus suggesting an impact both on fish welfare and risk of disease spread (A. Steigen, pers. comm).

5.1.4 Summary of Literature Review

This first section of the analysis suggests that there currently is very little awareness around fish health and disease management in Uganda. Most of the information related to this topic exists only as grey literature. Consequently, this impact negatively on the dissemination of knowledge since such reports are written for various purposes and often hard to get hold of. The NaFIRRI achievements reports (NaFIRRI 2017, 2016) does however indicate that there is an increasing focus on fish health and biosecurity, both in basic research and policy making. This probably come as a result of development of larger scale production using cages, pushed forward by the many stakeholders utilizing the great lakes. This being said, some studies have materialized in to published, peer-reviewed literature and will serve as important baseline data for future studies (Steigen et al. 2013; Walakira et al. 2014; Wamala et al. 2018; Mugimba et al. 2018). But to date, very little is known about the significance of these pathogens in fish health management, which may contribute heavily to poor biosecurity in the sector.

5.2 Expert Interviews

This part of the analysis is based on results from semi-structured interviews of three respondents with expertise in the field of fish health and biosecurity in Uganda. The questionnaires were outlined based on a preliminary literature review. Notes and audio recordings from the interviews were categorized according to the framework presented in Figure 10. Statements of interest were recorded in writing for verbatim rendering. The answers were further analyzed for content and consistency (discrepancies, similarities and trends) between respondents, and between respondents and literature findings (Jacobsen 2013, ch.10). The forthcoming will present the key results descriptively and in some cases include literature references to supplement the information. Quotes from the interviews will be used to high-light statements of particular interest.

5.2.1 Biosecurity at Farm Level

The farm level, including hatcheries, nurseries and grow-out sites is cardinal for all biosecurity measures since this is the site from where diseases may arise and spread. Key questions were related to the origin of the fry, fish transports and on site disease management.

Fish Seeds, Health Certificates and Transport

"The farmers do not have the tools to assess the quality of the fry" (Q1)

"Yes, fish are moved everywhere" (Q2)

Since farmers have little possibility to transport large biomasses they normally buy the fry at 1-3 grams from governmental hatcheries (20%) or private suppliers (70%), or obtain them by farmer-to-farmer sales (5%) or harvesting from wild populations (5%). The fry does not come with a health certificate, and the price is set by demand and availability. From the farmer's perspective, quality is determined mostly on previous experience from the using the same seed. Small scale farmers transport fry in aerated Jerry cans, plastic bags or tubes to enable them to transport fish over long distances. The containers and equipment used for transport is not disinfected and can thus be a source of disease transmission since farmers collect and stock fry from different suppliers. Large scale farmers use trucks and open tanks (aerated and non-aerated) of 1 cubic meter to transport fish to all lakes in the country. There are about 10 large commercial producers who produce their own juveniles for cage farming. Movement of live fish (especially seeds) occurs between the major lakes. Uganda is also the largest supplier of fry to other countries in East-Africa (South-Sudan, Rwanda, Kenya, Tanzania), but veterinarians do not issue health certificates for such transports. There is however need for a *"fish transfer permit"*, as declared in rule 16 in the Fish (Aquaculture) Rules of 2003, but the rule does not demand for a disease record prior to movement. The Animal Diseases Act does however specify that fish with disease *"shall immediately segregate and quarantine the animals among which disease has been discovered*" (MAAIF 1918, rule 15). According to the knowledge of the respondents, fish are currently not imported *to* Uganda.

Zoning and Sharing of Equipment and Personnel

"…at one place, ten farmers shared the same collecting net…" (Q3)

Sharing of personnel and equipment is common practice, but it depends on the size of the farm. In commercial cage farming, personnel and equipment is normally not shared between sites, however this is not restricted as a biosecurity measure, but rather a result of frequent need for most equipment. For smallholders and pond farming, sharing equipment (Q3) and personnel is common due to high costs relative to production yield, combined with sporadic use of much of the equipment. Disinfection of shared or rented equipment is not practiced in grow-out farms and is thus an important source of disease transmission. In hatcheries, routinely disinfection of equipment and disinfecting foot baths at entry points are common. All commercial farms are reported to be protected by some form of fence. This measure was more likely because of prevention against theft rather than as a biosecurity measure. There are no guidelines or policies related to distance between farms. Together with the previous section on fish transport, these findings suggest that conceptual and structural biosecurity according to the MVM generally is not fulfilled.

Disease Management: Prophylaxis[8] and Therapeutics

"…we don't think diseases in fish. It is like a news. Fish also fall sick?" (Q4)

"For now, if I were to say that we have disease outbreaks, I would be lying to you…" (Q5)

This part of the interviews, that aimed to explore fish disease management at the farm site, became defining for the level of detail when discussing all other topics in the remaining of the interview. The reason was that the level of knowledge about fish diseases in Uganda was considerably lower than first anticipated when starting the study. First of all, disease outbreaks are apparently not common to experience in farms (Q5), as indicated by one of the respondents, a trained veterinarian, *"…I have seen a streptococcus outbreak once…"*. From this is becomes apparent that measures such as immune enhancing feed, vaccination or even use of antibiotics[9] will be uncalled for in the production at the time being. Consequently, vaccines and immune enhancing feeds are according to the knowledge of the responders not available in Uganda. Furthermore, the small holders, which constitutes the majority of farmers in Uganda, seems to be ignorant to the fact that fish can be affected by diseases (Q4), even though it is widely acknowledged in farming of other animals in Uganda, e.g. chicken. This is in line with the findings by Walakira and co-workers, who reported that as many as 69% of farmers had not seen sick fish in their farm (Walakira et al. 2014). To increase disease awareness, a smart phone application is under development/may be developed where clinical signs of the most common diseases in tilapia and catfish are depicted and descripted, along with recommended treatments. According to the World Bank, there are more than 22.8 million mobile cellular subscribers and about 22% of the population is using the internet (TheWorldBank 2016). Fish farmers are already using mobile phones to access technical guidance, and information about *inter alia* disease management has been reported as highly needed (Matuha 2015). From a biosecurity perspective, this could be a promising tool to disseminate knowledge about fish diseases, but a backdrop could be increased use and misuse of antibiotics due to misdiagnosis in lack of experience or trained health personnel.

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[8] Treatment given or action taken to prevent disease.

[9] Breeding stocks are treated with antibiotics (mainly oxytetracycline), probably due to their high value as providers of fish seeds. It was therefore underlined by one of the respondents that fish farming in Uganda is 100% organic.

All farm systems experience fish mortality during production, irrespective of disease outbreaks, and it was therefore asked how dead fish are handled when it comes to removal and disposal. The answer was that dead fish are often not recovered/found in pond farming, while in cage farming they are removed from the cage, but often thrown in to the surrounding water (small quantities). Larger quantities are usually destroyed by burning of burying. In one case of mass mortality, presumably due to suboptimal water quality, all fish in a pond died. In that case, the farmer dried the fish and fed them to the pigs.

In modern fish farming, so-called *"all-in, all out"* and fallowing are common practices to avoid pathogen establishment at the farm and minimize the risk of introducing disease to the farm system by reducing the number of stocking. None of these routines are routinely practiced in pond farming since most farms are smallholders keeping mixed sexes which results in breeding, while in commercial cage farming it has become more common due to all male populations of tilapia. However, *"all-in, all out"* is not done as a biosecurity measure, but rather for increased profit resulting from simplified production routines.

Farm Records and Disease Monitoring

"No, most farmers do not assess any parameters in the farm…" (Q6)

Basic parameters to record during production include feeding, fish weights, mortality, water exchange (for ponds), oxygen levels and temperature. This will allow the farmer (and other stakeholders) to evaluate production yields and improve coming productions, as outlined in the procedural biosecurity by the MVM (Collett 2018b). It will also enable retrospective assessments in cases when outputs are unexpected, which is essential for disease monitoring. According to the respondents, and in line with a previous study (AU-IBAR 2013), farm records are generally not kept in Ugandan fish farming, but in cases where they are all parameters listed above are included. Combined with absence of fish disease awareness (and lack of access to diagnostic tools, as presented later), this is a limitation for performing basic epidemiological assessments of farm populations and for establishment of national databases on diseases.

5.2.2 Health Professionals

"There are very few veterinarians working on fish diseases, not more than four or five" (Q7)

Investment in veterinary education is vital to offer adequate veterinary services to farmers (Ilukor 2017). Until recently, there was no specific course in aquaculture at public universities such as Makerere University of Kampala. Before the year 2000, aquaculture was not a distinct subject but covered as part of courses in fisheries. Graduates were thus ill-equipped to offer extension services to farmers (Hyuha et al. 2017). More recently, a degree in aquaculture which includes diseases in the curriculum has been introduced. For veterinary students, training in diseases and relevant diagnostic biomolecular methods are given but it is only a minor part of the curriculum. It is however possible to specialize in fish health, but according to one of the respondents only two (in total of the annual 50 (OIE 2016)) veterinary students have so far chosen to do so, and still very few veterinarians work with fish (Q7). Because of this, the vast majority of veterinarians only have knowledge about higher vertebrates related to agriculture and wild-life on land. Consequently, fish health is mainly dealt with by para-professionals.

5.2.3 Diagnostic Laboratories, Surveillance and Monitoring

"*…diagnostic laboratories are buildings, not more…*" (Q8)

As already covered above, disease surveillance and monitoring is currently not performed in the fish farming sector in Uganda, except for the few preliminary efforts reported by NaFIRRI and others (NaFIRRI 2016, 2017; Walakira et al. 2014; Wamala et al. 2018). Although diagnostic tools are available via the Makerere University the use is very limited due to lack of funding for expendables/reagents, as is also the case for the KARDC. On question whether there are diagnostic laboratories for livestock that can support the aquaculture sectors, it was pointed out that they are there, but that the waiting time is long and s/he has experienced that samples have been mixed up.

5.2.4 Documentation

"Sharing of information is a threat to the farmer's business" (Q9)

Recording and sharing of disease information is essential to increase the general knowledge about fish diseases and enable establishment of contingency plans. It was therefor asked whether Uganda has a disease reporting system for aquatic diseases, like the international World Animal Health Information System (WAHIS) by OIE or the national notification obligation of listed diseases to the National Food and Safety Authority in Norway. Given the lack of diagnostic tools and disease awareness, farmers would obviously not know what to report and such systems does accordingly not exist. But more importantly it was informed that farmers are "*…reluctant to report on negative things"*. It was emphasized that in cases where diseases could be the cause of mortality, farmers would not talk about it since they are afraid that no one would buy their fish and they would run out of business. This underlines the poor financial situation the farmers are in and their reliance on a successful production to maintain the business, as will be returned to later.

5.2.5 Regulations, Policies and Legislations

"*Our biggest problem is our selves*" (Q10)

"*…if you come to a certain level, things are bound to happen, and that is what is left behind*" (Q11)

"*The smallholders, you cannot regulate them. You cannot. How?... ...He has all his hopes in these fish. They will put it where they want*" (Q12)

According to one of the respondents, the new production target is about 1.2 million MT from fisheries and aquaculture combined. Since fisheries have been stable at about 400 000 MT in recent years, this would imply a 7-fold increase in fish farming production, which is drastically higher than the previous target. Although the time frame for this increase in production was not specified by the respondent, it was underlined that a sustainable growth is the goal and that soft laws are in writing to support this.

From the interviews, it was understood that detailed regulations for aquaculture is currently not included in Ugandan legislations, but that there are many initiatives to get it implemented. During the whole period of this study (January-May 2018), the home page of MAAIF has been down for maintenance, and requests sent to their contact email to get access to relevant information has been futile. Official documents were however retrieved elsewhere online. One of the respondents did also share information on the government's effort to review the Fisheries policy: the *National Fisheries and Aquaculture Policy Bill* which will be published by the MAAIF. This is an update of the *National Fishery Policy* (2004) and includes a stronger emphasis on aquaculture by acknowledging 1) that disease pose a threat to the country and region, 2) that the sector development comes at a time when there is scarcity of knowledge and limited capacity in the fish epidemiology and 3) that Uganda is central for biosecurity in the region due to its boarders in Lake Victoria and is near the beginning of the Nile River system which may cause introduced diseases to spread across the region. Its main objective regarding biosecurity and fish health is to prevent and control introduction of pathogens via strategies such as surveillance, disease reporting, strengthened fish laboratories and increased knowledge about diseases amongst stakeholders in the sector (MAAIF 2017).

Seen in light of the analysis herein, the new bill indeed addresses many of the current challenges and gaps regarding the procedural biosecurity in the sector. The implementation of the policies is however challenging first of all since fish diseases currently is not an obvious problem to the farmers. But as is indicated in Q11, it is recognized as a problem that will occur once the sector reach a certain size and biomasses are favorable of disease outbreaks and spread, especially in cage farming where most of the current growth seems to be. Implementing policies are also an issue due to the financial situation of the smallholders (Q12). As one responder pointed out, cage farming is encouraged by the government to increase the aquaculture production in Uganda and many farmers establish their farm systems without permission. Once established, there is little the local authorities can do since the farmer may be relying on this production as his/her only income. The fish in the cage thus represent all the farmer's assets and strict enforcement of disease policies may therefore discourage farm establishment.

5.3 General Discussion

A comparison of the results from the literature and media review, with the expert interviews, indicated a consistency in the overall narrative of fish health/biosecurity in Uganda. The former is to a large extent a reflection of the latter; few publications due to a general lack of skilled human resources, technical equipment and funding combined with a seemingly low level of awareness about fish diseases amongst farmers. Much of the data gathered here does however suggest that focus is changing since more efforts are being allocated to the research issue.

This study and other reports (Hyuha et al. 2017; FAO 2005) shows that the human capacity to push the sector forward is highly limited. Trained farmers, veterinarians and para-professionals are cardinal to be able to comply with any of the biosecurity levels outlined in the IAVBC approach (Palic, Scarfe, and Walster 2015). With the geographical spread in production and smallholders still dominating the sector, it is apparent that more resources than the very few veterinarians currently serving the sector is needed. The profitability in the aquaculture sector may still not be high enough to attract veterinarians and trained para-professionals from the private sector serving the intensive livestock production. Governmental engagement can therefore be required in the provision of veterinary services. A recent study have shown that even for terrestrial livestock the normal market forces have failed to attract veterinarians to pastoral or extensive production systems, partly because of the high transaction costs in serving small holders in rural areas (Ilukor 2017). In terrestrial subsistence farming systems, farm biosecurity is reported to be largely non-existent and disease outbreaks often go unreported, which creates significant epidemiological knowledge gaps and pose a huge risk for larger farmers (Chenais et al. 2017). Similar mechanisms have been reported in the aquaculture sector, where low government salaries have created a situation whereby staff charge desperate farmers for advice even though it is part of their work (Isyagi et al. 2009, p.34). While livestock is a well-established sector this illustrates that the aquaculture sector, still being in its infancy, will have many issues to resolve and a long way ahead.

With this in mind, it is difficult to discuss biosecurity on the fish farm level in Uganda using the IAVBC framework. Fish diseases are described as not being a prominent limitation to the production and very little is seemingly known about pathogen prevalence and significance in grow-out farms. Combined with an almost non-existing veterinary service, measures such as hazard identification, risk assessments, diagnostic testing and disease surveillance will be difficult to implement and perform on a routinely basis throughout the sector. For the same reasons, not even the most basic biosecurity measures outlined in the two lowest levels in the MVM hierarchy are easily implemented (Collett 2018b). This include, amongst other things, general disinfection and zoning both at farm level and between regions. To increase disease awareness and understanding it demands for more hard data on the subject, which according to this and other studies seems to be lacking (Isyagi et al. 2009, p.61). A central question is how it can be expected that policies, strategies and plans can be understood and implemented if not based on relevant field data.

Current aquaculture policies in Uganda have been criticized for being written in too general terms and lacking time frames (Isyagi et al. 2009, p.56). The responders also added that the government in many aspects are lagging behind farmers, which is in line with a previous study (AU-IBAR 2013). The media, on the other hand, is ahead of the government in addressing farmers, but often without relevant content. The active role of the public media was a surprising finding in the current study (section 5.1.1) and suggests a general need for knowledge-based information about farming. The media can in this regard serve as a diverting factor with the potential to change the output needed for successful evidence based policy implementation, as suggested in the PARIHS framework (Kitson, Harvey, and McCormack 1998). All respondents also underlined that current policies are not implemented or enforced. The fact that the Fish (Aquaculture) Rules (2003) and the National Fisheries Policy (2004) came into force more than a decade ago and that the industry has had a massive increase in production since, indicate that it is timely to revise the aquaculture policies. Unless a vast amount of unpublished data exists, there is however apparently little substantial research to base new policies on other than the knowledge that the scientists, government officials and other stakeholders possesses[10]. This skewness in the *"core circumstances"* (objective, information and power) as described in the contextual interaction theory (Bressers and Klok 1988) is likely to be in favor of the policy implementers and thus result in a top-down implementation approach for the new National Fisheries and Aquaculture Policy (MAAIF 2017). In fact, one of the respondents was not familiar with the new policy and was surprised that s/he was not included in the hearings since there are few researchers specialized in aquaculture and fish diseases. A key question is whether the context will be receptive to substantiate the implementation of a new policy when the current ones seemingly are poorly implemented and enforced (Kitson, Harvey, and McCormack 1998). Seen in light of the ADEPT model, clear goals and opportunities may not be enough if there is lack of resources and a lack of a common understanding of enforcement obligations both at the implementers and the targets (Rütten, Gelius, and Abu-Omar 2010). More field relevant research may be needed to close this gap. So far, much of the research undertaken has been influenced by the objectives of the financier and availability of funds (Isyagi et al. 2009, p.39). A recent NaFIRRI report also highlights inadequate and irregular flow of funding for research equipment, research staff, and information generation and dissemination as particular challenging through the year (NaFIRRI 2016, p.15-16). Together this suggests that there still are few mechanisms in place to facilitate policy implementation (Rycroft-Malone 2004).

Intensive industrial aquaculture will demand for a knowledge based and research driven approach (Hersoug and Revold 2012; Bondad-Reantaso et al. 2005). Development of cage

[10] This was addressed to one of the respondents during the interviews, to which s/he replied, *"There is so much information, but nothing is shared"*.

farming in Uganda can therefore be a game changer and driver for increase in research initiatives towards fish health and biosecurity, as well as recruitment to the sector. With increasing biomass per unit (farm or cage) the production function is likely to improve (Thrusfield 1995, p.313), and increase profitability as well as taxes, which in turn may justify higher investments in research and extended services. As with other farming sectors, the likelihood of major disease problems occurring will increase as aquaculture activities intensify and expand, simply due to increased opportunities for disease transmission (Bondad-Reantaso et al. 2005). This implies that more investments in biosecurity and fish health may be a necessity both to reach the production targets indicated in the new aquaculture policy (MAAIF 2017), but also to be able to adhere to the obligations Uganda has to the EAC and OIE. It can be speculated that a few years down the line from now, implementation and enforcement of new policies may still be difficult, not only because of limitations in resources in the competent authority[11], but also because consolidation of the industry may leave a large group of subsistence farmers behind. Although they generally may benefit from professionalization of the sector by improved seed and feed quality, they are likely to still represent a majority (in numbers, not necessarily production) with little or no training or formal education in aquaculture. Even though focus on fish health is increasing on a regional (AU-IBAR 2013), non-governmental (FAO 2016; Hersoug and Revold 2012) and national level (MAAIF 2017), this illustrate an inherent conflict of interest between the need to produce food for a growing population on one hand, and the need to build a sustainable industry with adequate biosecurity measures on the other. How diseases will affect the sector once the production is intensified, and if *tragedy of the common* again will play a role as it has done with the overexploitation of wild populations in the fisheries, remains to be seen. But while the private sector aim for increased productivity and profitability of the aquaculture sector, the public sector has a dual role of maintaining socio-economic considerations while also protecting the environment and natural resources (AU-IBAR 2013). An interesting question is therefore how the need to use aquaculture as a tool in poverty alleviation by subsistence farming in rural areas will influence biosecurity and fish health management in the commercialized parts of the sector.

In addition to the subject of policy enforcement, there was consensus between the respondents about where improvement in biosecurity and fish health management is most needed to support the growth in the sector. They all pointed to upstream processes, that is, establishment of diagnostic testing that will allow for screening and certification of all seed producers. From a resource and economic perspective this would be a sound initiative since it targets the potential source to the problem. Licensing of breeders and issuance of health certificate for fish batches may help to reduce the general and undetected spread of disease through carrier

[11] According to the OIE glossary, competent authority means the veterinary authority or other Governmental Authority of a Member Country having the responsibility and competence for ensuring or supervising the implementation of aquatic animal health and welfare measures, international health certification and other standards and recommendations in the aquatic code in the whole territory (OIE 2017b).

fish. Combined with establishment of regional/local seed producers to serve designated areas (lakes or river systems), this could serve as a first step in creating zones or EpiUnits for disease management. From a critical standpoint it has been underlined that certification will demand for more resources to make sure that breeders adhere to standards (AU-IBAR 2013). In addition, the breeders may be reluctant to implement such standards as they can be held accountable in cases of disease outbreaks. Others have also reported that Fisheries Officers are given too much power for licensing[12] through The Fish Act (Isyagi et al. 2009, p.55). Because of this, it has been suggested that an alternative approach would be to empower farmers by giving education on seed quality and disease risks. This can enable farmers to make choices based on knowledge, encouraged by the prospects of increased profitability. From a biosecurity and fish health management perspective a combination of the two would be preferable.

[12] One of the respondents mentioned this as some form of *personalized mandate*.

6 Conclusions

The current study has assessed biosecurity and fish health management in Ugandan fish farming. The subject has been studied by combining a literature and media review with expert interviews. The study aimed to answer two research questions:

3. *What is the current status of fish health management in Uganda?*
4. *What biosecurity related factor(s) can be regarded most important to support a continued growth in the sector?*

The findings from the study suggests that fish health management and biosecurity still is in its infancy in Uganda. From the literature and media review, it can be concluded that very few published studies have focused on pathogen and disease prevalence, geographical distribution and impact on aquaculture production. Lack of predictable funding and human capacity seems to be main constraints in that work. The results also suggest that fish diseases still are not a pressing issue for fish farming in Uganda. This may however be masked by other more prominent issues, such as the need for quality feed and seed, as well as the low level of disease knowledge and awareness among farmers. Para-veterinarians seems to be the most important providers of disease information since very few trained veterinarians are working with fish or have specialized within aquaculture. Some basic biosecurity measures are carried out in hatchers, but very few or no basic biosecurity measures are routinely implemented in grow-out farms. There is still very little use of antibiotics even though farmers do not use vaccination as a prophylactic strategy. The most important existing policies were written almost a decade ago and are currently enforced only to a small degree. However, a new policy with more emphasis on aquaculture will soon take effect. Adequate implementation and enforcement will be important for Uganda to reach its goals of maintaining a sustainable fish farming sector while the production increases. This in turn, will depend on available resources for facilitation, the *implementor-target* interactions and how receptive the sector is to such changes. A key factor for success may be to collect more hard field data in the subject to ensure a knowledge-based way forward.

The study indicates that securing the upstream part of production may be the most cost-efficient approach to improve biosecurity at the time being. Maintaining disease free brood stocks and health certification of seed producers may contribute to decrease the general risk of diseases throughout the sector as it will be limited from the source.

Further research should focus on the efforts and impacts of policy implementation. This may contribute to get a more detailed understanding of where resources and expertise are lacking and how they can best be allocated to support the improvement of biosecurity and fish health management in Uganda.

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9 Appendixes

Appendix 1. Summary of global fish farming.

Region	Total quantity farmed fish in tons *(value USD 000)*	Fraction of global production (%)	Production increase the last 5 and 15 years*	Top 5 producers (2015)	Main species
Africa	1 764 864 (*3 444 991*) 1950**	3.4 %	'00-'15: 349% '10-'15: 38%	Egypt (67%), Nigeria (18%), Uganda (14%), Ghana, Zambia	Tilapias and other cichlids (61%)
Asia	45 705 772 (*74 856 752*) 1640**	88.1 %	'00-'15: 153% '10-'15: 35%	China (63%), India (10%), Indonesia (8%), Vietnam, Bangladesh	Carps, barbels and other cyprinids (63%)
Americas	2 020 726 (*8 474 428*) 4320**	3.9 %	'00-'15: 93% '10-'15: 42%	Chile (41%), Brazil (24%), USA (10%), Canada, Colombia	Salmons, trouts, smelts (54 %)
Europe	2 338 321 (*10 237 532*) 4380**	4.5 %	'00-'15: 84% '10-'15: 22%	Norway (59%), UK (8%), Russian Federation (6%), Greece, Faroe Islands	Salmons, trouts, smelts (81 %)
Oceania	77 778 (*792 198*) 10200**	0.1 %	'00-'15: 229% '10-'15: 24%	Australia (81%), New Zealand (16%), Papua New Guinea (3%) Rep. of Fiji, Guam	Salmons, trouts, smelts (78 %)

* Years 2000 and 2010 relative to statistics from 2015. Calculated by (((production 2015/production [year])*100)-100)).

** Value relative to production quantity (value USD/tons).

Source: (FAOstatistics 2015), data generated and processed September 2017.

Appendix 2. Overview of the most relevant farmed species in the five largest fish farming countries in Africa.

Country	Total production volume (tons)	Species (common name)	Species (Latin name)	Percent of total production in the country
Egypt	1 370 559	Nile tilapia	*Oreochromis niloticus*	69%
		Miscellaneous coastal fishes	-	13%
		Common carp	*Cyprinus carpio*	4%
		Other cyprinids	-	11%
Nigeria	306 727	North African catfish	*Clarias gariepinus*	52%
		Torpedo-shaped catfishes	*Clarias Spp.*	10%
		Nile perch	*Lates niloticus*	5%
Uganda	118 051	North African catfish	*Clarias gariepinus*	37%
		Nile tilapia	*Oreochromis niloticus*	63%
Ghana	52 470	Nile tilapia	*Oreochromis niloticus*	97%
Zambia	30 285	Nile tilapia	*Oreochromis niloticus*	72%
		Redbreast tilapia	*Tilapia rendalli*	10%
		Three spotted tilapia	*Oreochromis*	14%

Source: (FAOstatistics 2018), data generated and processed March 2018.