Thesis for the Degree of Master of Fisheries Science

Aquaculture biosecurity: Models for commercial culture of Nile Tilapia (*Oreochromis niloticus*) in Uganda

by

Isebaiddu William

KOICA-PKNU International Graduate Program of Fisheries Science

Graduate school of Global Fisheries

Pukyong National University

February 2016

Aquaculture biosecurity: Models for commercial culture of Nile Tilapia (*Oreochromis niloticus*) in Uganda

양식장 생물안전(Biosecurity): 우간다의 틸라피아 (*Oreochromis niloticus*) 상업 양식 모델 제안

Advisor: Prof. Kim Do Hyung

by

Isebaiddu William

A thesis submitted in partial fulfillment of the requirement for the degree of

Master of Fisheries Science

In KOICA-PKNU International Graduate Program of Fisheries Science

Graduate School of Global Fisheries

Pukyong National University

February 2016

Aquaculture biosecurity: Models for commercial culture of Nile Tilapia (Oreochromis niloticus) in Uganda

A dissertation

by

Isebaiddu William

Approved by:

____

(Chairman) Prof. Jeong Hyun-Do

____

(Member) Prof. Huh Min Do

____

(Member) Prof. Kim Do-Hyung

February 26, 2016

Table of Contents

List of Figures

List of Tables

Aquaculture biosecurity: Models for commercial culture of Nile Tilapia (*Oreochromis niloticus*) in Uganda

Isebaiddu William

KOICA-PKNU International Graduate Program of Fisheries Science

Graduate School of Global Fisheries

Pukyong National University

Abstract

Uganda’s aquaculture industry has been growing at a rate of over 200% for the last decade with eminent intensification, and commercialization of Nile tilapia (*Oreochromis niloticus*) culture enterprises. Cases of infectious disease caused by bacteria, parasites, unexplainable mortalities in both hatcheries and grow-out farms have been established. A survey of some aquaculture facilities, and literature review on aquaculture management and related policies and regulatory framework in Uganda revealed significant lapses in biosecurity system at both farm and national level. Notably, gaps were identified in awareness of farmers on fish health management, husbandry practices, aquaculture inputs and products quality assurance, technical capacity, enforcement of aquaculture regulations and research. Up to now, Uganda lacks a national aquaculture biosecurity policy; hitherto the National fisheries policy has limited focus on fish health management among others. Less knowledge is available on pathogens and diseases of cultured fish species in Uganda; moreover, fish diseases diagnostic facilities are still basic. Control and prevention strategies; regulation and enforcement of statutory instruments are hardly in practice. Hence, there is a dire need to improve aquaculture biosecurity systems in Uganda; focusing on promotion of simple better management practices at farm level, and improvement of national and supranational management framework. This study provides benchmarks for improvement of biosecurity system and regulatory framework related to aquaculture at national and farm level; to facilitate effective control and prevention of fish disease and other undesirables from fish culture environments. Consequently, that not only protects the nascent aquaculture and vital fisheries sectors in Uganda but also safeguards aquaculture enterprise and trade development in the entire East African Community region.

CHAPTER 1. Introduction

1.1 Introduction

Aquaculture, the farming of aquatic organisms such as fish, molluscs, crustaceans, and aquatic plants, has apparently demonstrated the strongest potential to meet the increasing demand for cheap animal protein, and other aquatic products in most regions of the world. As the world population increases, so does the demand for aquatic food products. Since production from capture fisheries at a global level is leveling off, the potential contribution from aquaculture to local food security, livelihoods and nutrition of many remote and resource-poor rural areas of the world is highly significant (Rohana P. Subasinghe, 2005). Hence, aquaculture is emerging as an important industry of environmental and social economic change in many regions of the world; contributing immensely to food security, improved quality of life, and incomes.

However, Aquaculture development; i.e. intensification, diversification and trade expansion, is now faced with diseases and other biosecurity issues as major concerns, requiring critical attention (Subasinghe, 2004).

Biosecurity, strategic and integrated approaches that encompass policy, and regulatory frameworks (including instruments and activities) used to analyze and manage risks to animal/plant welfare and health, food safety, including associated environmental risks (Scarfe,2003; FAO, 2007; State of Victoria, 2010) ought to be promoted to counter threats from emerging diseases, now facing aquaculture development. It is a holistic and important concept, relevant to the sustainability of agricultural enterprises, public health and protection of the environment.

Precisely, aquaculture biosecurity would require the application of appropriate measures such as proactive risk analysis; to reduce the probability of undesirable pathogenic or invasive organisms spreading to individuals, populations or aquatic ecosystems. It further requires means to mitigate the adverse impacts that may result from spread of infectious diseases; including reduction of stressful conditions that could make fish more susceptible to diseases (Yanong, 2012). Thus, in Uganda concern is mainly required for management of fish health, through minimizing introduction or spread of fish diseases, and minimizing stressful conditions to enhance fish immunity against disease pathogens. Conserving aquatic biodiversity and reducing public health risks associated with production and consumption of aquaculture products would be equally vital (Subasinghe & Bondad Reantaso, 2006).

Worth noting, is that most aquaculture products from developing countries such as Uganda could potentially harbor zoonotic parasites and pathogens owing to the culture environment and farm conditions. Thus, that underscores the need to treat such products or secure them during the production processes, so as to negate the threats of pathogens, zoonotic diseases and hence, permit food safety for human consumption (Hine, M., *et al.,* 2012). For that matter, effective biosecurity systems are essential for protecting cultured fish and human welfare; the valuable aquaculture enterprises, and environmental assets as implied by this study (Scarfe, 2003; State of Victoria, 2010).

1.1.1 Background

The emerging and future dependence on farmed fish as highlighted above, presents incentives for the African region aquaculture sector to contribute to; food security, poverty reduction, and economic development. In Sub Saharan Africa, aquaculture is gradually developing in many countries; hence, it has only made a small contribution to economic development and food security. However, with evolution of approaches built on a fusion of local and outside technology development and knowledge transfer; fish production models that are more productive, environmentally and socially sustainable will most likely develop in the long term (Brummett et al., 2008). Although still predominantly for subsistence purposes, national as well as regional efforts to promote and develop aquaculture such as culture of Nile tilapia have resulted in its wider acceptance in Uganda and throughout the East African Community, NPA (2010 as cited in Akol & Mwanja, 2012). Nonetheless, sustainability of such aquaculture investments will be premised on appropriate management; culture practices with minimum negative impact on culture organisms and the environment but with maximum societal benefits.

1.1.2 Aquaculture importance in Uganda's social economic development

The farming of fish for food in Uganda started in the early 1950s'; as a means of providing cheap animal protein that could easily be accessible to rural subsistence households, (Sustainable Aquaculture Research Networks in Sub-Saharan Africa (SARNISSA), 2009). The major concern was Supplementing family nutritional needs especially for communities that lived a distance from the country's natural water bodies (SARNISSA, 2009). Currently the industry is segmented into; emerging large scale commercial fish farms, medium-scale commercial fish farms and smallholder fish farms (MAAIF, 2012). Nile tilapia fish culture products apparently contribute to the economy, ranging from feeding households and hotels, to regional export markets. More so, widespread consensus among stakeholders asserts that the widening fish "supply-demand" gap for domestically produced fish products will only be narrowed through sustainable aquaculture development through the culture of fish species such as Nile tilapia among others (World fish, 2012).

1.1.3 Aquaculture development and Biosecurity management in Uganda

Available production data pointed to a general growth trend of the industry over the years, and production figures indicated a significant rise from 285 metric tons in 1999 to about 95,906 metric tons in 2011/12 (FAO 2012). Moreover, as aquaculture development in Uganda took root, intensification, and expansion became consequently noticeable. On a number of Uganda's intensive Nile tilapia culture farm layouts, fish stocks were apparently predisposed to a number of stress factors, with little ecological balance. Some of them were beginning to succumb to fish diseases as well as subsequent unguided veterinary drugs usage; to control diseases and ensure harvests (Tamale et al., 2011). This not only raised the production costs but could potentially result into among others, future stock mortalities, chemical accumulation and degradation of the habitats that receive liquid waste discharges from such facilities as argued by Ozbay et al., (2014).

The nature of integrated agricultural production models, promoting optimal utilisation of farm resources, more often without proper farmer guidance, had enhanced the likely hood of contamination due parasites and pathogenic bacteria. Heavy metals, and agrochemicals that would consequently accumulate in fish; thus, resulting in food safety hazards were equally of concern (Bagumire et al., 2009).

Concealed potential aquaculture environmental hazards such as disease communication between cultured and wild fish populations, eutrophication due cage culture, threat to genetic integrity of indigenous fish species as qualified by Garret et al., (1997), existed. They were likely to increase with intensification, and expansion of Nile tilapia culture, given the highly prospected commercial land based culture; aquaculture parks and commercial cage fish culture ongoing on a number of Uganda's lakes (MAAIF, 2012). Such ambitious aquaculture development strategies equally required far-sighted management strategies, such as risk analysis, environmental impact assessment and regular disease monitoring and surveillance; to prevent the conceivable negative aquaculture environment interactions.

The farm conditions and environment of most Nile tilapia fish farms in Uganda, significantly exposed aquaculture products to a variety of hazards as observed above; worse still, there is no fish health management framework or functional biosecurity system (FAO, 2015; Akol &Mwanja 2012). Thus, the need to put in place counter measures, biosecurity strategies geared to consolidation of the economic and social benefits of aquaculture was long overdue.

1.2 Statement of the problem

Uganda's aquaculture is gradually transforming from small scale subsistence to commercial intensive farming systems, with production growing at a rate of over 200% annually. This is mostly attributed to emerging commercial scale Nile tilapia fish farmers as reported by MAAIF, (2004); Aganyira, (2005). Cases of bacterial, fungal and parasitic disease outbreaks have been reported on some Nile tilapia grow-out farms and hatcheries though still at low scale (Tamale et al., 2011; Ondhoro, personal communication 20th/08/2014). The apparent significant increase in movement of Nile tilapia fish seed, and aquaculture products within and between districts; across national borders, implies potential increase in risks of introduction, and spread of pathogenic organisms. The blooming aquaculture sector is equally faced by other attendant biosecurity risks, associated with inappropriate culture conditions cum farm management practices. Product safety and potential aquaculture hazards that could be imposed on wild fisheries, in advent of commercial Nile tilapia cage culture on Uganda's lakes (Kifuko, 2015) are now of concern.

Although Uganda has some policies and legal provisions for management of fish diseases, emphasizing the restriction of fish movement and fish products, there is lack of effective enforcement of regulatory strategies. More so, Uganda lacks an aquaculture biosecurity policy or popular guidelines and Code of practice for appropriate aquaculture. Worse still, the current fish disease diagnostic facilities are basic and non-specific (Akoll & Mwanja, 2012). Hence, effective disease prevention, control, and management inter alia are non-existent; thus, warranting the observation of appropriate preventive biosecurity procedures as the only feasible alternative. The above highlighted risks incase ignored or neglected, could in the near future seriously jeopardize Nile tilapia culture productivity, product safety, public, and environmental health in Uganda. Consequently, this could negate the potential socio-economic benefits ascribed to Nile tilapia culture and aquaculture development as a whole.

To date, no study has been conducted to specifically address concerns of Uganda's aquaculture biosecurity in a more comprehensive manner; however, earlier related studies by Bagumire et al., (2009); Bagumire et al., (2010); Akoll et al., (2011), have revealed presence of pertinent industrial biosecurity related gaps at farm and national level. Owing to that, there is urgent need to examine the current practices of aquaculture and identify remedial strategies towards addressing the biosecurity gaps evident at farm and national level. Therefore, this study will among others provide benchmarks for probable establishment of required management and regulatory frameworks at national level; including practical strategies at farm level. This will spur improvement and sustain responsible aquaculture practices in Uganda.

The proposed production scale appropriated biosecurity models once observed, would certainly guarantee effective fish disease management practices, and elimination of other undesirables of public interest. Thus, not only protecting the nascent aquaculture and vital capture fisheries sectors in Uganda, but also safe guarding aquaculture enterprise trade development in the entire East African community region.

1.3 Objectives of the study

1.3.1 Main objective

To improve aquaculture biosecurity practices in Uganda's Nile Tilapia culture.

1.3.2 Specific objectives

I. To identify the factors affecting fish health and fish product safety in the culture of Nile Tilapia on commercial fish farms.

II. To examine the potential effects of interaction between Nile tilapia culture, and the environment in Uganda.

III. To identify sustainable practices adoptable or adaptable; for optimum fish health and product safety of cultured Nile Tilapia in Uganda.

Relatedly, it was hypothesized (H_a) that; "*Better management practices reduce fish disease incidence; optimize fish product safety and environmental health*", the study thence, set out to provide answers to the following research questions:

1. What are the biosecurity related factors affecting fish health, fish product safety, and environment health on Nile Tilapia farms in Uganda?

2. How do such identified factors affect the growth and development of Uganda's aquaculture industry?
3. What should be done to address such identified biosecurity challenges in Uganda's aquaculture industry sustainably?

1.4 Conceptual frame work

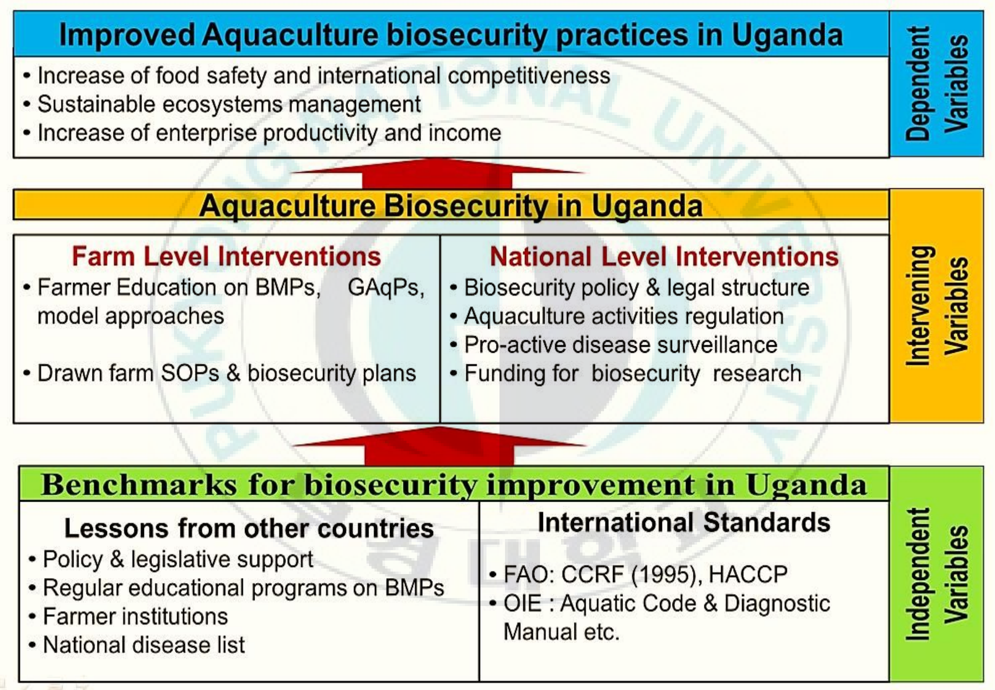

Fig. 1. Inter relationships between the study variables.

The conceptual framework above was based on the consideration that; Uganda's aquaculture biosecurity could be improved by learning and drawing lessons from the South Korean aquaculture biosecurity system; Asia-Pacific, and other success cases in the world. In principle, this could be by majorly focusing on adaptability, adoptability of techniques; technologies, which could potentially be applicable in the Uganda's situation (Subasinghe, 2004). Such lessons drawn from other world aquaculture communities; harmonized with international standards (instruments, guidelines & agreements) would constitute the hypothetical independent variables; to benchmark improvements in Uganda. The final effect of improved farm level aquaculture biosecurity practices (dependent variable) would thus, depend on successful achievements from interventions (intervening variables). That is; establishment of biosecurity policy, capacity building of extension officers, and pro-active disease surveillance; empowerment/education of farmers on aquaculture biosecurity to ultimately establish better management practices (BMPs) in Uganda, among others.

CHAPTER 2. Research Methods

2.1 Scope of the study

Precisely, the study involved a review of the current fish health/disease management system in Uganda, to establish biosecurity weaknesses obtaining at farm and national level. Case studies and observation experiences of aquaculture biosecurity practices, from Asia and other countries were equally reviewed so as draw lessons towards biosecurity improvement in Uganda.

2.2 Study approach

A cross – sectional survey/study approach, as illustrated by Stuart and Nicola (2009); an inspection approach for aquaculture facilities (EurepGAP, 2005) were adopted to gather data about the practices and regulations related to aquaculture biosecurity. That is; fish health management, aquaculture food fish safety inter alia in South Korea and Uganda. Due to the scattered nature of fish farms, the study involved purposive sampling (Stuart and Nicola, 2009) with due concern about economics, and convenience; given the limited time allocated to the study. The South Korea sampling was further based on proximity from Pukyong national University and species of fish cultured at target farms. In Uganda, it included the choice of two (**2**) fish farms from each of the selected districts (Wakiso, Mukono, Buikwe), based mainly on the scale of investment; that is, commercial scale farm establishments. Fish farm proprietors/managers; aquaculture inspectors, Law enforcement personnel researchers; civil servants under fisheries departments in both South Korea and Uganda constituted the sampling frame of respondents; hence, sources of primary data.

2.3 Data collection

Qualitative data was collected by means of; observation checklists, telephone interviews that is, for primary data. Documents review generated secondary data on experiences, challenges and benefits of implementation of the aquaculture biosecurity. The instruments for collection of qualitative data are briefly described below

An observation checklist (appendix 1) was prepared and photographic camera used to capture images; depicting fish health management or aquaculture biosecurity strategies cum measures, at South Korea farms visited. That is, photographs of fomites, gears, active personnel, and images of farm structures were captured; these observations were used to provide data on farm practices and implementation of the aquaculture biosecurity related activities.

Documents review involved mainly; FAO reports and guidelines, Uganda national fisheries policy and statutory instruments, published journal papers, annual Ministry of Agriculture Animal Industry and Fisheries (MAAIF) /Department of Fisheries Resources (DFR) reports from Uganda, technical papers on aquaculture biosecurity and related issues, and statistical abstracts among others, as the main sources of secondary data.

Telephone interviews (appendix 2 &3); were conducted to aid information gathering through discussion with Ugandan farm proprietors and managers of fish farms, fisheries departmental heads; at local government and national level. The interactions were thus, unstructured typical of Stuart and Nicola (2009). Information concerning apparent disease cases, aquaculture policy issues, number of disaggregated fish farmers; regulatory and management strategies underway in the interest of aquaculture biosecurity were gathered using this instrument.

2.4 Data processing and analysis

Qualitative data were descriptively analyzed and modeled into frameworks; maps were also used, in effect of set research objectives as recommended by Denzin and Lincoln (eds.), (2000). Quantitative data were analyzed and presented as graphs.

CHAPTER 3. Results and Discussion

3.1 Nile tilapia culture and biosecurity management in Uganda

3.1.1 Nile tilapia culture production and development

3.1.1.1 Nile tilapia culture potential and distribution

Uganda lies between latitudes 1^{o} South and 4^{o} North, and longitudes 30^{o} East and 35^{o} East (Fig. 2). Excluding the mountain ranges, the average altitude of the country is 1,100 m above sea level. Air temperature ranges from 16 to 30^{o}C. All year round fish production is possible owing to the minimal air temperature and day-length fluctuations Balarin (1985); Anquila-Manjarezz and Nath, (1998as cited in SARNISSA, 2009). The geographical conditions could permit Nile tilapia fish farming across most of the country.

Uganda has significant potential for development of a commercial aquaculture industry; one which could produce critical volumes of fish to fill the growing gap in national fish supply, as wild fish catches continue to decline

(MAAIF, 2012). Among others, Uganda has fast growing fish species including Nile tilapia (*Oreochromis niloticus*), common carp (*Cyprinus carpio*), and North African cat fish (*Clarias gariepinus*); abundant fresh water resources. Most of the required raw materials needed for fish feed formulation even at farm sites were available; hence, all of which could permit broad scale aquaculture investments (SARNISSA, 2009).

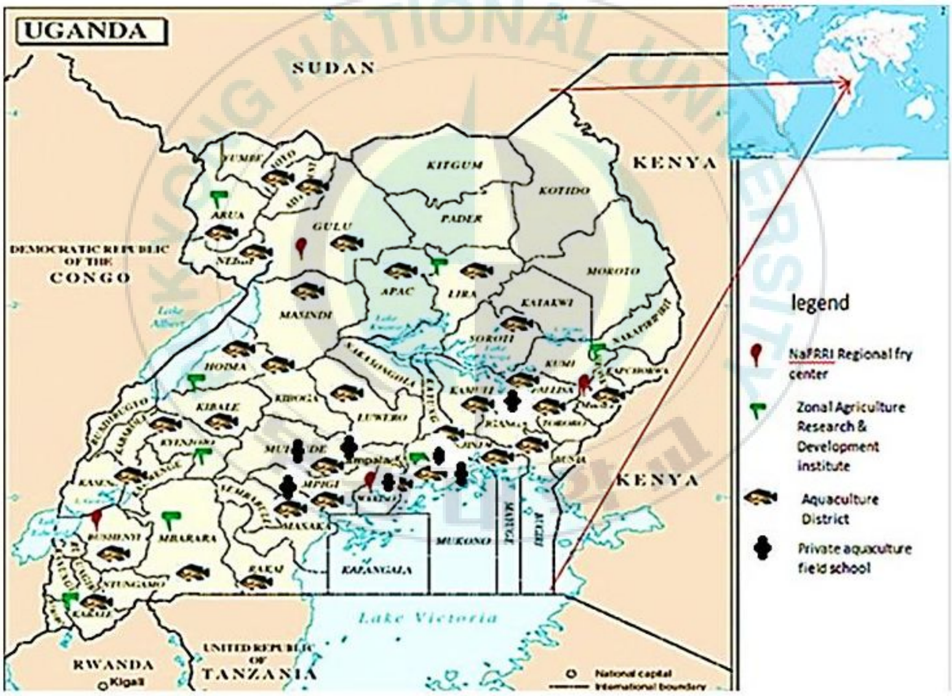

Fig. 2. FAO aquaculture approved Districts (MAAIF, 2008).

Previous scoping studies had identified most suited production regions for aquaculture; taking into consideration natural and socio economic factors. Hence, 31 districts were found suitable for aquaculture including Mayuge, Jinja, Bugiri, Busia, Mukono, Mpigi, Wakiso, Masaka, Rakai, Mbarara, Bushenyi, Ntungamo, Kasese, Hoima, Masindi, Nebbi, Gulu, Adjumani, Arua, Kamuli, Soroti, Lira, Iganga, Tororo, Pallisa, Mbale**,** Apac, Kaberamaido, Kabarole, Kamwenge, Namutumba and Kyenjojo, (IFOAM, 2013; FAO, 2008). These districts were located around the country's major water systems (see **fig.2**).

3.1.1.2 Aquaculture development trajectory

Available production data indicated a general growth trend of the industry over the years (**Fig.3)**. Aquaculture production had risen significantly from 285 metric tons in 1999 to about 95,906 metric tons in 2011/12, indicating an increase of about 340 times (MAAIF, 2012).

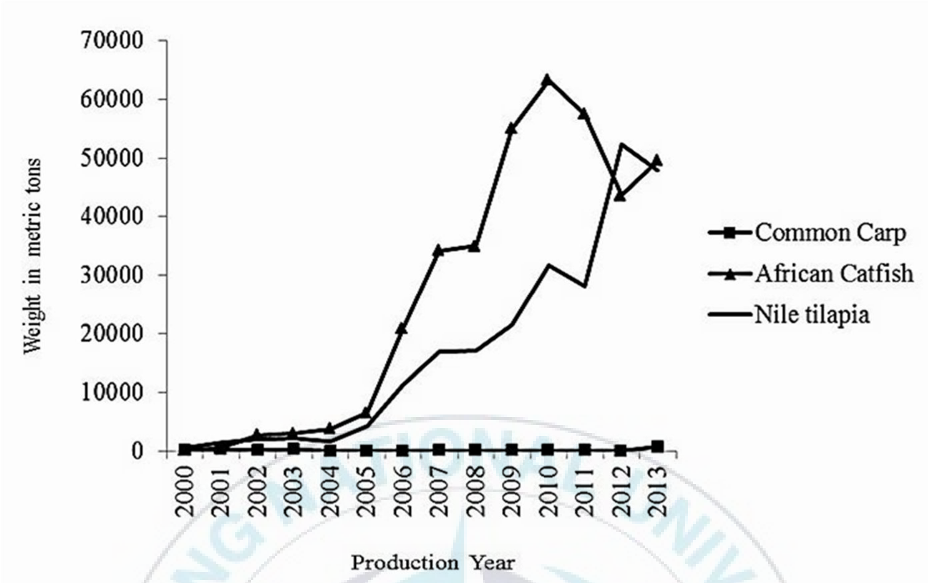

Fig. 3. Growth trajectory by major cultured species (source: FAO online query data).

The increased demand for fish, owed to dwindling wild fish stocks in the major lakes, had provided incentives to invest in aquaculture. Consequent aquaculture development and expansion had resulted in the movement of live fish within and between farms, communities, countries and across borders. Thus, posing serious fish health concerns; typical of observations by Subasinghe et al. (2001); Bondad-Reantaso (2004) in Asia –Pacific region.

Uganda, till then acted as a regional hub for the supply of aquaculture inputs (feed, seed, fingerlings) and small amounts of culture-produced Nile tilapia. Along with large quantities of wild caught fish, aquaculture fish products were exported to neighboring countries, such as the Democratic Republic of Congo (DRC), Rwanda, Kenya, and South Sudan. Hence, there was greater potential for Uganda to take on a more significant regional role in the supply of aquaculture inputs and products in the future as reported by World fish CGIAR, (2012).

However, Nile tilapia culture was still scattered throughout the country and dominated by subsistence production, realizing low productivity. Therefore, the government aimed at developing aquaculture parks, combining groups of fish farmers with a centralized input supply and onsite technical assistance, so as to increase productivity (IFOAM, 2013). Given the apparent role and future prospects of Uganda's aquaculture industry, there is need to put in place measures and strategies that would protect investment in aquaculture. There by guaranteeing fish health, production of safe products, with minimum deleterious effects on the environment. This would eventually sustain the socio economic benefits of aquaculture.

3.1.1.3 Culture facilities and infrastructure

Apparently the subsector was dominated by small scale or smallholder fish farmers; managing over 25,000 earthen fish ponds (90%), on land holding of at least 10,000 hectares (MAAIF, 2012). It was, however, estimated that over 2,000 farmers with over 5,000 ponds and over 1000 cages by groups or individuals had emerged there by constituting the small and medium scale commercial fish farmers. Pilot trials for Low Volume High Density cages had been undertaken by the USAID FISH and NaFiRRI-Chinese projects for Tilapia culture (USAID FISH Project Final Report, 2009). Over 100 tanks had also been constructed for demonstration, as a way of promoting commercial aquaculture at regional fry centres.

3.1.1.4 Culture inputs(seed, feed, fertilizers, chemical &drugs)

Records indicated that in the 1950s and 1960s Nile and other tilapia species such as *Tilapia zillii*; mirror carp (*Cyprinus carpio*) were culture species of choice. This was based on local acceptability of the species and suitability to the production systems being promoted by then according to Isyagi, (2001 as cited in SARNISSA 2009). However, of late Nile tilapia and African catfish (*Clarias gariepinus*) were the dominant species. Since 2008, sex-reversed *O. niloticus* seeds had been produced commercially and became available to farmers and now most cultured. A report by MAAIF, (2012) observes that studies at the Aquaculture Research and Development Center were being undertaken to domesticate indigenous species such as, *Labeo victorianus (Ningu)*, *Barbus atlantis (Kisinja)* as well as Nile perch (*Lates niloticus*) under the country's Millennium Science Initiative. This would enhance potential for increased diversity of cultured species in the near future.

Four regional fish fry production (hatcheries) and demonstration centers were constructed in Mbale, Gulu, Kajjansi and Bushenyi (Fig. 2) by government. Over 50 hatchery operators existed in the country and had good establishments with capacity to produce quality fish seeds (MAAIF, 2012). However, there still existed numerous smaller and rural uncertified hatchery facilities, some of which are dual purposes (seed and grow out farms) especially in areas appreciably far from well-established hatcheries. These were variously constrained, often run by inexperienced managers thus the quality and safety of fry from such facilities had many attendant risks. Generally seed production and quality assurance was up to then still a persistent problem (SARNISSA, 2009).

Feeds constituted the greatest cost item to most Ugandan fish farmers. Raw materials for feed were readily available in Uganda although there were variations in quality and seasonal fluctuations in price and availability.

In Uganda, two animals' feed manufacturers produced commercial fish feed for Tilapia and African catfish (Ugafeed and Ugachick); both companies produced floating fish feed pellets (World fish, 2012).

Local feed distribution channels were lacking, so most farmers who are far from the feed processing companies in Kampala (capital city) couldn't afford access to high quality feeds. Hence, majority of small holder farmers produced on farm feeds (locally made feeds) or induced generation of natural food in fish ponds through fertilization. Farmer empowerment programs; in feed formulation, so as lower the cost of pelleted feeds, for the majority financially constrained producers, were still lacking. Uganda's Agricultural Sector

Development Strategy and Investment Plan (DSIP) further highlighted lack of feeds to sustain improved aquaculture production as a major bottleneck (SARNISSA, 2009).

Primarily animal manure was used to fertilize the ponds; that is cow dung, poultry and piggery wastes which were locally sourced from own farm or obtained from neighbors for urban settings. Only a few farmers used artificial fertilizers and significant misuse of manure by fish farmers was a common phenomenon. Farmers were equally reported to apply raw or unprocessed manure directly into their ponds. Thus, posing risks of transmitting other animals pathogens to the cultured fish, and increasing the biochemical oxygen demand (BOD) of the pond systems, as previously reported by Muyodi, (2014).

The use of chemicals and drugs was still limited to the few commercial farmers and hatchery operators. Most farmers were still small scale farmers; hence, the use of chemical and drugs was not well pronounced. However, cases of unguided drug or chemical use were common i.e. based on farmer’s knowledge and experience. Use of chemicals such as; formalin, potassium permanganate, copper sulphate to counter suspected ectoparasites and fungal infections; oxytetracycline for suspected bacterial infections were reported by Akol and Mwanja (2012). Important to note is that the chemicals and drugs being used were not approved and apparently no related legislation existed in Uganda.

Table 1. Major sources of aquaculture inputs

Input	Source	Percentage supply (%)	Comment
Seed/fry/fingerings	wild	<30	(NARO/MAAIF,2000; Isyagi, 2007)
	Hatchery	>50	Hatcheries mostly private (only 4 regional government hatcheries).
	Other farmer	11	Other farmers supply seed from production ponds
Feed	On farm	80	Kitchen wastes, maize bran(low protein supplements)
	Commercial formulated feed & ingredient stores	20	Includes ingredients used for on farm formulation & commercial pellets
Fertilizers	On farm	>90	Mainly organic/animal manure
	Farm supply stores	<5	Mainly SSP,TSP,DAP, Urea, Lime
Chemicals & drugs	Veterinary drug stores	<5	Preserve of intensive culture systems

Source; Adapted from SARNISSA, 2009.

3.1.1.5 Water resources and waste water management

About 18-20% of the 240,000 M^2 Uganda's land area is covered by water hence an enormous fresh water aquaculture potential (MAAIF, 2012). So accessibility to water resources per se may not currently be a constraint on development of the sector. However, according to World Fish (2012) water for aquaculture was, vulnerable to climate change and variability.

The quality and suitability of water for aquaculture varied relatively; given the nature of agriculture integration in Uganda. Most fish ponds are located in marginal areas not suited for but adjacent to other agricultural enterprises. Therefore, some fish ponds were prone to contaminated water supply due to; surface water supply, agrochemical sprayed in adjacent crop fields, domestic wastes on farm premises or from the neighborhoods. Some aquaculture establishments close to major towns were located in areas where municipal waste could reach their water sources; thus, compromising the safety of the fish raised on such facilities (Bagumire et al., 2009)

Aquaculture effluents usually contain high concentrations of nutrients, and bacteria as part of the natural micro-flora of the fish and environment". A study by Muyodi, (2014) in Uganda; established presence of diverse bacterial species such as; *Aeromonas, Corynebacterium, Neisseria, Staphylococcus, Vibrio, Citrobacter, Eschericia, Klebsiella, Micrococcus, Enterobacter, Lactobacillus* and *Streptococcus* some of which are potential fish pathogens. Significant effect on; COD, BOD, DO, TP, TN due to effluents hitherto discharged directly into the surrounding environment without prior treatment are equally eminent on a some commercial farms . Such scenarios directly point to the likely environmental hazard posed by the untreated wastes.

However, in place was the Water Statute of December 1995 (Statute No. 9 of 1995); promoting the rational management and use of the waters of Uganda, for purposes other than domestic use, such as fish culture, in ways which minimize harmful effects to the environment.

The 1998 Water (Waste Discharge) Regulations (No. 32 of 1998), prohibited discharge of effluent or waste on land or into aquatic environment unless one had a waste discharge permit (NEMA, 2007). This regulation underscores the requirement from persons granted such permits, to ensure that effluents or wastes discharged conformed to the maximum permissible limits established. Further, permit holders are subjected to payment of a waste discharge fee annually. In principle, this truly reflected that, the costs of environmental pollution would be borne by the polluters (farms); thus, an incentive intended to counter irresponsible waste disposal. Important to note is that, the above regulations including the Fish (aquaculture) rules 2011 No. 81, reckoned the general obligation to mitigate pollution under which every farm establishment, had to install anti-pollution facilities, for the treatment of effluents as reported by FAO, (2015). However, many players in aquaculture sector were not yet familiar with regulations associated water safety hazards; thus, hardly practiced any precautionary screening of waste water before releasing it to the environment. Furthermore, lack of basic water quality test kits and know how couldn't permit ascertaining the suitability of water before its use in aquaculture, for most farmers. Hence, achieving a balance between providing safe, nutritious, and good quality aquaculture products, while maintaining environmental sustainability, was still very challenging in Uganda.

3.1.1.6 Culture systems and husbandry practices

Three culture systems were evident in Uganda's fish farming enterprises. These included small, medium and commercial scale farmers, which differed significantly in management and resource use as equally established by IFOAM, (2013). That is; small-scale (smallholder) aquaculture, fish cultivation was an integral part of the rural farming system and hence linked to the livestock/crop production. The integration was intended to enhance the diversity, resilience and output of the total farm system; to improve household food security and nutrition but with obvious need for regular technical assistance to fish producers, on how to best combine fish farming with other production activities (Bagumire et al., 2009 ; SARNSSA, 2009).

Usually on farm resources such as animal wastes, agricultural by-products, family labor were used; it was thus, mainly extensive characterized with low or rather no inputs in terms of skill and technology, but sometimes semi-intensive. Under small holder extensive monoculture systems, tilapia as major culture species are mainly not fed; in case fed, then supplementary feeds, like vegetable leaves, "kitchen waste "or commercially, low protein supplemental fish feeds such as maize bran were used. Production relied on the natural production capacity of the ponds; boosted by the application of animal manure from extensive animal rearing (cattle, pigs, chicken, goat and sheep) more often applied in a raw form (IFOAM,2013). The fish produced was majorly for domestic consumption and rarely for local markets. Most of these farmers were inexperienced; very often mixed sex tilapia was used in extensive systems with high stocking densities (3 and more fingerlings per m^2). Uncontrolled tilapia reproduction, coupled with infrequent harvesting resulted in extremely low marketable yields and thus disappointing. This category constituted above 50% of the total fish farming community in Uganda (SARNISA, 2013).

The medium scale, semi intensive aquaculture farmer category, an emerging category, most probably owed to the sustained promotion campaigns that have dominated the last decade. They were a little more specialized farming enterprises compared to the subsistence farmers; using artificial feed. Mainly semi intensive or small scale fish productions for local and urban markets, and apply mainly family labor; though, at medium scale also hire labor. They depended on external inputs of supplementary commercial feeds, and fertilizers to induce endogenous pond food production; use of all male tilapia for intensive and semi intensive monoculture in earthen ponds was almost mandatory (SARNISSA, 2009). Where mixed sex tilapia had to be used, then poly culture with catfish was always done to check on the prolific reproduction of the tilapia.

Cases of using poultry offals and fish abdominal wastes (from wild fish markets) to feed Cat fish in both poly-culture and monoculture system were a common phenomenon among the medium scale fish farmers (Kabuye, personal communication). This was found risky, since hardly any measures were taken to ascertain the safety and worthiness of such food materials for fish feed. Apparently this category constituted above 30% of the total farmers.

The commercial farmers, this is an emerging category of fish producers; vertical integration of fingerling and fish feed production, on growing, processing and marketing is apparently less developed and a preserve of a handful established farms. Hired technical management and labor is evident; production is mainly targeting regional and national premium markets in a form of value added products. Routine hygiene practices such as disinfection are common especially in hatchery facilities and on growing tanks in a few farms. Owing to their nature of intensification, HACCP procedures as precautionary strategies to counter disease are sometimes pursued as evident at Ugachick, Source of the Nile fish farm and Green fish limited (IFOAM, 2013). These farmers used both earthen ponds and cages, which have been introduced on Lake Victoria and source of the Nile though still in infant stages. They constituted at most 20% of all farmers. However no known biosecurity strategies were reported to be undertaken to counter diseases communication between caged and wild fish.

3.1.1.7 Farmer organization and education

Fish farmers' groups/associations had been established by some farmers; a number of them are dormant, while others like "WAFICOS" were functional. Where they existed the major objectives included collective marketing, sourcing of inputs, mobilization of technical and financial support for their members (SARNISSA, 2009). However, majority of small holder fish farmers operated as individuals. According to IFOAM, (2013), the government of Uganda recognizes the stimulative effect of private investment in aquaculture development at both medium and large scale levels. Hence, public private partnerships had been promoted over the years, increasing the number of commercial investors in both aquaculture production and service provision. Services offered among other included, manufacture of cages and seine nets by Uganda fish net manufacturers limited; dealership in assorted aquaculture in puts by Balton Uganda limited among others.

Private demonstration farms; previously utilized under the USAID FISH project, were still maintained as farmer field schools by their proprietors, and some of them on demand, offered residential and nonresidential modular trainings to facilitate hands on skills attainment in fish production to other farmers (SARNISSA, 2009).

Table 2. Private aquaculture field schools

Farm	location	Service
Blessed investment	Mityana	-Tilapia& catfish pond grow out. -Tilapia cage culture in reservoirs.
Edrhon fish farm	Kampala	-Tilapia& cat fish pond grow out. - Fish preservation by smoking
Mpigi fish farm	Mpigi	Tilapia& catfish pond grow out. -Tilapia &catfish nursery production
MUSO fish farm	Iganga	-Tilapia& catfish pond grow out. -Tilapia nursery production -Cat fish hatchery production
Namuyenje mixed farm	Mukono	Tilapia cage in reservoirs
SoN fish farm	Buikwe	-Tilapia nursery pond production -Tilapia cage culture -Tilapia hatchery production
Sun fish farm	Wakiso	Catfish hatchery production
Tende fish farm	Wakiso	Catfish hatchery production
Umoja fish farm	Wakiso	Catfish hatchery production

Adopted from, SARNISSA, 2009

3.1.1.8 Extension, advisory and information services

Aquaculture like any other agricultural extension services were decentralized, and under the mandate of local governments in Uganda. The extension staffs at local government level were obliged to routinely support and supervise aquaculture farming practices in communities under their jurisdiction. However, this was hardly attained since they were generally under facilitated and playing a less significant role in overall aquaculture development process.

Apparently, many were poorly informed, and lacked adequate knowledge on critical aquaculture issues such as fish health/ disease management; thus lacking in technical competence (SARNISSA, 2009).

The gap between the departments of fisheries resources, national fisheries research institutions and local government extension staff had widened over the years; this was indicated the by complete lack of drawn programs to enhance local capacity by the competent authority, Mulambi (personal communication, 14/05/2015).

Considering the pivotal role that the extension officers play at community level, the obvious technical gaps existing in local governments require pragmatic effort to be addressed; to improve aquaculture extension services.

3.1.1.9 Aquaculture products marketing

Generally, Ugandans are a fish eating people and fish was an important source of animal protein for most of the Ugandans in rural as well as in urban areas, implying significant lucrative local market availability. According to MAAIF, (2011) 70% of produced fish was locally consumed and the annual per capita consumption was 5.7 kg, far below the recommendation of FAO/WHO (12.6 Kg per capita). Thus, emphasizing the importance of food fish production to Ugandans.

Fish from aquaculture in most cases was sold directly at the ponds and local market stalls, although some fish farmers and intermediaries sold mainly processed fish at border market points or different regions within the country (MAAIF, 2012). Apparently there were no strictly observed food safety regulations reported; during the marketing of Nile tilapia products at a local level and regional markets.

Uganda was on the Third Country List of the European Union and approved to export both capture fishery products since 2001 and farmed fish in form of chilled and frozen products since 2010 as per IFOAM, (2013) report. Thus, observation of HACCP principles to ensure safe products handling during fish processing for export markets was evident by processors.

Nonetheless, the conditions and environment obtaining in the Nile tilapia farms, was faced with challenges of producing safe and acceptable products; for the strict market standards of the developed countries, local and regional markets. Hence there was need to improve and minimize exposure of such products to the various food hazards along the production chain, that could jeopardize lucrative market opportunities as recounted by Bagumire, *et al*., (2009).

3.1.2 Fish healthy management and food fish safety

3.1.2.1 Fish health management

As already observed, innovations and commercialization of aquaculture, was shifting management from subsistence to intensive commercial levels in Uganda. Disease cases in Nile tilapia culture had begun impacting economic losses, due to human mediated movements of aquaculture commodities (brood stock, fry and fingerlings). Gaps in fish pathology, interactions between cultured and wild fish populations; lack of appropriate management frame work for fish diseases or functional biosecurity system equally enhanced fish disease risks in Uganda (Akol and Mwanja, 2012).

Of major concern were zoonotic parasites like trematodes, cestodes and nematodes, and pathogenic bacteria such as *Salmonella* spp., *Escherichia coli*, *Shigella* spp., *Campelobacter*, *vibrio* spp., *Aeromonas* spp., *Plesiomonas* spp. and *Clostridium botulinum* that are known to infest / infect tropical farmed fish (WHO, 1999; Muyodi, 2014).

Apparently, the culture conditions in most Ugandan fish farms, pose high risks of disease transmission and parasite infestations among cultured fish species (*Oreochromis niloticus*, *Clarias gariepinus*). Hence, increase the level of uncertainty which fish farmers and managers have to contend with to develop the industry. Parasites were reportedly the most diverse; a total of 121 species of parasites, including 20 species of Protozoa, 24 species of Monogenea, 17 species of Digenea, 14 species of Cestoda, 21 species of Nematoda, 2 species of Acanthocephala, 8 species of Branchiura and 15 species of Copepoda. Further, 5 bacterial species, 3 fungal species and 1 viral species, were also reported to infest fish in East African waters; hence posing potential challenges to Uganda's aquaculture development, as qualified by Akoll et al., (2011); Akoll and Mwanja, (2012).

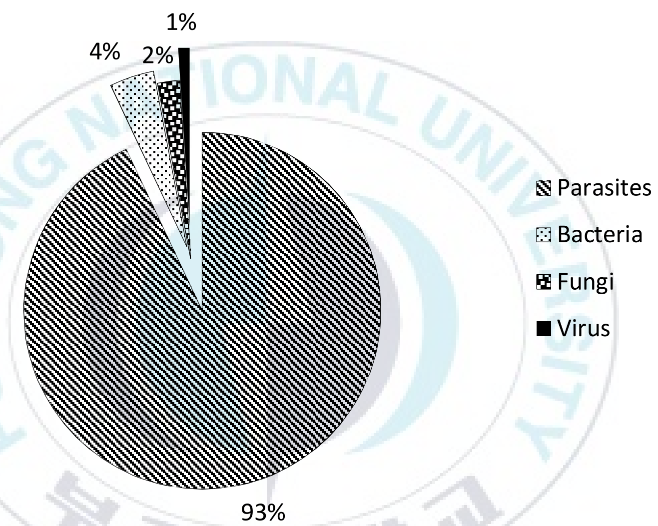

Fig. 4. Proportions of important fish disease-pathogen occurrence in East Africa (Adapted from; Akol and Mwanja, 2012)

On-farm disease diagnosis was a major constraint, given that even fish health experts weren't very many. Therefore, most simple disease outbreaks were managed locally by farmers. The choice of management options and the application of drugs were based on the farmers' knowledge and experience. In most cases, the application of drugs and chemicals was done without identification of the pathogens (Akol & Mwanja, 2012). Additionally, most chemicals and drugs used were not officially approved. No legislation spelt out the prohibition of specific chemicals for aquaculture, in order to minimize abuse of chemotherapeutics in Uganda's aquaculture.

Revelations from previous reviews of national records showed limited use of quarantine facilities, and the risk analysis regarding the trade in live aquatic animals and the introduction of new species for farming (Bagumire et al., 2009). Therefore, one could argue that Uganda had no functional biosecurity strategy and system in place to safeguard cultured fish from diseases as well as minimize environmental deleterious effects due to other undesirables.

Table 3. Identified pathogens in hatcheries and grow out farms

Pathogen species	Mortality rate (%)	Fish species
Columnaris	14-100	Oreochromis niloticus(1-3g)
Aeromonas	14-100	Oreochromis niloticus(1-3g)
Clinostomum (ich)	-	Oreochromis niloticus(20-80g)
Diplostomum	-	Oreochromis niloticus (20-80g &>100g)

Source; Bagumire, 2009

With regards to institutional capacity for management of fish diseases, fish diagnostic laboratories worth recognizing by World Organization for Animal Health (OIE) were lacking. Diseases outbreak diagnoses were virtually performed at some Universities and public research organizations, with such results being largely contestable.

3.1.2.2 Disease surveillance

There was apparent ignorance of microbial profile of cultured fish, and aquaculture products owed to lack of formalized fish disease surveillance programs; to ensure safety and wholesomeness of products (Akol and Mwanja, 2012; Bagumire et al., 2009) . Relatedly, there was no up to date list of diseases to guide monitoring or facilitate development of comprehensive disease management plan (Akol and Mwanja, 2012). Thus, absence of required public health mechanisms; consequently increased the risks of spreading known zoonotic pathogens such as, *Streptococcus* and *Vibrio*; from cultured tilapia to humans.

3.1.2.3 Aquaculture food fish safety

Aquaculture products are a product of their environment, the environment and farm conditions in Uganda potentially expose Nile tilapia culture products to a variety of food hazards. Food safety hazards in Uganda's aquaculture products would most likely include; chemical contaminants, foodborne pathogenic bacteria, and trematodes infestations as evident from WHO, (1999); Kasozi, et al., (2006); Bagumire, 2009). Potential chemical contaminants could include, toxic inorganic and organic compounds like heavy metals such as mercury, lead and cadmium, and polychlorinated biphenyls (PCB), dioxins and furans, veterinary drug residues, and over used agro-chemicals including persistent organochlorine pesticides (WHO, 1999; Bagumire, 2009).

Organochlorine pesticides like Dichlorodiphenyl-trichloroethane (DDT) and its metabolite Dichloro-diphenyl-dichloroethylene (DDE) and Endosulfan1 were previously found in some culture Nile tilapia fish in the range of 0.01–0.002 mg kg^{-1} by Bagumire, (2009). Kasozi et al., (2006) also detected Pesticide residues in fish from Lake Victoria, receiving water from some of the catchments areas providing aquaculture water and current under increasing Nile tilapia cage culture. Thus, suggesting that pesticide residues should be of concern in in Uganda's aquaculture.

Table 4. Pesticides levels from Lake Victoria fish samples

No.	Pesticide	Quantity in fish(ppb)
1	Lindane	0.74
2	Aldrin	0.28
3	Endosulfan	1.70
4	Dieldrin	0.30
5	DDE	0.80
6	DDT	0.59

Source; Kasozi et al., 2006

Therefore, understanding the sources of hazardous contamination remains critical in managing the safety of aquaculture products in Uganda. Aquaculture was still a young industry and many players in the sector were not yet familiar with associated food safety hazards. In agreement with Bagumire et al., (2009), safety and quality of Uganda's aquatic products required attention; to ensure pollution-free, nonhazardous, high quality, traceable farmed aquatic products, which can access local, regional and international markets.

3.1.3 Shrouded aquaculture hazards in Uganda

With due Consideration of the prospective future of Uganda's aquaculture, it's eminent potential to supply safe as well as wholesome products, there were additional inherent, but less obvious public health hazards. These were found associated with; ignorance, abuse and neglect of aquaculture technology in Uganda.

3.1.3.1 Nature of integrated farming system

Untreated animal manure, such as raw poultry manure, was used continuously in fish ponds (SARNISSA, 2014). This was quite insensitive of the fish health implications; the possibility for transmitting of pathogens such as *Salmonella* to cultured fish was hardly considered by farmers and their service providers. Hence, requiring integration of food safety education in aquaculture biosecurity as recommended by Scarfe, (2003); Amagliani et al., (2012).

Fig. 5. Poultry–fish integration, at Salaama fish farm (source; SARNISSA, 2014)

3.1.3.2 Aquaculture and capture fisheries interactions

The perceptible interactions between aquaculture and fisheries could be more often neglected. Of paramount importance were the likely negative effects of such interactions; interfaces between aquaculture and fisheries owed to; culture based fisheries, stock enhancement programs and aquaculture structures such as cages could pose negative consequences, if neglected or ignored in Uganda as equally observed by World fish (2013).

Apparently, there were no known biosecurity frameworks in Uganda, for adequate control of seed and other inputs quality; used by fish farmers now engaged in Nile tilapia cage culture on Uganda lakes. Prevention of escapees from containment facilities, proper husbandry practices, enforcement of national norms and regulations; routine monitoring and surveillance of diseases in wild cum farmed fish required due attention. Potential transfer of pathogens from farmed to wild or wild to farmed fish was possible as further observed by FAO, (2012b). In case of containment damage due to catastrophic natural events and human error, farmed fish could as well escape from enclosures to the wild; interbreed with wild fish, thus, compromising their genetic integrity or potentially communicating diseases.

3.1.4 Aquaculture governance and associated biosecurity issues in Uganda

3.1.4.1 Policy framework

Uganda's National Fisheries policy (2004), highlighted the objective of aquaculture fish production being increased, so as to reduce the gap between fish supply and the increasing demand for table fish. Prospecting 305,000 tons by 2017/2018 (MAAIF, 2012; DSIP, 2010-2015). The agriculture Development Strategy and Investment Plan (DSIP), a key policy document for the agriculture sector was consistent with the broader National Development Plan (NDP). It observed that, fish farming in Uganda presented immense opportunities for socio-economic development, in terms of livelihood, income, and employment (MAAIF, 2012).

Policy strategies in Uganda, related to the development of small scale fish farming for subsistence production and commercial fish farming. The overall national development vision was; "to ensure sustainable and efficient exploitation, and culture of fishery resources, for posterity without degrading the environment" (MAAIF, 2012).

Precisely aquaculture development was on the policy agenda, in the shape of a strategic aquaculture plan. The government planned to develop aquaculture parks in up to five gazetted areas including lakes and rivers in the central and western regions, as detailed in the drafted Aquaculture Parks Policy (2013).

As observed above, the national fisheries policy; other related policies, underscored aquaculture (fish farming) as a key investment opportunity. It is highly anticipated that, over the medium term fish farming could close the gap between the supply of fish in natural stocks and the growing demand for fish by local, regional and international markets. However, the National fisheries policy (2004), had limited focus on fish health management and did not provide for aquaculture biosecurity.

3.1.4.2 National Regulation and standards

The Department of fisheries resources (DFR) was the competent authority mandated to promote, guide and support the sustainable fisheries and aquaculture development. It was responsible for setting, enforcing standards and regulations of practices pertaining to fisheries and aquaculture (MAAIF, 2012).

The Fish Act (Cap 197) in 2000, and was the major law providing for the rules and regulations for the control of fishing, conservation and other transactions in the fishing industry. Article 12 of this Act prohibited introductions or transfers of fish and their eggs, without written permission from the 'Chief Fisheries Officer', in an attempt to prevent the spread of fish disease or pathogens, including parasites and other undesirables. However regulatory mechanisms to ensure adherence or enforcement of article 12 were not in place. Other laws relevant to aquatic animal health available in Uganda include the Animal Disease Act (1964) of Uganda; this law required modification to accommodate fish diseases as observed by FAO, (2015).

In place were the Fish (Aquaculture) Rules of 2011 (No.81 of 2011) which were subsidiary rules made under the Act regulating the aquaculture sector in Uganda. The Rules set forth the different permits that are required to engage in aquaculture, their modalities of issuance, the prescribed offences and penalties under the Rules. The rules specified aquaculture inspectors' powers, promoted responsible aquaculture activities, and prescribed conditions for fish seed production, fish transfers, live fish imports and exports. They also provided for the DFR to work in collaboration with other bodies, such as the National Environment Management Authority (NEMA), the National Drug Authority (NDA), the National Bureau of Standards (NBS) to ensure that practices in aquaculture complied with national legislation and standards (Fish [Aquaculture] rules, 2011). However, fish farmer guidelines on appropriate practices to address fish health and disease management, Code of good aquaculture practice, had neither been promulgated nor issued to farmers as stipulated in Fish [Aquaculture] rules, (2011) No. 81. Seemingly, aquaculture controls were recent, still weakly regulated hence, most farmers hadn't acquired the necessary knowledge about what is expected of them; to even fulfill basic certification of their establishments. Mulambi, (personal communication, 15/05/2015) further reported about the low government support to the sector, affecting overall framework conditions, enforcement of regulations and implementation of national sector development plans.

3.1.4.3 Compliance with international standards and guidelines

By virtue of its membership to the Food and Agriculture Organization (FAO), Uganda subscribed to the FAO Code of Conduct for Responsible

Fisheries (1995). The National Fisheries Policy, the new Fisheries Law (Fish Act 2000) to be passed, reflected the principles enshrined in the Code of Conduct for Responsible Fisheries/CCRF (1995).

Uganda was also Party to a number of international conventions related to fish health and food fish safety inter alia, such as FAO's Codex Alimentarius Commission/CAC, (1999); World Trade Organization/WTO's Convention on Biodiversity/CBD, (1992), Cartegena Protocol on biosafety, (2000) and Sanitary and Phyto-sanitary (SPS) measures agreement, (1995); World Organization for Animal Health or OIE's Aquatic Code and manual; International Union for the Conservation Nature or IUCN's institutional frameworks on Alien invasive species (FAO, 2015).

At a regional level, Uganda was a Party to the African Convention on the Conservation of Nature and Natural Resources. Uganda, Tanzania and Kenya, adopted the Convention for the Establishment of the Lake Victoria Fisheries Organization (LVFO) in 1994 whose main objective was to promote the conservation and sustainable utilization of the living resources of the lake. The Organization (LVFO) had additionally a developed regional strategy for aquaculture research and development in the Lake basin as reported by World fish, (2012). Nonetheless, Uganda's aquaculture industry up to then manifested severe weaknesses in observing certain provisions of a number of international codes and agreements to which it subscribed. Specifically, improvements or reforms were needed in among others; observing guidelines and integrating pro-active disease surveillance mechanisms, sanitary and hygienic practices; food safety education into the current aquaculture production models as recommended by Boyd, (2005); Lee and Connelly, (2006). Strict adherence to quarantine principles especially for non-native fish species importation in view of the highly prospected aquaculture expansion, would equally be requisite; to ensure safe aquaculture development in Uganda.

3.1.4.4 Institutional landscape

Under the current set-up, the DFR (competent authority) was mandated to nationally promote, guide and support the fisheries and aquaculture activities, at district level is the fisheries department. Governance in Uganda is based on a decentralized system hence local Governments (through districts) drew development and technology dissemination plans through the District Fisheries

Officer and field staff. Priorities for investment were relative and based on majority farmer needs. Enterprise selection was focused on those that provided improved incomes and food security for the greater majority; owing to finite financial resources. From the findings of SARNISSA, (2009), aquaculture had not yet developed into an enterprise that could compete for grants compared to other agricultural enterprises

Although attempts to enhance the enabling environment for the sector were evident, the institutional governance capacity remained weak. Weak institutional frameworks could result in introduction of alien species, and pathogens with environmental consequences; spread of fish diseases due to unprecedented fish movement both within the country and across national borders.

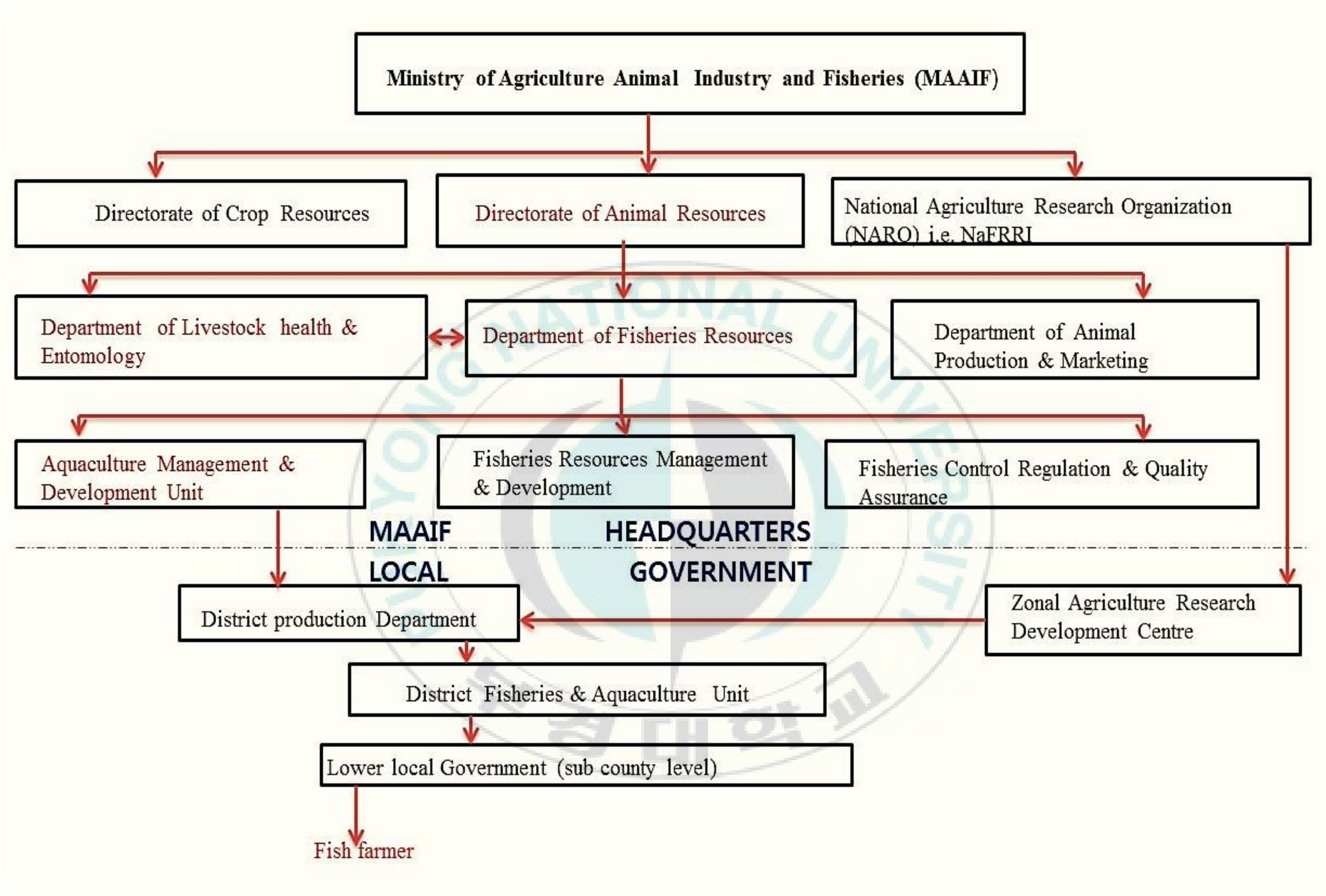

Fig. 6. Organization structure for MAAIF institutional linkages

3.1.5 Summary of identified biosecurity issues in Uganda's aquaculture

The review of Uganda's aquaculture sector, revealed the lack of a functional biosecurity system, in the aquaculture industry. Precisely, specific biosecurity gaps highlighted above were constituted into 2 thematic areas below; deduced to compound profound biosecurity challenges in Uganda's aquaculture as outlined:

- Farm based biosecurity system
- National biosecurity system

Based on such sectoral, analysis potential proposals or suggestions for improving aquaculture biosecurity in Uganda were identified. These were based on experiences, lessons drawn from Asia-Pacific and other successful world aquaculture communities as further elaborated.

3.2 Towards improving Aquaculture biosecurity in Uganda

It was found out that aquaculture is and will be an important enterprise in Uganda's socio-economic development. It is highly prospected that through aquaculture the ever increasing fish demand would be met and thus, cater for food and other socio-economic needs of the rapidly increasing human population as previously reported by MAAIF, (2012). However, Fish diseases, as well as other biosecurity concerns, were further established, beginning to affect the culture of Nile tilapia in Uganda. This is further evident from studies conducted by Akoll et al., (2011); Walakira & Nankya, (2013) among others.

Certainly, the culture of Nile tilapia on a number of Uganda's fish farms could be subjected to negative publicity in the near future similar to that already happening in some developed aquaculture communities in Asia-Pacific (Rahman, personal communication), if the biosecurity gaps now obtaining among Nile tilapia farmers continued unchecked (section 3.1). There are lots of concerns about potential introduction, spread of fish diseases, and parasites to farmed and wild fish populations, potential spread of zoonotics, biological and chemical food fish safety hazards, ecosystem damage as indicated by Bagumire et al., (2009); Akol et. al., (2011), all of which are conspicuous in Uganda.

Therefore, development and promotion of sound national policies and production models at farm level, with secured biosecurity systems to guarantee economic feasibility of aquaculture as a business in Uganda, are now required. The proposed models will have to be founded on appropriate scientific principles, underpinning what can be practically achievable at both national and farm level. Further, the proposals should be able to ensure resource protection (nascent aquaculture, wild fisheries, environment health and welfare), food security, safe aquaculture products and guaranteed trade; future investment and development issues in Uganda. Hence, consistent with Bondad-Reantaso et al., (2005)'s observation in Asia-Pacific countries. Accordingly, the highlighted below were found potentially valid proposals; through which aquaculture biosecurity improvement could be nurtured in Uganda. They were found commensurate to the socio-economic and environmental factors obtaining in Uganda's aquaculture industry.

3.2.1 Farm biosecurity practices

Given the current rate of aquaculture development and established biosecurity gaps at farm level, regulation and guidance on appropriate aquaculture and management practices; regular effective support supervision and advisory services, farmer education about pathogens and diseases of cultured fish including appropriate husbandry practices are highly required. Such will optimize biosecurity at farm level as previously proved to work by Subasinghe, (2005) among the shrimp farmers of the Indian state of Andhra Pradesh.

However, the appropriate farm specific management practices would have to be developed by technical officers in consultation with farmers. Due consideration would be required, for species cultured, type of aquaculture practice, location, surrounding habitat and, economy of scales; to ensure appropriation of improvement management measures or strategies. Studies by Boyd, (2003); Ozbay et al., (2014) approve of simple BMPs as the most technically practical and economically feasible, in minimizing disease impacts, reducing environmental impacts, and limiting production costs at aquaculture facilities. In countries such as Thailand and India simple farm specific BMPs were developed and reportedly proved to work. Below, are some commendable practices; found applicable to Nile tilapia culture for optimizing biosecurity and productivity, in respect of the identified biosecurity gaps at farm level in Uganda.

3.2.1.1 Farm siting and design

Nile tilapia farming in Uganda was found to be characterized with lack of appropriate professional guidance prior to construction of ponds; haphazard and unprecedented pond siting based on farmer judgment, as vividly evident on most rural small scale or subsistence farm layouts as reported by Kadisa, (personal communication, 9/03/2015). However, proper site selection should be an important consideration during the commencement of any fish culture endeavor. It minimizes water quality problems, aids fish health, and quality of culture products including reducing treatment costs. More so, the location and design of a farm determine the degree to which various control measures can be applied. Therefore, farm lay outs should be designed in such a manner as to permit easy pond drainage and periodic cleaning; isolation of affected populations/animals to minimize diseases spread within the farm or adjacent farms sharing the same water source. Precautions against disease or pathogens from significant point sources within the environs of the proposed fish culture area or management of incursions in case of outbreaks as observed in previous studies by Lazur, (2007); Perera et al., (2008) Yanong, (2013) should always be provided for.

For open water cages, it is advisable to ensure appropriate distances between cages or groups of cages as this would equally benefit compartmentalization in the bid to control disease spread. Siting fish cages away from wild fish migratory routes; use of anti-predator nets would further minimize possibility of broken nets/escapees; hence, minimizing potential interbreeding between hatchery originated and wild populations as well as the consequent issues of disease transmission (FAO, 2012a).

On a related note, the nature of integrated farming systems practiced in Uganda requires due guidance in form of appropriate fish farm siting in relation to other farm enterprises. Fish ponds should be consciously located away from any potential sources contamination, such as crop fields under application of agro chemicals or agricultural runoffs during rainy days among others. Crop fields could act as potential sources of chemical contamination to farmed fish products, under earthen pond culture.

3.2.1.2 Farmer institutional development and Codes of good practices (COP)

Emphasis on formation of fish farmer groups and associations, at community level requires support in Uganda. Apparently majority of Nile tilapia farmers still work as individuals thus, forfeiting the benefits that arise from group synergy. Formation of farmer groups would facilitate farm registration, formulation of industry codes of practice by groups or aquaculture clubs/farmer groups; to ensure acceptable levels of standards of practice for every farmer. Salient biosecurity issues such as fish health, and welfare, operative health and safety; environment health; traceability including farmer education or advocacy programs are easily established when farmers work in a group. The Scottish salmon producers (Salmon producers organization) of United Kingdom, according to Oidtmann et al., (2011); small scale shrimp farmers in the state of Andhra Pradesh of India Subasinghe,(2005) reportedly owed their success to group synergy.

3.2.1.3 Farm level biosecurity plans and standard operating procedures (SOPs)

No verifiable information proved existence of biosecurity plans or standard operating procedures at sampled commercial fish farms in the study areas. On the other hand, plans engage and guide aquaculture operatives at fish farms; they facilitate implementation of appropriate practices at control points on farms and in accordance to intended biosecurity strategies. However, plans have to be founded on proper risk analysis and developed with technical guidance. Furthermore, the species of culture, investment capacity of farmer (type of operation and scale); farming system (stocking density, life stage of animals), culture environment, and pathogens threats envisaged must be respected, for their effectiveness (Oidtmann et al., 2011; Ozbay et al., 2014).

While constituting biosecurity plans, the following could be included; better management practices, identification of potential hazards (risks of contracting and spreading diseases, environmental impacts, operatives welfare); subsequent hazards or risk mitigation measures, training of staff in diseases recognition and fish healthy management, diagnostic and detection methods for infectious diseases, disinfection and pathogen eradication methods according to Yanong and Erlacher , (2012).

Overbearing for tilapia farmers in Uganda, is the need to put in place biosecurity plans which are; simple and easy to follow (in local languages where possible), with effective and practical measures; facility maps and should be preceded by employee awareness or training programs. Additionally, to ensure effectiveness at farm sites, the specific pathogen or disease control strategies, issues in the biosecurity plans should be translated and toned down into precise and site specific standard operating procedures or protocols; applicable at given critical points within the production chain. They have to be written out, accessible and easily understandable to employees. This would overcome misunderstanding; thus, minimizing operatives' error and oversight and consequently enhance compliance (Bagumire et al., 2010; Roy P.E. Yanong, 2013).

However, according to; Bondad-Reantaso et al., (2005); Rohana Subasinghe, (2005); Oidtmann et al., (2011), competent authorities such as DFR in Uganda, were obliged to design guidelines to help farmers identify biosecurity measures that could be applicable to their farm conditions. Relatedly, it is advisable to appoint biosecurity managers in cases of highly commercialized Nile tilapia culture facilities; to develop and oversee the biosecurity programs. They ought to work closely with fish health professionals and aquaculture extension specialists in fine tuning plans, identifying diseases of importance and establishing management options suited to given facility conditions.

3.2.1.4 Education, training and information sharing

The concept of aquaculture biosecurity could be relatively strange to many fish farmers in Uganda; owing to the fact that fish disease concerns are only recent and the industry is still young. Therefore everyone at fish farms, including visitors and suppliers should be relatively educated about biosecurity issues. They should know about the potential fish diseases, epizooties, and means of pathogen spread, risk factor areas through which pathogens can be introduced and applicable biosecurity principles or practices.

The individual roles of farm staff/visitors in responding to a disease events and countering aquaculture environmental foot prints should always be emphasized. That would raise awareness and instill the biosecurity concept into peoples' psyche over the long-term. Hence, biosecurity in Uganda would only be successful if the farm staff, visitors understood and observed the established protocols at farm facilities; otherwise they would most likely increase the risk of disease incidences.

Well planned and coordinated work schedules; programmed periodic worker retraining, could be organized to further facilitate consolidate benefits of biosecurity education and enhance employee compliance at farm sites. Perera et al., (2008); Yanong and Erlacher (2012) equally emphasized the need for regular reviews and evaluation of the education programs to keep track of attained compliance levels by farm staff or general program effectiveness among others. Therefore, better biosecurity education of Nile tilapia producers in Uganda, with special consideration for public health, economic and environmental benefits; adoption and sustained use of better management practices, would in the long run be more rewarding, providing impetus for easier adoption than enforcing regulations.

3.2.1.5 Personnel and farm site traffic management

In many cases Uganda's Nile tilapia farms have inadequate staff or depend on family labor; hence, attendance to ponds needed to begin from those with youngest to the oldest or from the healthiest to the diseased ones. More so, equipment would warrant specification for the different ponds, or else equipments needed to always get cleaned and disinfected between ponds. On a related note; concise and clear rules for personnel and visitors regarding areas access, receiving locations, designations of areas that are off limits or restricted, have to be appropriately posted to minimize potential disease pathogen vectoring by human beings. Disinfection points for footwear and hands require strategic locations, since they are critical in limiting spread of pathogens by people at farm sites.

Protocols such as showering and changing of clothes (waders) and shoes especially at hatchery facilities need to be considered so as to further minimize risks of carrying infectious disease organisms mechanically by operatives and visitors. Workers could carry pathogens on their skins or clothes during routine and periodic management activities such as harvesting; hence, facilitating transmission between culture facilities among others. Where possible, employees could be assigned to specific areas and only allowed in others upon thorough disinfection at least.

Personnel safety should of concern. Hence, protective gears need to be used, so as to protect operatives/staff from risks of zoonotic infections due from fish or to fish from man; to safe guard them from infectious pathogens such as *Edwardsiella ictaruli*, *Mycobacterium marinun*, *Klebsiella sp* or their transmission from man to fish, which could be present at some Ugandan farms. Farm personnel should always observe safety precautions while handling disinfectants, drugs, pesticides and other aquaculture chemicals is important; to ensure sustained personnel safety, and welfare.

3.2.1.6 Inputs; utilization, control and management improvement

Aquaculture inputs such as fry, feed, water, and manure potentially carry attendant biosecurity risks at some of Uganda's tilapia farm sites (Tamale et al., 2010). They can potentially act as routes of pathogen introduction into culture facilities, given the current nature of management practices at many Nile tilapia farms. Therefore, Fish seed, and brood stock sourcing should be from only certified hatcheries or populations determined to be free from pathogens; such as those subjected to regular monitoring and thus, of good health status. If possible new arrivals should be quarantined for 4-6 weeks away from other fish; tested and treated to reduce risks, as precautionary measures against the transmission of any potential viral, bacterial or fungal pathogens as encouraged by Subasinghe, (2005). Furthermore, fish health monitoring should continue, throughout the production cycle to ensure minimized pathogen spread on and between farms.

Grow out feeds would be restricted to commercial pelletized feeds with relative pathogen inactivation, if it were possible. They have to be of good quality suited for the cultured species and used before the expiration date. Proper feed storage should be paramount, by ensuring cool dry and well ventilated conditions; to minimize nutrient (fatty acid and anti- oxidant vitamins) break down and probable increase in fish susceptibility to diseases once consumed. Storage facilities should keep away pests and vermin such as rats, mice, roaches and conditions which could potentially contaminate and facilitate bacterial or fungal growth in feed. Hence, producing mycotoxins which reduce feed quality, and consequently cause diseases in fish (Perera et al., (2008); Yanong, (2013),).

Since on farm made feeds are the most affordable by majority of resource constrained farmers in Uganda, there is need to train farmers on proper formulations, required hygienic handling and use of indigenous technical knowledge such as sun drying; to minimize multiplication of pathogens. However, even with high quality feeds, conservative feeding practices with feeds of high efficiency ratios are highly recommended; to counter overloading the culture environment with organic material. Thus, that would minimize fish stress and feed cost. On the contrally heavy organic loads, could impact negatively on the quality of both pond and effluent water, by increasing ammonia and other metabolites. It would also deplete the oxygen required by fish; hence, stressing fish and rendering them more prone to infections.

Pertaining to live feeds often fed to early stages of Nile tilapia species especially in hatcheries; harborage of potential pathogens would be avoided by cleaning and regular disinfection to reduce pathogen loads. Disinfecting cysts of rotifers with sodium or calcium hypochlorite/ organic iodine; rinsing newly hatched organisms with clean water and testing them for freedom from pathogens, before their use as juvenile fish feed (Bagumire et al., 2009).

Good quality water is critical to the health of fish; risk analysis and precautionary influent water quality testing and treatment prior to use would be highly recommended for most of Uganda's Nile tilapia farms. Surface water sources as mostly used present greater pathogen risks. Mechanical filtration would reduce introduction of unwanted aquatic species and fomites, which are equally potential pathogen carriers. Ozonation or ultra violet radiation could as well be used, funds permitting. Ideally, management of potential adverse interactions and impacts resulting from contamination of aquaculture water sources due to pathogens; release/use of drugs and chemicals from other agricultural and animal husbandry enterprises inter alia, could be informed by proper risk analysis. Critical analysis of domestic waste water, animal and aquaculture effluents; agricultural runoffs, released into aquatic environments serving as water sources for aquaculture, would be required for most Ugandan farms. It would enable determination of potential chemical contaminants in water sources including their likely effects on quality of cultured fish incase used. It would thus, be necessary to acquire basic water quality test kits at farms and always conduct thorough water quality tests including all required parameters of water chemistry (pH, temperature, dissolved oxygen, etc.); prior to committing any water source for aquaculture usage. As stressed by Yanong and Erlacher, (2012), the systems' water quality and water chemistry parameters, need to be safe and compatible to the requirements of the cultured species; hence, regular water quality monitoring to counter any deviations from the optimal levels is required.

Indiscriminate organic manure usage could be a common phenomenon at most tilapia farms in Uganda; thus, increasing the likely hood of transmission of potential pathogens to farmed fish. Cases of using raw livestock, poultry manure are reportedly eminent; without conscience about the cost implication in case of pathogen infested wastes. Therefore, farmers would require education about the attendant risks borne by raw manure including knowledge on simple compositing techniques. They should be sensitized about minimum and judicious usage of organic manure in earthen ponds; commendable manure being that free from drug residues and thoroughly decomposed prior to its use. Thoroughly decomposed manure eliminates or reduces potential pathogenic microbes naturally occurring and utilizing organic matter for their survival. Use of raw chicken manure should be discouraged, to further reduce the risk of transmitting infectious zoonotic bacterial pathogens such as Salmonella to cultured fish.

The current rate of aquaculture intensification in Uganda presupposes increased incidence of disease cases, increased chemicals, drugs usage and abuse during intensive Nile tilapia culture to combat pathogens. Apparently Uganda lacks popular regulations in respect of aquaculture drugs; hence, the establishment and regulation of only approved aquaculture drugs and chemicals is now required. Certification of professional drugs and chemical dealers; farmer education, regular monitoring and support at farm premises for compliance with administration procedures, will ensure appropriate drug usage, product safety and operatives' welfare.

In situations of bacterial disease outbreaks, warranting usage of antibiotics, only approved aquaculture antibiotics, should be used with care; upon proper guidance and judgment of fish health specialists. More so, antibiotics should be used only as complementary to good management, disease surveillance, optimal nutrition and farm hygiene among others. Observation of the above criteria, would preserve the efficacy of existing drugs, limit evolution of drug resistance genes in potential pathogens and consequently minimize transfer of drug resistant foodborne pathogens to humans as observed by Amaglian et al., (2012).

3.2.1.7 Pond maintenance and effluent management

Most commercial scale culture of Nile tilapia in Uganda is done in outdoor earthen ponds; which are exposed to many biosecurity challenges such as pests, predators, water sources, and complex disease management inter alia. Of major concern are the detritus/organic build up in ponds, from feces, uneaten food, dead and decaying organisms; thus, potential reservoirs for bacteria and other microorganisms which can cause fish diseases. Therefore, Ponds require maintenance and periodic cleaning depending on type, condition, size, amount of organics as well as potential disease concerns. They could be drained and dried by removing of organics; to improve water quality, reduce reservoirs for diseases causing organisms such as bacteria (*Aeromonas sp, Flavobacterium columnare*,), fungi (*Saproleginia sp, Branchiomyces sp*), viruses and parasites (*Trichodina spp, Epistylis sp*) all of which have been reported to infect fish in East Africa by Akoll & Mwanja (2012). Intermediate pathogen hosts such as snails and predators' reptiles resident in detritus materials are equally of concern and would also be eliminated or reduced in number, thereby minimizing diseases spread between crops.

Earthen pond disinfection, is apparently a common practice at most fish farms in Uganda; however, its often challenged by presence of soil/organics combination as the primary substrate at pond bottoms limiting the effectiveness of common disinfectants. Slaked lime ($Ca[OH]_2$) or quick lime CaO is recommended for spreading evenly over freshly cleaned pond bottoms, at a rate of 227-590Kg/acre. Quick or hydrated lime rapidly increases the pH>11, desiccates organics; thus, killing or reducing the number of pathogens that could affect fish (Yanong, 2013). Alternatively plowing and drying of ponds in areas which experience loss of water during dry season would equally disinfect ponds by microbial degradation, sunlight/UV exposure, aeration and desiccation (Yanong, 2013; Yanong & Erlacher, 2012)

Tethering of cows and goats around ponds to control weeds is a common practice on some Nile tilapia fish farm in Uganda. The practice increases the interface between fish and other animals; hence potentially presenting significant risks and means of diseases spread from other animals to fish. This could be through their fecal matter and urine run into ponds or pathogen carried on their bodies and later introduced into pond water. Mowing of pond banks and levees, to control weeds is a feasible alternative to reduce hiding places for predators (potential vectors). Further, use of pond nets (for small ponds), noise canons or visual deterrents other than dogs; to scare birds equally reduces disease risks due to fish other animals interface.

Hardly any provision for pond effluent treatment currently exist at most fish farm sites in Uganda, regardless of the clear stipulations laid out in the Fish(aquaculture)rules (2011); most probably because aquaculture controls are a recent phenomenon and their effectiveness aren't yet appreciated. Development of simple effluent treatment systems such as settling basins, created wetlands, and biological filters, including effluent reuse for agricultural irrigation, would reduce and prevent organic matter loads into receiving waters. This would minimize nutrients, and potential disease pathogens in pond effluents from polluting receiving waters and other farms along similar watering systems.

In cases of large scale commercial aquaculture facilities; effluent limitation guidelines should be a near future consideration. Industrial regulators depending on production capacity of fish farms, could come up with an appropriate scheme, against which to institute a control system; to reduce discharges effects due to conventional (total suspended solids, nutrients, pathogens) and non-conventional (heavy metals, drug residues, hormonal chemicals) into receiving waters (Ozbay et al., 2014).

3.2.1.8 Integrated aquaculture

In Uganda, poly culture of multi trophic species is commonest among small scale farmers similar to Bastin, (2013) and Bennett et al., 2012, findings in China and other Asia-Pacific countries. Integrated aquaculture, including complementary fish species (multi trophic) logically stocked together, could be strategic to reduce nutrients loading while optimizing feed utilization, and hence, increase pond productivity. However, this practice could find application challenges at commercial scale in Uganda, owed to low taste for popular candidates such as common carp; it has detestable fillet quality to majority fish consumers. Otherwise, poly culture involving African catfish, Nile tilapia, and common carp or any other complimentary species, would optimize feed utilization in the culture facility. Feeds lost to one species within the water column, could be taken up by another species; thus, minimizing feed accumulation in the bottom sludge. Water quality would be optimized, eliminating fish stress that could have led to compromised fish immunity against potential opportunistic pathogens.

3.2.1.9 Integration of food safety education and HACCP

Once the safety of farmed fish products is compromised, there is no business model that can work. Therefore, this study assumed a broader/ comprehensive definition of biosecurity to include not only biological hazards (already covered) but also chemical pollutants which very often obtain in the culture environments in Uganda as revealed by Kasozi (2006); Bagumire et al., (2009). Chemical contaminants such as agro-chemicals, polychlorinated biphenyls (PCBs), mercury (Hg), lead (Pb), DDT, veterinary drug residues are ignored or disregarded biosecurity concerns and yet impose physiological effects and toxicity leading to fish stress (Alan, 1993). They have previously been detected in Uganda's farmed fish (Bagumire, 2008) and hence, now require due concern, given that they lead to fish stress thus, compromising fish immunity against potential pathogens. In addition, they render fish products unworthy for human consumption. Farmed fish safety for human consumption is very critical and of public health significance; for both domestic consumers and international market product competitiveness. Hence, food safety assurance has to be an integral part of the farm to table food fish safety continuum as recommended by FAO et al., (1999).

Food safety education for farmers should be undertaken to increase awareness and hence facilitate risk assessment by farmers; to enable consequent application of valid risk management strategies during fish production. Education programs would entail among others; hazards identification, safe use of chemicals and fertilizers; safe food fish processing and associated risks assessment and management (Murray & Peeler, 2005). Practical demonstrations where possible, could be conducted to emphasize practicality of situation specific measures, and enhancement of farmer understanding. Such iterative education and training programs would in the long run enable effective application of hazard management tools; to avoid usage of potentially contaminated in puts, implementation of adequate hygiene or sanitation strategies and observation of regulations issued by national regulatory authorities. Consequently that would facilitate production of safe aquaculture products, required for human consumption.

At Uganda's commercial Nile tilapia farms, Hazard analysis and critical control points (HACCP) principles could be applied to; identify potential critical points along the production chains for specific farming systems. This would facilitate appropriate hazard identification and facilitate systematic application of well-founded biosecurity management measures. That would generally minimize disease pathogens, and ensure food safety; based on thorough hazard analysis.

3.2.1.10 Aquaculture-capture fisheries coupling

Potential negative interactions exist between cage culture and capture fisheries in Uganda. Therefore, the ongoing rapid expansion of lake based Nile tilapia production in cages on Ugandan Lakes, calls for critical analysis of the potential effects of interaction between cultured and wild fisheries; by both aquaculture developers and natural resource conservationists. Looming cases of diseases and parasites, habitat modification, pollution, release of organic and inorganic nutrients, genetic interactions, competition, release of drugs and chemicals are apparently noteworthy, at the current aquaculture development trend. Given the weak disease management and sectoral regulatory frame works in Uganda, the above if ignored could negatively impact through transmission of pathogenic microbes and parasites between wild and cultured fish.

Eutrophication and consequent algal blooms, due to supplied organics or inorganics rich in phosphorus and nitrogen from fish feed would be eminent; thus, resulting in stressful conditions consequently affecting fish immunity and facilitating opportunistic fish infections. Wild fish could as well eat medicated feed with antibiotics from the cages later eaten by people and hence, facilitating antibiotic resistance in humans. Long term weakening of wild stocks due to genetic interaction owed to interbreeding and interspecific hybridization could also result (Ozbay et al., 2014). It is now imperative to observe, optimum numbers of cages per unit of culture area and optimum stocking densities, strong cage nets, pathogen free seed fish from only certified hatcheries; these would ensure minimized fish disease communication between wild and cultured fish. Further, food safety and responsible aquaculture practices with minimum effect on the wild fish populations and habitats would be attained.

3.2.1.11 Traceability and records keeping

Fish farmers in Uganda reportedly lack properly kept records and traceability measures as revealed by Bagumire et al., (2010). However, in principle good records management facilitates good biosecurity management. Therefore, sensitizing and training farmers about the urgency of proper records keeping and supporting the initiation of traceability systems for farms would enable logical documentations. Properly kept records facilitate management of batch information, and augment traceability for food safety reasons. Information on feeds and feeding, drugs, stocking, treatment and health, inputs suppliers, could be better managed; to avoid misuse of inputs and managing food safety challenges in case of product recall. Production and marketing records would equally facilitate monitoring of sales, profits and losses as well as traceability purposes. Records could also be used to track effectiveness of farm biosecurity plans among others.

Good fish production and health records generally permit fish health, disease and biosecurity management. Documenting general health observations, morbidity, mortalities, disease signs, feeding response, water quality among others, enables detecting subclinical disease problems; highlighting their severity and provides clues for disease diagnoses (Dvorak, 2009). Healthy records also provide reference for fish health specialists in case of need. All the above highlighted forms of records are very important in enabling identification of potential disease entry points prior to imminent disease outbreaks. Thence, the need and benefits of facilitating appropriate information management, training farmers on simple coding techniques and establishment of a functional traceability system at farm level, cannot be over emphasized.

The above proposed biosecurity measures are generic in nature not limited to species, investment scale or restricted to farming system; hence, could be recommended promoted for implementation of by all fish farmers, regardless of investment capacity. However, their application should be guided by potential biosecurity risks envisaged at short and long-term scales; existing farm conditions (examination of pathways by which disease agents could enter the farm) and resource economics (Boyd, 2003; Corsin et al., 2008).

Collaboration among farmers, aquaculture healthy or production specialists, and government regulators; to provide guidance on farm specific biosecurity requirements and facilitation of proper farmer judgment is encouraged. It ultimately determines the level of success for the drawn biosecurity strategies at both farm and National level. That is, such teamwork would enable identification of more cost effective management measures suited for ones' kind of farm conditions and thus, permit rational resource allocation.

Below is a model frame work (**Fig.7**); to summarize, and visualize the implementation of some of the above proposed strategic biosecurity practices at farm level. The practices are intended to optimize biosecurity at respective identified potential control points; along the Nile tilapia production chain, at commercial scale. The control points included site and facility, water (source & quality), fry/fingering/ stock, feed, manure, other animals, equipment & chemicals, people, pond effluents, harvest and transportation; a slight modification of those proposed by FAO/WHO, (2003). See the illustration following.

.

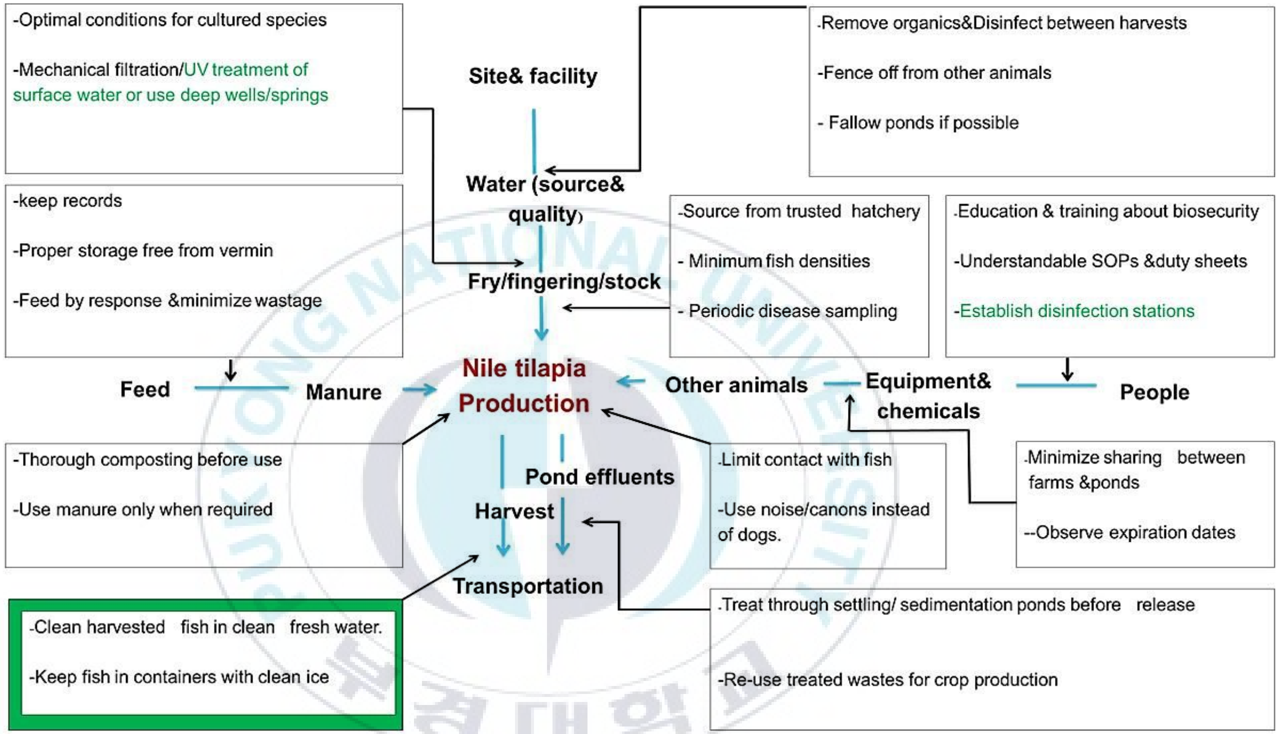

Fig.7. Proposed Model, farm level biosecurity implementation on commercial farms in Uganda.

The proposed interventions at farm level illustrated by the framework above are largely based on better management practices with integrated fish health/disease management strategies. They were found applicable to earthen ponds at the commercial scale of aquaculture investment in Uganda in line with Ozbay et al., (2013) and Yanong, (2013) recommendations for optimizing pond culture biosecurity.

It was determined that optimization of aquaculture biosecurity in Uganda at farm level, could cost effectively be achieved by ensuring implementation of appropriate practices; at specific targeted control points along the Nile tilapia production chain as illustrated above (**Fig.7).** However, adoption of BMPs by farmers is hardly spontaneous as equally observed by Yanong and Erlacher, (2012); relative reluctance to change in management practices should be expected. Nonetheless, iterative support supervision provided by local government extension officers, and some progressive farmers (sometimes serving as community leaders) could enhance the rate of change within fish farming communities. Furthermore, realizing improvement in farm practices will require complementary effort/support from local and national government. Support could be in form of sound policies, funds, support supervision, effective regulation and enforcement of some of proposed strategies at farm level; spearheaded by national level competent authority or aquaculture inspectors as proposed below.

3.2.2 National aquaculture biosecurity strategy

The cases of disease outbreaks or fish mortalities beginning to manifest in some Nile tilapia farms and hatcheries in Uganda, although still reported at a low rate, point to potentially greater occurrences of unreported disease cases or imminent ones in the near future. Relatedly, it could be a reflection of ineffective biosecurity and fish health management systems, at national and farm level. Thus, requiring observation of sound national biosecurity policy and principles; dully translated into disease and other bio-hazards preventative measures at farm level, observed above, as recommended by Scarfe, (2003).

3.2.2.1 Aquaculture biosecurity policy

The need for Uganda to have a comprehensive national aquaculture biosecurity frame work was found long overdue (FAO, 2009; Akol & Mwanja 2012). Arguably, the appreciated standards of adherence to the principles and practices of aquaculture biosecurity at farm level; in some aquaculture developed countries worldwide, were all premised on legal policies with sound strategies. Good biosecurity policies are required to guide, direct and secure the process of aquatic animal health management; aquaculture product safety, cum maintenance of aquatic biodiversity. Thus, formulation of a national biosecurity policy to provide strategies for farmer education, fish disease surveillance and monitoring; legislation, and enforcement of promulgated regulations /standards inter alia, was found critical to secure Uganda's aquaculture learning from the Australian experience(Aquaplan, 2005-2010), as reported by Perera et al., (2008).

3.2.2.2 Farm registration

Fish farm registration in Uganda is still haphazard and limited to commercial scale (semi-intensive and intensive) establishments as a pre-requisite for operational permits. However, majority medium and small scale fish farmers hardly get their farms registered. Legislation and enforcement of farms or aquaculture production business registration, is now a necessity and would be fundamental to improvement of Uganda's national biosecurity. At a minimum legislation of farm registration could facilitate and guarantee obligatory disease reporting and control by registered farms. Farm registration would further ease preliminary planning and facilitate higher level farmer associations; farmer education and awareness creation about reporting obligations especially on early signs of diseases outbreak inter alia (Corsin et al., 2008; Bagumire et al., 2010). Thus, as a strategy to ensure adherence, farm registration would be a pre-condition for authorization to operate any aquaculture production business, including small scale farms in Uganda.

3.2.2.3 Multi-sectoral linkages and collaborations

Establishing an effective and functional biosecurity system in Uganda will require concerted effort and input from a number of national and local government agencies (**Fig.6.**) including; National Drug Authority (NDA), National Environmental Authority (NEMA), Directorate of Animal Resources, DFR, farmers groups/associations, Universities, Research institutions etc. Therefore, linkages and collaboration must be established between critical competent authorities and professionals; mandated to handle aquatic animal health management and food products safety issues, among others. Such an integrated approach to biosecurity involving fisheries, veterinary, environment, and drugs authorities; or rather fish biologists, veterinarians, public health, food safety and environment experts, working together, exploits their multidisciplinary skills. It permits development of integrated sound policies and laws required of a functional biosecurity system. The synergistic effects of such collaboration could further result into pronounced efficiency and thus, effective implementation of drawn strategies (Boyd, 2003; Ozbay et al., (2014).

3.2.2.4 Institutional strengthening and manpower development

The apparent lack of an established biosecurity system implies the need for drastic institutional strengthening and manpower development in Uganda. National reference laboratories and Zonal/regional laboratories would require appropriate upgrading and re-equipping with better diagnostic tools; to enable precise diagnosis of disease causes through molecular techniques such as PCR among others.

The existent knowledge, technology and skills gap in fish health management, now facing Uganda's aquaculture industry will require organizing and conducting short / long-term training courses; in fish health and disease management including other aquaculture biosecurity related issues. Among others the training would include; basic and intricate disease diagnostics for technical service providers at local and national level; including cross "pollination of veterinarians," into aquaculture development service. This coupled with appropriate funding, would support research, disease surveillance and upgrade laboratories to advisory cum training centers. Thus, offering better fish health, disease or pathogen management reference services to farmers (Subasinghe, 2005; Perera et al., 2008; Oidtmann et al., 2011).

3.2.2.5 Inspection and regulatory services

Although it was established that Uganda had in place an aquaculture inspectorate; mandated among others to support and supervise adherence to the fish (aquaculture) rules (2011), their role in realizing a number of regulatory controls was still insignificant. On the other hand, it is fundamental to have an effective and accountable aquaculture inspectorate; with clearly defined responsibilities pertaining to application of the aquaculture statutory instruments. It should work closely with other stake holders in the industry such as aquaculture service providers, fish farm managers, trade associations, farmer groups, and the general public. The aquaculture inspectors should be facilitated to provide advisory and support services, aimed at increasing the effectiveness of fish health and product safety controls; follow up on farmer compliance to industrial regulation and set standards inter alia.

3.2.2.6 Monitoring, pro-active diseases surveillance and reporting

Uganda lacks institutionalized fish disease monitoring and surveillance frameworks. However, given the unpredictable nature and dynamic disease situations, due to rapid changes in culture intensity and expansion, trade, microbial adaptation and complexity of culture environments; it is advisable to ensure regular surveillance (passive and active) and disease reporting (Dvorak, 2009). Essentially Passive surveillance, principally involving farmers to promptly report any suspicion of disease or unexplained mortalities at farm facilities; complemented by coordinated national wide active surveillance, involving professional routine sampling and diagnostic testing, would enable informed establishment of control and eradication measures. It would further facilitate generation of a national fish disease list, apparently lacking in Uganda; thus allowing collating and disseminating information about diseases of national importance, including facilitating contingency planning among others. Besides, development of a national fish disease list for Uganda should consider the farmed and traded fish species, economic impact of specific diseases on farmers and national economy. Diseases exotic to the country, those present in neighboring countries in view of shared water resources and the porous borders, should equally be considered. This would guide appropriate resource mobilization and effective precautionary management strategies (Mohan, 2009). Knowledge of important pathogens or diseases and the life stages of fish they affect, as observed by Akoll et al., (2011) will facilitate development of good and objective biosecurity strategies such as emergency preparedness, consequently preventing disease outbreaks and potential economic loses in Uganda.

3.2.2.7 Need for aquaculture biosecurity research

It's apparent that Uganda lacks adequate research programs and infrastructure focused on addressing the fish disease or pathogen challenges, to generate information about diseases of national importance or diseases of cultured fish. Proactive mechanisms such as surveillance; use of scientific research for diseases prevention are not yet established. Needless to emphasize, aquaculture biosecurity practice requires good information to permit proper risk analysis, assessment, and hence, management decisions (Bondad-Reantaso et al., 2005). Such information could be generated from routine surveillance, fish health research studies including; epidemiological approach to disease management, food fish safety research, preventive practices in fish disease management (probiotics) among others, which are currently lacking. One would argue that fish diseases and food fish safety concerns are only a recent phenomenon in Uganda, without significant economic losses so far reported. Besides, there are resource constraints disabling establishment of disease diagnostic facilities; sufficient human resource expertise and infrastructure in Uganda. Notwithstanding, the cost implications of ignoring the need now will be greater in the near future.

Nonetheless, Uganda's current rate of aquaculture development requires institutionalization of holistic biosecurity management strategies founded on good research and infrastructure such as laboratories. It's the only feasible alternatives, to cost effectively generate information with which to counter, imminent future economic losses due to diseases and other biosecurity risks.

Precisely, relevant and supportive research needed to primarily focus on existing diseases of cultured Nile tilapia, other cultured species including diseases detected from the wild; to inform pathology and methods of rapid diagnosis. Research on pathways of pathogens spread, methods of inactivation of infectivity, and preventive strategies such as vaccination and probiotics, would equally be pursued resources permitting. More so, collaborative research involving farmers should be prioritized, as it encourages innovations such as farmer self-regulation, farmer empowerment and establishment of BMPs at farm level.

In addition, Uganda government should consider increased funding for research on fish health and disease management activities in the medium-long term, to upgrade research institutes on aquatic animal health, operating reference laboratories, funding research and disease control programs as observed by Bondad-Reantaso et al., (2005), for most Asia-Pacific countries. This would be precautionary against prospective heavy economic losses; usually encountered with significant disease outbreaks under intensive commercial aquaculture enterprises.

3.2.2.8 Supranational aquatic biosecurity strategy and management framework

Uganda and other EAC countries were found to be involved in drastic aquaculture development programs. Regional trade in Nile tilapia seed, fish feed, cat fish seed as well as cultured Nile tilapia products for EAC countries was pronounced as reported by IFOAM, (2013). However, technical cooperation among these countries for the cause of fish pathogens/ disease control wasn't evident; probably, due to the infant stage of the aquaculture, in the region. Nonetheless, the dynamic situation now obtaining in the regional aquaculture industry, demands for a regional body, akin to NACA of Asia-Pacific in the near future. To provide a forum for technical collaborations among governments including non-government organizations or other stake holders, purposely cooperating to address the challenge of fish diseases. Food fish safety, capacity building and improvement of communication among countries with respect to fish health management programs, would be enhanced by such concerted effort. Technical guidelines developed by the EAC countries, consistent with principles of the relevant international Codes, Standards, and agreements; would provide invaluable guidance for national and regional efforts towards safe guarding trade in aquaculture inputs and products, by minimizing potential disease/ pathogen risks. Ultimately, potential impacts of disease on farmer livelihoods, human health, national economies and trade would be greatly minimized.

3.2.2.9 Adherence to International Codes, Standards and Agreements

Uganda was found party to a number of fisheries related regional and international conventions, treaties and agreements. It had membership to international agencies concerned with management, conservation and sustainable utilization of fisheries resources among others. That is, the Food and Agriculture Organization of the United Nations (FAO), World Trade Organization (WTO), World Organization for Animal Health (OIE) inter alia (FAO, 2015). These organizations had direct concern about control of spread and management of fish pathogens or diseases as further explained with respect to the status quo in Uganda's aquaculture industry.

3.2.2.9.1 Code of conduct for responsible fisheries (FAO, 1995)

By virtue of its membership to FAO, Uganda subscribes to the Code of Conduct for Responsible Fisheries (1995). Thus, with reference to the CCRF, the department of fisheries resources (DFR) as the aquaculture development competent authority, needed to formulate and promulgate a comprehensive aquaculture biosecurity policy to guide responsible aquaculture development. Promotion of aquaculture practices that would minimize diseases effects of farmed fish or effect of aquaculture on wild fish populations among others would have to be prioritized.

Therefore, regardless of the voluntary and non-mandatory nature of the CCRF, Uganda government as a party to the CCRF should not be reluctant to put in place appropriate policies on fish health and disease management.

3.2.2.9.2 Office International des Epizooties (OIE) Standards, (Aquatic Code and Aquatic Manual [2014])

The World Organization for Animal Health (OIE); by regularly publishing international standards and guidelines, seeks to achieve, prevention for importation of pathogens that are dangerous for animals and humans (zoonotics) through international trade. It also aims at strengthening Veterinary Services, so that they can improve their surveillance and response systems (OIE, 2013). In Uganda the Directorate of Animal Resources of MAAIF, was found to be the competent authority for animal health management recognized by OIE (FAO, 2009); hence, effective collaboration between the former and the DFR on fish disease pathogen control and management was found very critical. Fish disease or pathogen surveillance was critically found lacking, as indicated by Uganda's lack of disease lists; neither for the OIE notifiable diseases nor an up to date country list of prevalent fish diseases and pathogens (Akol & Mwanja, 2012). Therefore, in line with OIE's Aquatic Code, (2014), requirements of member countries, appropriate diagnostic services, facilities and an effective pro-active surveillance system to establish important fish pathogens and diseases for Uganda, will be urgently needed in the medium term.

3.2.2.9.3 Codex Alimentarius commission/CAC (FAO/WHO, 1999)

Complimentary to the above is the Codex Alimentarius Commission; the international body which sets standards, Codes of practice and guidelines for food safety and quality. CAC requires of member countries, to demonstrate evidence for minimum substantive criteria that reflect good practices along the aquaculture production and value chain (WHO, 1999). In view of CAC, Uganda had to develop a list of approved drugs and chemicals for use in aquaculture; conduct farmer trainings on approved use, methods of application and certification of professional drug / chemical handlers would be equally needed. Such farmer empowerment would in effect counter potential drug and chemical abuse; food hazards, attributable to bioaccumulation or potential toxicity of farmed Nile tilapia products.

Implementation of good aquaculture practices, would consequently lead to a fair and level playing field among Nile tilapia producers; in terms of guaranteed product competitiveness at local and premium export markets.

3.2.2.9.4 Sanitary and Phyto-sanitary Measures agreement/SPS (WTO, 1995)

As the highest international agreement, it sets out basic rules on food safety, animal and plant health standards; the purpose of which is to provide a framework of rules aimed at securing trade that would have otherwise been subjected to barriers due to protectionism (WTO, 1995). Precisely Uganda as member of the World Trade Organization (WTO) needs to review her sanitary measures, and promote sanitary practices in aquaculture production. This should be in accordance with the international safety standards, guidelines, and recommendation; to minimize potential for future challenges that would arise due to WTO disputes from her international farmed fish trade. This could be by ensuring effective laws, decrees, and regulatory requirements; testing, inspection, certification, quarantine and approval procedures. Relevant statistical methods, sampling procedures, packaging and labeling requirements that are related to food safety for aquaculture producers and product processors would be required.

Figure.8 below is a model frame work; to summarize and illustrate implementation of some of the initiatives, as proposed for the national aquaculture biosecurity strategy. Emphasis has been made on the hypothetical urgency during activities implementation to be observed by stake holders at national, local government (districts), and their ultimately impact at farm level.

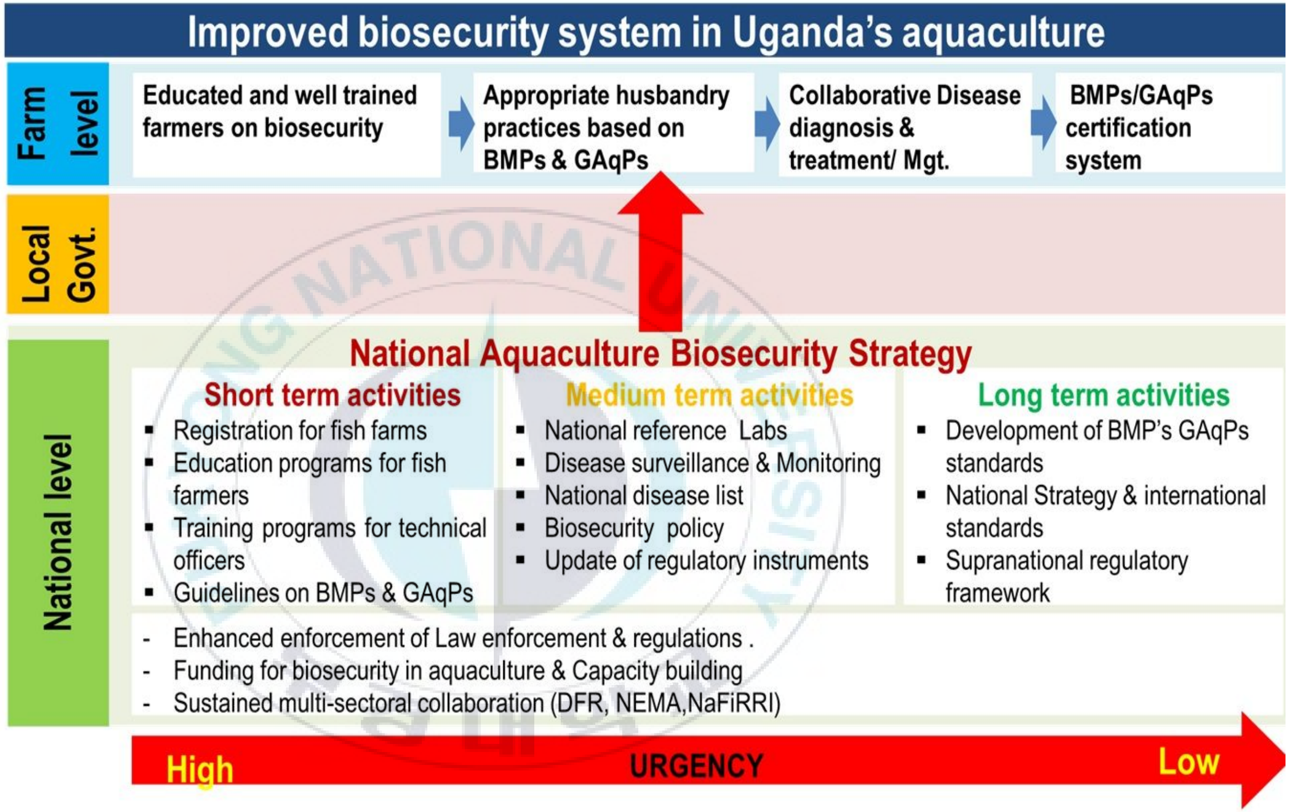

Fig.8.Proposed model, illustrating national strategy to improve aquaculture biosecurity in Uganda

Proposed national strategy for aquaculture biosecurity improvement in Uganda

Although there aren't many cases of alarming large scale disease scenarios reported in Uganda, the current rate of intensification and expansion of Nile tilapia culture equally warrants strategic planning. This would provide the basic frame work and principles, on which to implement perceived precautionary counter strategies intended to deter any such potential or looming disease and pathogens incursions, as depicted by national strategy above.

The above model framework highlights conceived initiatives of the proposed national strategy. Given the finiteness of resources, phased implementation of various activities by the different stake holders at respective levels, is hereby proposed; according to perceived urgency of strategies towards improving aquaculture biosecurity in Uganda.

On the short-term, farm registration, awareness, education and training programs for key fish production stake holders on fish diseases, development of basic BMPs among others are proposed as urgent activities. They would be undertaken within the existing governance frame works, to address the challenge of emerging fish diseases, fish product safety, and other public health issues. Distributing the developed BMPs guidelines (standards) to respective production chain players, would provide an invaluable resource; for guiding aquaculture extension officers and farmers to develop simple, BMPs that are system specific and applicable to their homegrown situations.

In the medium-long term, biosecurity policy development and harmonization of required laws /regulations; facilities such as diagnostic laboratories at national and zonal level, along with human resource capacity building to operate them would be considered. Policy development and promulgation would enable regularization of the implementation of drawn strategies for effective institutionalization of biosecurity into Uganda's aquaculture.

Therefore, enhancing and sustaining aquaculture biosecurity practices in Uganda, requires understanding and emphasizing the complementarity of international, national, and farm level biosecurity needs, during the development of national biosecurity strategy, as equally argued by Mohan, (2009). This is because the extent of success for national level strategies would be reflected and therefore judged by noticeable improvement in practices at farm level among others.

Accordingly, the local government fisheries departments at districts, as link administrative and technical agencies between farmers and national level competent authority (DFR) should be facilitated; to ensure adoption of simple BMPs at farm level, consistent with national level approval for greater success.

3.3 Limitations of the Study

This study proves a principle and proposes generic practical approaches to biosecurity, but does not offer case specifics applicable to all fish farm conditions in Uganda. Therefore, there is need for individualized farm based visits in Uganda by aquaculture extension service providers; to develop customized farm models, founded on the same principle but defined by species of culture, purpose of the system, economics, and pathogens envisaged, among others. That would permit effective identification and implementation of practices suited for given farms.

CHAPTER 4. Conclusion and Recommendation

4.1 Conclusion

Significant biosecurity lapses were identified at farm and national level in Uganda; they are likely to become substantial, given the current intensification and expansion of Uganda's aquaculture. Climate change, unprecedented movement of aquaculture inputs, and products, in country, across national and international borders due to socio-economic incentives; changing patterns of land and water resources use, human, livestock, wildlife and cultured fish interactions are now apparent. They are most likely to continue altering the disease/pathogens risks faced by the aquaculture industry, the environment and society in Uganda.

Therefore, securing Uganda's nascent aquaculture industry and sustainably enhancing its' socio-economic benefits for the future, will require addressing the fish health questions with both pro-active and reactive strategies. Hence, the department for fisheries resources (DFR) needs to champion the establishment of a strong and comprehensive biosecurity system inter alia. The view of aquaculture biosecurity improvement should focus on prevention of risky diseases rather than treating them. Practically, this will call for; institutionalization and integration of biosecurity practices into the current fish culture production models or other better ones identifiable. Fundamental to an effective biosecurity system, will be an urgent need for national aquaculture biosecurity policy formulation and promulgation. The policy should provide for farmer education and awareness creation on fish health, disease and food fish safety management; promotion, regularization, and dissemination of better management practices as the core strategy at farm level. Simple BMPs have been proved to work in Asia-Pacific; to sustainably reduce fish disease incidence, optimize fish product safety, and environmental health, as previously described by Subasinghe (2005). Enhancement of local and national level service providers' capacity; infrastructure, human resource development as well as improvement in regulation and law enforcement will be requisite. As a regional strategy, a supranational biosecurity framework akin to NACA for EAC countries ought to be established in the near future; to facilitate regional collaboration in fish health and disease management, biosecurity research among others.

Finally, observing the recommendations below could further facilitate co-evolution of inherent industrial incentives, appealing to Uganda's Nile tilapia farmers' and consequently ensure sustenance of biosecurity practices at farms.

4.2 Recommendations

4.2 1 Short term recommendations;

- Farm registration and farmer mobilization for institutional development at national and local government level.
- Awareness programs on infectious fish diseases and their effects on fish farming as a business.
- Farmer training on basic fish health and disease management practices such as day to day health monitoring.
- Hatchery management training courses for hatchery proprietors and other farmers dealing in Nile tilapia seed production.
- Enhanced networking of local extension officers with, farmers and national level DFR aquaculture unit staff.
- On farm made feed improvement programs and access to information on appropriate fish feed formulas.

- Monitoring, surveillance and sampling for diagnosis or identification of diseases and pathogens of national importance.

4.2.2 Medium and Long term recommendations;

- National aquaculture biosecurity policy formulation and promulgation.
- Education and awareness programs on BMPs development and implementation strategies, for local government fisheries extension officers and farmers
- Instituting regulations on aquaculture drugs and chemicals dealerships.
- Funding biosecurity research, upgrading national, / zonal reference laboratories and human resource capacity building.
- Public private partnerships (PPP) development for involvement in BMPs promotion.
- Government subsidies to fish hatcheries for good quality fish seeds
- Formation of a supranational biosecurity framework with other EAC countries for regional cooperation.

References

AFFA 1999. AQUAPLAN. Australia's National Strategic Plan for Aquatic Animal Health 1998–2003. Canberra, Government of Australia, 34 pp.

Aganyira Kellen 2005. Master's thesis in Development Studies, Specializing in Geography Submitted to the Department of Geography, Faculty of Social Science and Technology Management Norwegian University of Science and Technology. Spring 2005, Trondheim-Norway

Akoll P., Robert Konecny, Julliet Kigongo Nattabi and Fritz Schiermer 2011 Parasite fauna of farmed Nile tilapia (Oreochromis niloticus) and African cat fish (Clarias gariepinus) in Uganda. Accessed on 16/07/2015 from, http://www.researchgate.net/publication/51233482

Akoll P. and Mwanja W. W. 2012. Fish health status, research and management in East Africa: past and present. *African Journal of Aquatic Science,* 37**,** 117-129.

Alan G. Heath, 1993. Water pollution and fish physiology. 2nd edition, Pages 4-6,Blackburg Virginia.

Amagliani G., Brandi G. and Schiavano G. F. 2012. Incidence and role of Salmonella in seafood safety. *Food Research International,* 45, 780-788.

Bagumire A. 2008. Food safety regulations in international trade: The obstacles for export of Uganda's aquaculture products. Thesis. Kampala. Uganda: Department of food science and technology. Makerere University.

Bagumire A., Todd E. C. D., Nasinyama G. W., Muyanja C., Rumbeiha W. K., Harris C. et al., 2009. Potential sources of food hazards in emerging commercial aquaculture industry in sub-Saharan Africa: a case study for Uganda. *International Journal of Food Science & Technology,* 44, 1677-1687.

Bagumire A., Ewen C. D., George w. Nasinyama and Charles Muyanja 2010. <food-safety-regulatory-requirements-with-potential-effect-on-exports-ofaquaculture-products-from-developing-countries-to-the-eu-and-us (2).pdf>. *African Journal of Food Science and Technology,* Vol. 1(2), pp. 031-050.

Bastin L. 2013. International aquafeed. Incorporating Fish Farming Technology; 16(1) 26.

Bennett L., Diana J., and Qiuming L. 2012. Learning from Tradition. In: Integrated Aquaculture Practices in Yingbin Bay. Accessed 20 Jan uary 2015 from http://pdf.gaalliance.org/pdf/GAA-Bennett-Nov12. pdf.

Bondad-reantaso M. G., subasinghe, R. P., Arthur, J. R., Ogawa, K., Chinabut, S., Adlard, R., Tan, Z. & Shariff, M. 2005. Disease and health management in Asian aquaculture. *Vet Parasitol,* 132**,** 249-72.

Boyd C. E. 2003. Guidelines for aquaculture effluent management at the farm-level. *Aquaculture,* 226**,** 101-112.

Brummett R. E., Lazard, J. & Moehl J. 2008. African aquaculture: Realizing the potential. *Food Policy,* 33**,** 371-385.

Denzin NK., Lincoln YS. (eds.) 2000. *Handbook of Qualitative Research*, second edition. London: Sage Publications. Accessed on 2/03/2015 from http://depts.washington.edu/methods/readings/com501_lincoln_paradigmatic_controversies.pdf

EurepGAP 2005. Chain of Custody Accessed on 12 January 2015 from http Checklist Integrated Aquaculture assurance, Version1.0. Ac cessed on 4March 2015 from http://www.globalgap.org/cms/upload/The_Standard/Version_Archive/Checklists/English/EUREPGAP_CoC_Checklist_IAA_V1-0_Jun05_update 281105.pdf.

FAO⁄WHO 2003. Code of Practice for Fish and Fishery Products. Codex Alimentarius Commission. CAC⁄ RCP 52-2003, Rev. 2-2005.

Garrett, E.S., Lima dos Santos, C. & Jahncke, M.L. (1997). Public, animal, and environmental health implications of aquaculture. Emerging Infectious Diseases, 3, 453–457.

FAO 2007. Biosecurity principles and components; biosecurity toolkit part1

FAO 2009. Workshop on the development of an aquatic biosecurity framework for southern Africa, FAO Fisheries and Aquaculture Report No. 906(FIMA/R906 (En)), Lilongwe, Malawi, 22–24 April 2008.

FAO 2012a. Farming the waters for People and Food: Proceedings of the global conference on Aquaculture 2010. Accessed on 11 January 2015 from http://www.fao.org/docrep/015/i2734e/i2734e.pdf

FAO 2012b. <improving biosecurity through prudent and resonspible use of veterinary medicime in aquatic food production.pdf>Fisheries and Aquaculture Technical Paper. No.547.Rome, FAO.207 pp.

FAO 2013. Fisheries and food security. Sustainable aquaculture developme nt. Accessed 5 February 2015 from http://www.fao.org/ focus/e/fishe ries/sustaq.htm

FAO 2014. Fishery and Aquaculture Statistics. Global aquaculture production 1950-2012 (FishstatJ). In: FAO Fisheries and Aquaculture Department [online or CD-ROM]. Rome. Updated 2014. http://www.fao.org/fishery/statistics/software/fishstatj/en.

FAO 2015. National Aquaculture Sector Overview. Uganda National Aquac ulture Sector Overview Fact Sheets. Text by Mwanja,W.W. In FAO Fisheries and Aquaculture Department [online]. Rome. Updated 19 July 2005. Cited 17 March 2015 from http://WWW.fao.org/fishery/c ountrysector/naso uganda/en.

Gery W. Ryan and H. Russell Bernard 1997. Data Management and Analysis Methods. Accessed on 6/03/2015 from http://nersp.nerdc.ufl.edu/~ufruss/documents/ryan and bernard.pdf .

Glenda Dvorak 2009. Biosecurity for Aquaculture Facilities in the North Central Region. North Central Aquaculture Centre & USDA.

Hine M., Adams, S., Arthur J.R., Bartley, D., Bondad-Reantaso, M.G., Chávez C., et al., 2012. Improving biosecurity: a necessity for aquaculture sustainability.

IFOAM 2013. Report on scoping study for organic Aquaculture in 5 east African countries. Accessed on 30 December 2014 from www.sarnissa.org/tikidownload_file.php?fileId=649.

Kasozi G N., Kiremire B.T., Bugenyi F.W.B., Kirsch, N.H. & Nkedi Kizza P. 2006. Organochlorine residues in fish and water samples from Lake Victoria, journal of environmental quality, 35, 584-588. Accessed on 24 December 2014 from .http://www.greenpeace.to/publication/Technical_Note_06_02.pdf

Kifuko Richard 2015.The state of Cage fish farming in Uganda: Actors, enabling environment, challenge and way forward.

Lee Daniel and John Connelly 2006. "Global Aquaculture Alliance on Best Aquaculture Practices: An Industry Prepares For Sustainable Growth." Sustainable Development Law & Policy, 60-62.

MAAIF 2011. Statistical abstract. Agricultural planning department. Entebbe, Uganda. Accessed on 12 January 2015 from http www.agriculture.go.ug

MAAIF 2012. Department of fisheries resources, annual report 2012, Uganda. Accessed on 18 January 2015 from http://www.agriculture.go.ug/userfiles/DFR%20ANNUAL%20REPORT%202012.pdf

Melba G. Bondad-Reantaso, Rohana P. Subasinghe , J. Richard Arthur, Kazuo Ogawa , Supranee Chinabut , Robert Adlard , Zilong Tan , Mohamed Shariff 2005 . Disease and health management in Asian aquaculture, Veterinary Parasitology 132 (2005) 249–272.

Mohan C.V. 2009. National Strategies for aquatic animal health management, Aquatic animal health, Aquaculture Asia Magazin Pages 39-42

Murrell D., Perera R., Smith P., Subasinghe R., Phan P.T. & Wardle R. 2012. Improving biosecurity: a necessity for aquaculture sustainability.

Muyodi 2014. Aquaculture effluent effects on environmental quality and bacterial diversity of aquatic habitats. Accessed on 12 January 2015 from http://w.w.w.fao.org/fishery/countrysector/naso_uganda/en

NEMA 2007. State of environment report, 2007. Accessed on 13/1/2015 from http://www.nemaug.org/reports/national_state_of_ Environment_report_2007.pdf

Noga E.J. 2010. Fish disease: diagnosis and treatment. 2nd edition. Ames, Iowa: Wiley-Blackwell.

Oidtmann B. C., Thrush M. A., Denham K. L. & Peeler E. J. 2011. International and national biosecurity strategies in aquatic animal health. *Aquaculture,* 320**,** 22-33.

Ozbay G., Blank G. & Thunjai T. 2014. Impacts of Aquaculture on Habitats and Best Management Practices (BMPs).INTECH (2014). Accessed on 30th /04/ 2015 from http://dx.doi.org/10.577/57471

Ramesh P. Perera, B. J., Peter Beers, Sarah Kleeman and Sharon Mcgladdery 2008. <maintaining biosecurity in aquaculture systems.pdf>. *Diseases in Asian Aquaculture VI***,** 3-20.

Rangen Inc, 2013. Salmon Feeds/ Trout Feeds/ Tilapia Feeds/ Quality Feed for Catfish. Rangen Inc. Buhl, ID, USA. Accessed on 11/02/2015 from http://www.rangen.com.

SARNISSA 2009. Uganda Assessment of National Aquaculture Policies and Programs in Uganda. Accessed on 20/11/2014 from http://www.sarnissa.org

SARNISSA 2014. Aquaculture policy brief No.2. Accessed on 12 December 2014 from http://www.**sarnissa**.org/tiki-download_file.php?fileId=540

Scarfe A. David 2003. State, Regional, National and International aquatic animal health policies: Focus for future Aquaculture biosecurity. Pdf. Accessed on 16/07/2015 from http://www.researchgate.net/publication/275334404

Setty K. 2013. Design Manual: Retention Basin. Bren School of Environmental Science and Management. University of California, Santa Barbara, CA USA. p7.

State of victoria 2010. Biosecurity Strategy for Victoria: Implementation plan 2010 to 2013.

Stuart MacDonald and Nicola Headlam 2009.Research Methods-Handbook. Accessed on 5/03/2015 from http://www.cles.org.uk/wp-content/uploads/2011/01/Research-Methods-Handbook.pdf

Subasinghe R. P. 2005. Epidemiological approach to aquatic animal health management: opportunities and challenges for developing countries to increase aquatic production through aquaculture. *Prev Vet Med,* 67**,** 117-24.

Subasinghe R.P., J.R. Arthur, D.M. Bartley, S.S. De Silva, M. Halwart, N. Hishamunda, C.V. Mohan & P. Sorgeloos, eds. *Farming the Waters for People and Food.* Proceedings of the Global Conference on Aquaculture 2010, Phuket, Thailand.22–25 September 2010. pp. 437–494. FAO, Rome and NACA, Bangkok.

Tamale A., Ejobi F., Rutaisire J., Isyagi N., Nakavuma J., Nyakarahuka L. et al., 2011. Prevalence of Columnaris, ecto-parasite and fungal conditions in selected fish farms. Proceedings of the International Conference on Agro-biotechnology, Biosafety and Seed Systems in Developing Countries (2011). 71-75

Tamale A., Ejobi F., Rutaisire J., Isyagi N., Nakavuma J., Nyakarahuka L. and Amulen D. 2010. Implications of aquaculture production husbandry practices on fish health in Uganda. African Journal of Biomedical Sciences 5 (1): 85-89

Walakira J., Nankya E. 2013. Bio-control strategies for fish disease conditions in Uganda: Use of Banana (*Musa sp.)* leaf extracts in Aquaponic systems, Accessed on 14/03/2015 from http://www.africaaquaponics.com

WHO 1999. Food safety issues associated with products from aquaculture: Report of joint FAO/NACA/WHO study group. WHO technical Report series 883.Geneva 1999.Pp.68

WTO 1994. Agreement on the application of sanitary and phytosanitary measures, pp. 69–84. In: The results of the Uruguay Round of multilateral trade negotiations: the legal texts, General Agreement on Tariff and Trade (GATT), World Trade Organization, Geneva.

World fish 2012. Uganda aquaculture value chains: strategic planning, mission report. Final draft 2012, CGIAR research program 3.7- Livestock &Fish.

World fish 2013. Report on an ASARECA workshop on cage aquaculture and environment. Jinja, Uganda, 14-15 March 2013.

Yanong R.P.E., Erlacher-Reid C. 2012. Biosecurity in Aquaculture, Part 1: An Overview. Southern Regional Aquaculture Center No. (4707) 16.

Yanong R.P.E. 2012. Biosecurity in Aquaculture, Part 2: Recirculating Aquaculture Systems. SRAC-Publication No. 4708.

Yanong R.P.E. 2013. Biosecurity in Aquaculture, Part:3 Ponds. Southern Regional Aquaculture Center No. 4712.

Acknowledgements

This thesis has been produced with support from range of actors; academicians, government officials, respondents that provided the vital data for the study. Special appreciation goes to Professor Dr. Kim Do-Hyung who supervised my research; this study would not have been made better without your advice, guidance, and selfless endurance. To my Thesis advisory committee (TAC) chaired by Prof. Jeong Hyun Do, that helped improve the thesis. My appreciation go to Nam- Eun Kim a researcher in Fish disease prevention Laboratory (FDPL) at Pukyong National University (PKNU) for her invaluable technical support , Yun-Jin, Ahran-Kim, and the entire FDPL family, for enormous support during Laboratory experiments and my study period in South Korea. I would like to recognize the scholarship offer from Korean Government through KOICA; PKNU-KOICA program coordinator Dr. Kyoungmi Kang, for the facilitation that enabled me pursue the Master degree. In special way, I would like to thank Mukono District Local Government that granted me the study leave. Finally, special recognition goes to my wife, children and entire family for the moral support during my study period in South Korea. For those I cannot mention because of want of space I thank you all.

Appendix 1. Observation check list (South Korea fish farms)

Observation checklist (Researcher) Farm No………..

Issue /item /Facility/Practice	Category	Availability		Comment
		Yes	Not	
Culture system	Open/outdoor			
	Closed /indoor			
Farm enclosure				
Source of water	Open			
	closed			
Water treatment	Filtration			
	Ozonation			
	Ultra violet radiation			
Water supply	Quarantine facility			
	Other fish			
Quarantine facility				
Feed	Moist pellet			
	Dry pellet			
Feed store				
Records				
Handling tanks for sick fish				
Foot dips				
Employee coveralls/waders/foot wear				
Wash in/wash out facilities				
Vector control& management				
Sign posts				
Equipment ; hoses,nets,buckets,e.t.c	Specific use			
	General use			
Cleaning protocols/code				

of practice				
Conscious & limited movement between rearing units				
Wheel wells				
Effluent water	Pretreated			
	Not treated			
Disinfectants				

Appendix 2. Interview guide (Uganda Nile tilapia fish farmers)

1. How many years has your facility been operating?
2. Where do you get your fry/fingerings for culture?
3. How concerned are you about avoiding disease on your farm?
4. What kind of diseases are you most concerned about?
5. What do you do in case your fish get sick?
6. Has a fish health specialist or fisheries officer, ever visited your farm?
7. What do you think are the most serious issues regarding disease transmission?
8. At your farm, do you have problems with nuisance animals such as birds, insect, rodents or small aquatic organisms such as frogs?
9. What do you use to control the nuisance animals?
10. Do you keep written records of the number of fish and other farm concerns?
11. Have you ever got information about preventing or controlling diseases and from where?
12. How many full time and part time staff do you employ?

Appendix 3. Interview guide (Uganda Fisheries officers)

1. How often do you visit farmers?

2. What services do you offer to farmers?

3. Are there any cases of fish diseases affecting tilapia fish farmers in your area of jurisdiction and what are they?

5. What has to be done to stop diseases from emerging at fish farms?

6. What is important for you to do in order to support farmers in fish healthy management?

7. What do you know about biosecurity in aquaculture?

8. Who do you think is responsible for the practice of biosecurity at farms?

9. What factors affect farmers' practice of biosecurity?

10. During your work day, how do you support farmers practice biosecurity?

11. What has to be done to improve the practice of biosecurity at fish farms?